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University of Washington
3935 University Way NE
Seattle, WA. 981056613

NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE

South Dakota Board of Regents

PERFORMING ORGANIZATION CODE (IF KNOWN)

4003838000

ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE

SD Board of Regents
1300 N Harrison # 304
Pierre, SD 57501-2833

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TITLE OF PROPOSED PROJECT **Underground Science for the 21st Century: The National Underground Science Laboratory at Homestake**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PREPROPOSAL NO., IF APPLICABLE
$ **281,090,368**	**60** months	**01/01/02**	

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☐ BEGINNING INVESTIGATOR (GPG I.A)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.6)
☒ NATIONAL ENVIRONMENTAL POLICY ACT (GPG II.C.9)
☒ HISTORIC PLACES (GPG II.C.9)
☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.C.11)
☐ VERTEBRATE ANIMALS (GPG II.C.11) IACUC App. Date _____
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Exemption Subsection _____ or IRB App. Date _____
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☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.E.1)

PI/PD DEPARTMENT

Physics

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Electronic Signature

Received :06/05/2001

CERTIFICATION PAGE

Certification for Principal Investigators and Co-Principal Investigators:

I certify to the best of my knowledge that:

(1) the statements herein (excluding scientific hypotheses and scientific opinions) are true and complete, and
(2) the text and graphics herein as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I agree to accept responsibility for the scientific conduct of the project and to provide the required progress reports if an award is made as a result of this proposal.

I understand that the willful provision of false information or concealing a material fact in this proposal or any other communication submitted to NSF is a criminal offense (U.S.Code, Title 18, Section 1001).

Name (Typed)	Signature	Social Security No.*	Date
PI/PD **Wick C Haxton**	**Signature Not Required**	**SSN's are confidential and are not displayed *ON FASTLANE SUBMISSIONS***	
Co-PI/PD **Janet M Conrad**	**Signature Not Required**		
Co-PI/PD **Sherry O Farwell**	**Signature Not Required**		
Co-PI/PD **Marvin L Marshak**	**Signature Not Required**		
Co-PI/PD **John F Wilkerson**	**Signature Not Required**		

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 01-2. Willful provision of false information in this application and its supporting documents or in reports required under an ensuring award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflict which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Debarment Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

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This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure Form to Report Lobbying,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME/TITLE (TYPED) **Sinh P Simmons**	**Electronic Signature**	**Jun 5 2001 5:28PM**

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Received :06/05/2001

A. Project Summary

During the past 30 years, scientists have developed an amazing new way to view the Universe around us—deep underground neutrino "telescopes." Seminal work in this field began more than 30 years ago with R. Davis's pioneering detector 4,850 feet underground at the Homestake Mine in South Dakota. The results of this experiment—the "solar neutrino problem"—have stimulated multiple investigations that now promise new insights into the Standard Model of the Universe—its origin, its interactions and its destiny. Recently, a whole range of "underground science" has become evident. Specific basic research topics include solar, atmospheric, long-baseline, supernova and high energy astrophysical neutrinos; double beta decay; precision assay of radionucleides, with applications to enforcement of disarmament treaties and environmental effluent studies; materials science; nuclear astrophysics cross-section measurements; multiple topics in geoscience and the study of the evolution of biological organisms under harsh conditions. There is also industrial interest in underground laboratories because of materials activation issues and cosmic-ray-induced error rates in microelectronics. Because the techniques used for research have considerable overlap, intellectual synergies and practical efficiencies suggest the establishment of a national underground science laboratory. The imminent cessation of mining at Homestake and the 8,000 foot depth and extensive physical plant available there make compelling arguments for the location of the National Underground Science Laboratory (NUSL) at the Homestake Mine in and near the City of Lead, Lawrence County, South Dakota. The opportunity at Homestake is time-limited. Substantial action is required in the near future to prevent deterioration of Homestake's human and physical resources, once the Mine ceases operation at the end of 2001.

This proposal is a collaboration between the Consortium for Underground Science (CUS), the South Dakota Board of Regents and its universities, and the State of South Dakota, with strong support from South Dakota Governor William Janklow and the South Dakota Legislature. The State of South Dakota is in the final stages of legislatively-approved negotiations with the Homestake Mining Corporation to obtain title to the Homestake site. The State thus shoulders indemnity and liability responsibilities. The laboratory will be managed by a Director, who will be appointed after an international search by the Consortium for Underground Science (CUS), a tax-exempt limited-liability entity that will represent the interests of the three partners, the National Science Foundation, the State of South Dakota and its universities, and the national and international science communities. Funds will be received by the South Dakota Board of Regents who, while guaranteeing that the laws and regulations of the State are followed, will otherwise delegate NUSL management responsibilities to CUS. CUS will contract much of the construction, operations, and maintenance at the site to state institutions, particularly the South Dakota School of Mines and Technology (SDSM&T), the University of South Dakota, and South Dakota State University.

This proposal lays out a conceptual design and budget for renovating the Homestake Laboratory and developing capabilities to host multiple underground science experiments at several depths, principally 6,500 m water equivalent (mwe). After an initial development of flexibly-assigned laboratory and support space, laboratory caverns would be "built-to-order" as scientific proposals are approved. The underground layout and the ventilation and safety systems are designed to enable safe use of difficult-to-handle materials needed for increased detector sensitivity, including flammables, cryogens, toxics and suffocating gases. An early priority would be an ultra-low-background counting facility. This facility would be used for prototyping proposed detectors, for qualifying materials to be used in detectors and for precision radioassay studies. NUSL would also provide deep underground space for storage and assembly of detector materials in order to reduce backgrounds due to cosmogenic activity.

NUSL proposes to pursue extensive broader impacts to its program of world-class science and technology. Many people find understanding the Cosmos exciting. With proximity to Mt. Rushmore and other tourist sites, NUSL has the potential to directly engage more Americans than any other U.S. research science site. In addition to an extensive outreach program for tourists, NUSL will provide on-site and distance education curricular experiences for K-Ph.D. students, distance education opportunities for the general public, astrophysical data outreach to scientists around the world and special participation opportunities for individuals and institutions in regional and national EPSCoR states and Puerto Rico. In its interpretative activities, NUSL will recognize the special significance of the Black Hills to Native-American community and will use both its special place and the excitement of its science to reach out to all communities, especially those underrepresented in American science and technology. The proposal discusses opportunities for NUSL to enhance diversity in science by promoting excellence in Native American science and engineering. NUSL will partner with existing strong programs sponsored by the National Science Foundation, State institutions, and the Tribal Colleges, and take the lead in initiating new educational outreach efforts.

Finally, this Proposal describes the extremely strong support in the Black Hills and South Dakota communities for the rebirth of the Homestake Mine, an important symbol of both American technology and the history of the American West, as a seminal site for global partnerships to better understand the Universe in which we live.

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*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

C. Project Description

1. Overview of Underground Science and the National Underground Science Laboratory at Homestake

Underground science, a field that barely existed twenty years ago, has recently made significant discoveries and today is on the threshold of producing important and exciting advances in fields as diverse as elementary particle physics, nuclear physics, astronomy, geology, biology, as well as applied areas such as materials science and nuclear non-proliferation. Underground science includes creative and original investigations that allow observers to probe the universe in new ways and with vastly increased precision. Key areas of inquiry in underground science include:

(a) neutrinoless double beta decay, where there is a real opportunity to understand the particle-antiparticle nature of neutrinos as well as probe neutrino masses;

(b) solar neutrinos, where increased sensitivity of proposed detectors will likely shed new light on neutrino properties and demonstrate our understanding of stellar evolution and nucleosynthesis;

(c) enhanced direct searches for "dark matter," which is thought to exist in the Universe from several indirect clues. New experiments should have at least an order of magnitude better sensitivity than previous detection efforts;

(d) searches for "proton decay" that test the ultimate stability of matter. Both finding and not finding nucleon decay at the 10^{35} year lifetime level will have significant influence on theories relevant to questions concerning the unification of the fundamental forces that advance beyond the current standard model of nuclear and particle physics;

(e) new experiments to examine the fundamental interactions through the measurement of "neutrino mixing parameters" in the study of both atmospheric and long-baseline neutrino oscillations;

(f) the exciting questions regarding neutrino emission by galactic supernovae, which lie at the intersection of elementary particle physics, nuclear physics, and astrophysics;

(g) new opportunities for using precision techniques to study fusion reactions at temperatures characteristic of stellar interiors;

(h) key questions in geoscience including heterogeneity of rock characteristics, hydrologic flow and containment transport paths, rock deformation and failure modes, and experiments to validate geophysical analysis techniques; and

(i) a study of the extrema of terrestrial biological evolution by exploration of the nature of microbial colonies, which dwell in the low solar energy, high temperature, high lithostatic pressure, deep underground environment. Underground science also addresses applied challenges ranging from materials development and sensing in ultra-low radiation environments, including the use of few-atom trace techniques, to the strengthening both national and global security through advances in the ability to detect nuclear non-proliferation violations. The materials activation issues are of importance to industries such as microelectronics. *Underground Science* (Appendix A) is an expository paper written by a U.S. scientific community committee, which further explores many of these topics. The National Science Foundation and the Office of Science, U.S. Department of Energy funded the work of this Committee.

Underground science provides a range of high-impact opportunities to promote teaching, training and learning, as well as to provide first-hand experience with "cutting edge" science by a large number of Americans. Underground science is intellectually exciting, because it addresses fundamental questions such as "How did the Universe evolve during the very early stages of the Big Bang?"; "What is the ultimate fate of the Universe?—will the Universe collapse on itself? will all matter decay into energy?;" and "How well can life evolve to adapt to harsh conditions deep underground?" Answers to this last question may also provide insight into how well life can evolve and survive in outer space. Underground science can attract a wide range of people to ponder these fundamental science questions because of its inherent connection to human curiosity and its high entertainment value. Visitors to an underground science laboratory will experience a Jules Verne-like trip into the depths of the earth, a chance to walk through football-field size cavities more than a mile underground, and a guided tour through the sophisticated instrumentation and computer displays of the deepest underground sky observatory in the world. The range of scientific fields and the diversity of sophistication in underground science will facilitate experiential learning opportunities for K-Ph.D. students in a multitude of academic disciplines. The ties between underground science and nature and the location of an underground science laboratory in an area revered by indigenous peoples will help build outreach opportunities to make science real for many traditionally underserved Americans.

We propose to establish the National Underground Science Laboratory at Homestake (NUSL), the world's deepest and most extensive underground science laboratory, through the renovation of the Homestake Gold Mine in Lead, Lawrence County, South Dakota. Our proposal describes a state-of-the-art laboratory that will probe the frontiers of underground science in diverse fields and a laboratory that will likely host more than 100,000 visitors annually to a first-hand observation of scientific research in a deep underground setting. Lead lies in the heart of South Dakota's Black Hills region, the home of Mt. Rushmore and other sites that attract more than 3 million Americans each year. Homestake is the birthplace of neutrino astronomy. For over three decades, it has housed the historic chlorine experiment. For more than a century, Homestake has symbolized the role of technology in the expansion of the American West and in the building of America's social and economic future. Its 126-year history of continuous operations, the longest of any U.S. mine, has roots in the gold-rush days of territorial South Dakota. For centuries before this time, the Black Hills were home to the ancestors of the Native American citizens of South Dakota and the region. NUSL will extend this story into the 21st century, enabling new discoveries about the science that governs our world, while preserving the history of the Black Hills in a way that respects the traditions and improves the lives of all of the region's citizens.

This proposal to build a National Underground Science Laboratory at Homestake (NUSL) for the United States and the scientific world is (a) timely, (b) well-suited to reach the limits of scientific understanding and instrumentation technology and (c) synergistic and efficient. The timeliness of this proposal is demonstrated by the more than 35 letters of interest from distinguished scientists throughout the world sent to the Underground Laboratory Committee during a three-week period earlier this year. These letters are summarized in tables on the next two pages. The *verbatim* text of the Letters of Interest is included by reference to a website noted in Appendix D. The letters are also available from the Institute for Nuclear Theory at the University of Washington. The Letters of Interest should be regarded only as representative of both the scientific topics that can be addressed by deep underground detectors and the scientists who are personally challenged by these questions. Because the letters were solicited in connection with planning initiatives in the physics community, they primarily describe proposed physics and astrophysics detectors. These detectors range in size from a few kilograms to 500 million kilograms. Their readiness for installation in an underground science laboratory ranges from immediately through several years of planning, development and refinement. The authors represent a wide range of distinguished universities in North America, Europe and Asia; most of the American national laboratories, including Brookhaven, Fermilab, Oak Ridge, Los Alamos and Lawrence Berkeley; several American government laboratories, including the National Institutes of Science and Technology (NIST) and the Naval Research Laboratory (NRL); and foreign laboratories, including the Italian National Institute for Nuclear Physics (INFN) and the German Max Planck Institutes (MPI). The topics described in these letters of intent include $\beta\beta$ decay, solar neutrinos, dark matter searches, long baseline neutrinos, nuclear astrophysics, low background counting, neutrinos from supernovae, atmospheric neutrinos, advanced detector development, neutrino factory studies, geoscience, proton decay, new species of microorganisms, weakly interacting massive particles (WIMPs), gravitational radiation and ultra-low background nuclear isotope measurements.

We note that several of the Letters of Interest refer specifically to sites other than Homestake and that some scientists believe that the United States should develop multiple underground laboratories. One reason noted for multiple laboratories is that a particular detector may not need all the advantages of a national laboratory with a deep site and could be built more cheaply or more quickly in an existing location in an existing mine. For example, the signature of a supernova is a large number of neutrino events in a short period of time. Such a signal is easily distinguished from background and does not require a very deep location. On the other hand, a supernova detector and a solar neutrino detector might be combined in one device that would require a deep location to faciltate the solar neutrino studies. Overall, such a detector would likely represent a more efficient use of limited resources and would have a significantly higher discovery potential. A second set of reasons for multiple underground laboratories concerns long-baseline neutrino oscillation experiments. For these studies, the key parameter is L/E, the ratio of the distance between the neutrino source and the neutrino detector divided by the mean neutrino energy. The optimal value of L/E is currently unknown, because the value of Δm^2 between neutrino generations is not well measured by existing atmospheric neutrino detectors. The optimal value of L/E could easily be a factor of two more or less than the current estimates. In addition, because of multiple proposals for new neutrino sources for long-baseline experiments, neither E nor the starting point for measuring L is known. Resolution of all of these uncertainties could well require ten or more years. After considering these multiple factors, we reach the same conclusion as the

Underground Laboratory Committee (see Appendix B). We believe the synergies and efficiencies that would result from developing a national underground science laboratory at a single site over the next decade would positively and profoundly influence the development of this entire area of science. At some future time, if and when sound scientific reasons support development of specific detectors at other sites, then such projects should also go forward. CUS and the NUSL at Homestake management structure might contribute to such efforts or they might be managed by other national laboratories or by one or more universities. In any event, the contributions to the development of underground science delivered by NUSL at Homestake will facilitate not impede the progress of these possible efforts.

Figure 1—Map showing the location of the Homestake Mine in Lead, Lawrence County, South Dakota.

Table 1: National Underground Science Laboratory at Homestake - Science Summary

Scientific Questions	Detector Requirements and Capabilities	Lab Requirements	Discovery Potential
Solar Neutrinos			

• What is origin of solar neutrino problem?
• Do we understand nuclear physics of stars?
• What is the nature of neutrino mixing?
• What can we learn about neutrino masses and mixing angles?
• Do neutrinos have non-Standard Model properties?
	• Ability to directly observe p-p neutrinos.
	  ‣ Low energy threshold (200-400 keV)
	  ‣ Ultra-low activity materials
	• Detectors have potential multiple physics capabilities: solar, supernovae, atmospheric and long-baseline neutrinos
		• Depths ≥ 5,000 mwe
		• Space of 7,500 to 500,000 m^3
		• Clean room environment
		• Low radon levels
		• Ability to safely handle cryogens and mineral-oil based scintillators
			• Neutrino mass hierarchy and mixing parameters.
			• Quantitative understanding of stellar evolution and nucleosynthesis.
			• Physics beyond current standard model.
			• Role that neutrinos play in cosmology and nuclear astrophysics.

Double Beta Decay			

• Is lepton number conserved?
• How does the neutrino transform under charge conjugation?
• What is the nature of neutrino mixing?
• What is the absolute scale of neutrino masses?
• What role do neutrinos play in new phenomena beyond the Standard Model?
	• Need sensitivities of $\langle m_{eff} \rangle \sim 0.01\text{-}0.05$ eV
	  ‣ Increased detector masses ~100-1000 kg
	  ‣ Isotopically enriched material (for some experiments)
	  ‣ Excellent energy resolution
	  ‣ Ultra low activity materials
	• Potential multiple physics capabilities: solar neutrinos, dark matter
		• Depths ≥ 4,000 mwe
		• Space of 700 - 4500 m^3
		• Clean room environment
		• Low radon levels
		• Ability to safely handle cryogens
		• Special shielding from external radioactivity.
			• Lepton number violation in the early universe is crucial to cosmology.
			• Opportunity to study rare second-order weak interactions in nature.
			• Absolute scale of neutrino masses is crucial to dark matter studies and understanding the large-scale structure of the universe.

Dark Matter			

• What is the composition of dark matter?
• How does it interact with ordinary matter?
• What role does dark matter play in cosmology, the evolution of the universe, and structure formation?
	• Extend sensitivities to the regions predicted by minimal supersymmetric models.
	  ‣ Increased detector masses ~100-1000 kg
	  ‣ Ultra low activity materials
	• Directionality sensitivity useful.
	• Potential multiple physics capabilities: double beta-decay
		• Depths ≥ 4,000 mwe
		• Space of 700 – 4,500 m^3
		• Clean room environment
		• Low radon levels
		• Ability to safely handle cryogens
		• Special shielding from external radioactivity.
			• Nature of the lightest supersymmetric particle.
			• Existence of weakly interacting massive particles.
			• Possible relevance to models of extra dimensions, string theories, and quintessence.
			• Insight into unification of gravity.

Scientific Questions	Detector Requirements and Capabilities	Lab Requirements	Discovery Potential
Nucleon Decay			
• Is baryon number conserved? • Are protons stable? • What models lie beyond the Standard Model?	• Sensitivities of proton lifetime > $10^{33\text{-}34}$ years ‣ Increased detector masses ~500,000 kg • Potential multiple physics: solar, supernova, atmospheric, long-baseline neutrinos	• Depths ≥ 4,000 mwe • Space up to 900,750 m^3 • Clean room (construction) • Low radon levels • Large staging area • Ability to safely handle cryogens and mineral-oil based scintillators	• Baryon number violation is crucial to understanding physics beyond the standard model. • Direct tests of most grand unified theories. • Direct probe of GUT scale.
Neutrino Oscillations: Atmospheric and Long-Baseline			
• What is the nature of the neutrino mixing matrix? • Do neutrinos oscillate to non-active flavors? • What can be learned about neutrino properties from controlled, terrestrial source measurements? • What is the strangeness content of the nucleon? • Do we know neutrino-nucleus cross-sections important to supernovae and the solar neutrino problem?	• Need larger statistics for more precise measurement of the mixing angle, hence bigger mass detectors. • Ability to observe tau neutrino appearance • Better sensitivity to oscillations • More statistics on neutral current events;	• Depths ≥ 4,000 mwe • Space up to 900,750 m^3 • Clean room during construction • Low radon levels • Large staging area • Ability to safely handle cryogens and mineral-oil based scintillators	• Laboratory confirmation of neutrino oscillations. • Perform quantitative tests of the accuracy of calculated neutrino-nucleus cross sections. • Accurate cross section can provide information crucial for understanding supernova physics, and nucleosynthesis. • Understanding of GeV neutrino interactions in nuclei.
Supernovae Neutrinos			
• Can we use the neutrino flux from the next galactic supernova to learn about the explosion mechanism and, probe properties of the proto-neutron star? • Can we exploit supernovae to search for new phenomena, including neutrino oscillations and neutrino masses?	• Need flavor sensitivity and ability to distinguish neutrinos and antineutrinos • good spectral sensitivity • sensitivity to events on the tail of the cooling curve	• Depths of ≥ 2,000 mwe • Space 15,000 m^3 • Ability to safely handle cryogens and mineral-oil based scintillators	• SN neutrino detection is a key component of the "supernova watch" program involving gravitational wave detectors and optical observatories. • Direct detection of neutrino mass. • Potential observation of tau neutrino oscillations.
Nuclear Astrophysics			
• Do we understand the low-energy nuclear physics reactions that power stars? • What is the influence of nuclear structure and reactions on the evolution, energy generation, and time scales in stars and stellar explosions? • What is the origin of the elements that make up the present day Universe?	• Extremely low rate measurements are dominated by backgrounds when done above ground. ‣ A high-intensity low-energy heavy-ion accelerator would allow inverse kinematics experiments.	• Depths of ≥ 4,000 mwe • Space of 6,000 m3 • Will need to be isolated from ultra low background experiments. • safety issues related to operation of an accelerator	• More precise understanding of fundamental low-rate p-p & CNO stellar processes • Understanding of nuclei far-from stability. • Understanding the origin of the heavy elements.

Scientific Questions	Detector Requirements and Capabilities	Lab Requirements	Discovery Potential
Geoscience			

• Do we understand the extremely long-term stability of hard rock cavities?
• How do environmental factors influence stability?
• How well do our predictive models work?
	• Widely placed sensors and monitoring readout system.
	  ‣ seismic monitors
	  ‣ strain gauges
	  ‣ temperature
	  ‣ pressure
		• Access to all available levels.
		• Access during mining.
		• Instrumentation readout system.
		• Special dedicated cavities and drifts for long term testing.
			• Assist in the design of long-term nuclear waste storage.
			• Assist in future cavity design.

Precision Radioassay			
• What sensitivity levels can be reached in counting low-background materials? • Can cleaner materials be found and utilized in the next generation science experiments ?	• Low-background Germanium counting systems. • Whole body scintillator based counter. • Space for specialized, dedicated counting systems	• Depths ≥ 5,000 mwe • Space 4000 m^3 • Clean room environment • Low radon levels • Special water shield to eliminate external radioactivity	• Verification of nuclear testing treaties • Facilitate the construction of next generation double beta decay, dark matter, and solar neutrino experiments. • Production of ultra-radiopure materials for commercial applications.
Microbiology			
• How do organisms survive in harsh, non-traditional environments? • What level of microbial activities are possible in such an environment? • Are the deep subsurface microbial communities present in fluid-filled fractures distinct from those embedded in the rock strata?	• Widely placed sensors and monitoring readout with some overlap to the geoscience system.	• Access to all available levels • Space 1200 m^3 • Some special bore holes. • Instrumentation readout system • Anaerobic glove box • Chemistry and biology facilities	• Understanding the relationship between the indigenous microbial communities and their environment. • Insight into life in extreme environments, such as ocean ridges and at the allowed zone of microbial thermophilicity.

Table 2: Summary of Letters of Interest Sent to National Underground Laboratory Committee

SCIENCE	DEPTH	PEOPLE	EXCAVATION	TIMESCALE	SPECIAL REQUIREMENTS
	(mwe)	Construction / Operation	m^3	Years	
Geoscience	All Levels	10 / 2	375	1	Access to all existing parts of mine
Microbiology	All levels	10 / 2	1,125	1	Clean room, Anaerobic glove box, chemistry and biology facilities
Monitoring Nuclear Tests	>5000	20 / 5	3,230	1	Liquid scintillator, cryogenic liquids. Low radon, clean room, wet chemistry
Materials Science	>6000	20 / 5	4,950	1	Liquid scintillator, cryogenic liquids, low radon, clean room, wet chemistry
Nuclear Astrophysics					
LUNA-II	>4000	20 / 5	2,000	1	Shielded accelerators
Double Beta Decay					
MOON	>2,500	25 / 6	2,000	2	Liquid scintillator, low radon, clean room, cosmogenic storage, large access
EXO	>6,000	30/5	4,500	2	Cryogenic liquids and storage, low radon, clean room, cosmogenic storage
MAJORANA-II	>4,000	30/5	680	2	Cryogenic liquids and storage, low radon, clean room, cosmogenic storage

Low Energy Solar Neutrinos					
HERON	>6,000	30 / 5	7,500	3	Cryogenic liquids, liquid helium storage capability, low radon, clean room, cosmogenic storage, large access for cryogenic dewars
CLEAN	>4000	50 / 15	8,000	3	Cryogenic liquids, liquid helium or neon storage capability, low radon, clean room staging, cosmogenic storage, large access for cryogenic dewars
HERD	>4,000	50 / 5	430,000	3	Low radon air, clean room, cosmogenic storage, some cryogens, Hazardous liquid.
LENS					
GaAs Detector					
Supernova Detectors					
OMNIS	>2,000	30 / 5	15,000	4	Liquid scintillator, large access while installing scintillator
Dark Matter Searches					
CDMS-II	>4,000	30 / 5	6,750	5	Liquid scintillator, cryogenic liquids, low radon, clean room staging cosmogenic storage, low background counting
Nucleon Decay					
UNO	>3,000	100 /20	900,750	4	Low radon, Clean room staging, 3 MW, large access during construction.
LLANND	>3,000	100/20	293,000	4	Low radon, clean room for staging, 2 MW, large liquid argon storage, large access during construction.

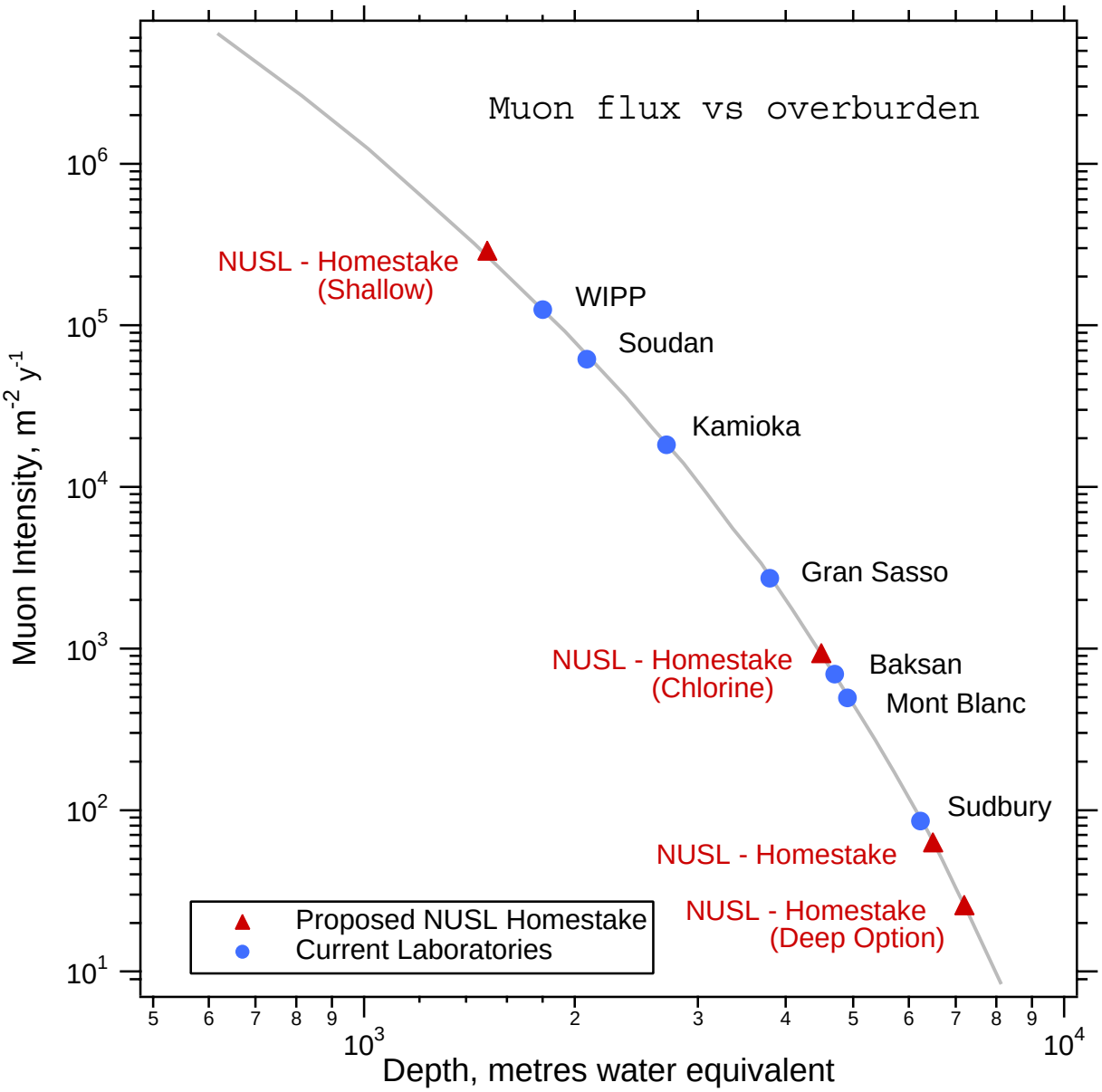
2. Requirements for a Premier National Underground Science Laboratory

There are a number of requirements that an underground laboratory must meet in order to undertake the next generation of more sensitive, more revealing underground detectors. Drawing on both our underground research experiences and using extensive input from the existing community of scientists, the key features of an ideal national underground laboratory can be defined as follows:

• *Depth:* The primary rationale for an underground laboratory is to provide an environment well shielded from ambient radiation, radioactivity directly and indirectly produced by cosmic rays and, in some cases, electromagnetic radiation. Deeper depth provides more shielding. Thus, the most sensitive detectors of low-rate events require ultra-deep locations, certainly deeper than the current world standard for a general-purpose laboratory, which is the 3,800 m water equivalent (mwe) location of the National Laboratory of Gran Sasso (LNGS). [Gran Sasso began operations two decades ago. In the intervening years, radiopurity standards in underground experiments, such as double beta decay, have improved by about three orders of magnitude. It is this improvement that makes concommitant reductions in cosmogenic backgrounds, by going to greater depths, important in many background-sensitive experiments.] While some detectors will require ultra-deep locations, others may prefer laboratories closer to the surface for (a) more convenient access, (b) less lithostatic pressure and thus easier and less costly laboratory construction or (c) a non-vanishing muon flux for detector calibration or other purposes. To capture the advantages of a single primary site that are discussed below, an ideal national underground laboratory should provide a range of depths, including, most importantly, one or more depths significantly greater than 4,000 mwe. NUSL at Homestake can provide laboratories at depths of 1,500 mwe, 2,100 mwe, 3,100 mwe, 3,400 mwe, 4,500 mwe, 6,500 mwe and 7,200 mwe. The 4,500 mwe and 6,500 mwe levels are currently planned as the foci of most experimental activities.

• *Detector Laboratories:* The heart of any such site is the underground laboratories. For example, the LNGS provides three large detector halls, each approximately 20 m wide by 100 m long by 20 m in height. In addition, some small detectors at LNGS are sited in various access tunnels and ancillary spaces. This large, multi-purpose hall model has worked well for LNGS. However, the Kamioka and Creighton Mine laboratories have very different layouts with upright cylindrical cavities with hemispherically-domed ceilings and primary access near the top. This design appears optimal for detectors with large quantities of liquids. For example, the Super-Kamiokande detector at Kamioka contains approximately 50,000 m^3 of water. An ideal national underground laboratory would provide a range of underground detector halls, including some large, general-purpose halls for quick, flexible installation of smaller detectors, and the ability to construct customized, "built-to-order" halls for detectors with special requirements, including large volumes of liquids, electrical isolation, and physical isolation for safe use of flammables, cryogens, toxic materials and suffocating gases. The rock integrity in this ideal laboratory should be sufficiently competent to facilitate excavation and long-term stability (50+ years) of "rural mailbox style" halls. It should be possible to construct such a hall with gross volume of at least 0.9 million m^3 (0.5 million m^3 of liquid) at depths of at least 4,000 mwe in order to host a water Cerenkov detector, which is more than an order-of-magnitude more sensitive than Super-Kamiokande. Both extensive experience at Homestake and rock mechanics calculations using models validated by experience indicate the feasibility of building diverse-sized laboratories at Homestake, including the 0.9 million m^3 Cerenkov detector at both the 4,500 mwe and 6,500 mwe levels. Experience with the IMB Detector in the Fairport Harbor, Ohio, Morton Salt Mine suggests that rock walls with or without a flexible bladder are more suitable for water Cerenkov detectors that walls composed of halites or anhydrides.

• *Cleanliness:* A low background site is complemented by high-purity detector materials, substances that are as free as possible from trace radioisotopes, chemical contaminants and "dirt." An ideal national underground laboratory will provide a variety of clean room environments (from Class 100 – 3000 level) for both detector assembly and detector operation in deep underground laboratories and efficient and secure methods to transport large, pre-cleaned instrumentation assemblies from the surface to the underground laboratories. Mechanical engineering consultants have validated the feasibility of NUSL at Homestake providing a range of classes of clean room spaces in both the upper and lower campuses, as well as sealed, containerized transport for particulate-sensitive instrumentation between the upper and lower campus. For many of the experiments, special steps such as polyurethane sealant on the walls and high levels of surface air ventilation flows will be required to implement environments with very low radon concentrations. The Homestake site is well suited for use of both of these techniques. The Homestake rock when blasted leaves relatively smooth surfaces that are easily spray-coated with



sealant materials. The existence of five shafts, large capacity ventilation fans and a modern ventilation control system at Homestake will facilitate air change rates that will minimize underground radon concentration.

Figure 2—Cosmic ray muon flux vs. depth in meters of water equivalent (mwe) for current and proposed underground laboratories.

• *Special Materials:* A new generation of underground science detectors will likely require some use of difficult-to-handle materials, including flammables, cryogens, toxic chemicals, suffocating gases and mega-Curie isotope sources for detector calibration. An ideal national underground laboratory will have the physical and operational systems required to safely transport, store and operate detectors with such materials. The required physical facilities include isolated laboratories, isolated and highly effective ventilation systems, and appropriate detection and suppression systems. The operational systems include the complete range of safety services and the capability to provide appropriate support to address regulatory and licensing issues. NUSL at Homestake will provide the entire required range of safety systems and services. In addition, NUSL will house experiments with significant safety issues in "built-to-order," isolated rooms with all large liquid inventories stored below grade. The existing workings at Homestake also provide extensive existing areas deep underground that can be used for long-term storage of

materials to reduce cosmogenic radioactivity.

• *Electrically Quiet and Stable:* Many underground science detectors use sensitive transducers that produce very low-level signals. While sensitive pre-amplifiers can always be protected with electrical shielding and good grounding, a national underground laboratory will benefit from well-designed and well-isolated clean power sources, as well as the electromagnetic shielding inherent in rock walls. The NUSL design will include electrical isolation and grounding systems that minimize ground loops and cross-talk. Electrically and mechanically noisy equipment will be isolated both electrically and physically in "built-to-order" individualized underground rooms. Although the local power supply historically is very stable with few outages, uninterruptible power supplies (UPS) will be provided as needed to keep critical equipment operating during any power spikes or failures.

• *Access for Large Dimension and Heavy Equipment:* The Letters of Interest represent a wide range of detectors with vastly different materials handling challenges. Since installation and debugging is a large fraction of the real cost of experiments, a national underground laboratory should have the facilities and skill to move large-dimension and heavy equipment from an enclosed semi-trailer unloading dock on the surface to the laboratory locations deep underground in minimal time, with minimal effort and with minimal shock or other handling damage. The ability to readily handle standard container-sized units will allow experimenters around the world to pre-assemble their equipment efficiently in their home laboratories and then ship the assembled modules to NUSL. The ability to transport underground large, oddly-shaped and heavy items will facilitate in-laboratory assembly of tanks, steel structural support, purification units and other mechanical systems while minimizing cost. Several options exist for developing underground access at Homestake. Currently, NUSL at Homestake provides access to all depths for objects of approximate dimension 1.5 m by 4 m by 2.5 m high with a mass of 7 tons, including custom-containers. We propose here an extensive access upgrade, that will accommodate standard sea containers of approximate dimension 3 m by 6.5 m by 3 m high with a mass of 15 tons, with minimal handling between the surface and the deep underground laboratories.

• *Convenient Personnel Access:* Observers familiar with how experimental science is really done understand that hardly any factor is more important than spontaneous, convenient personnel access to detectors, 24 hours per day, 7 days per week, 365 days per year. The ideal national underground laboratory will provide self-controlled access as easy as that of a 24-hour neighborhood convenience store, while using automated systems to enforce access security and to display at all times the precise location of each person in the underground campus. NUSL at Homestake will provide a self-controlled personnel and small equipment lift, similar to an office building elevator, with automated systems for access control and logging. The underground campus will be equipped with personnel locator systems that will monitor and log the location of all personnel at all times.

• *Efficient Work Spaces:* Scientists work long hours each day and week during installation and operation of detectors. Both underground and surface work spaces should be designed to maximize human efficiency and minimize fatigue through efficient layout, good lighting, well-controlled temperature and relative humidity and appropriate visual and sensory stimuli. Work and ancillary spaces should be well-maintained and cleaned to provide inviting surroundings, including nights and weekends when much science work is actually accomplished. NUSL's upper and lower campus workspaces will be designed by specialists in workplace ergonomics and in underground civil and mechanical engineering.

• *Quality of Life*: National laboratories need to also provide a variety of high-quality support services, including: a library, including access to electronically-archived literature; cafeterias; vending; attractive, private and inexpensive overnight accommodations for visitors; cultural events in cooperation with local communities; and opportunities for recreation and high-quality academic programs at nearby universities. At NUSL at Homestake, these on-site support services will be based on similar successful models used at other national laboratories and research centers. Both Black Hills State University and the South Dakota School of Mines and Technology are located within 40 miles of the NUSL site.

• *Outreach:* The Kamioka and Soudan Laboratories and the LNGS provide examples of successful outreach programs in underground laboratories. All three of these sites host regular, on-going tour programs for K-12

students. The Soudan Laboratory, as part of a state park, provides both historical and scientific tours to the lowest level of the Soudan Mine.

We expect NUSL to have a far more aggressive outreach program than these examples, one that combines the unique history of the Black Hills and the Homestake mine with its past and current role in science. The attractiveness of Homestake as a visitor destination is already clear: the Homestake Corporation has sponsored tours of the gold mine for many years, with Black Hills tourists the primary customers, and with tour proceeds donated to a variety of civic organizations and charities. One component of the new outreach effort will be a "destination-quality" history/science attraction for the general public as well as for visiting K-12 students. The importance of the Black Hills to Native Americans opens opportunities for attracting this underserved community to Homestake science through a respectful treatment of the region's history, including the linkages to science. NUSL will offer to both students and the general public a 2-3 hour tour including the history of the region and mine, the early use of Homestake in the chlorine experiment, hands-on exhibits, a multi-media presentation, and a Jules Verne-like trip underground to see modern detectors and working scientists.

NUSL will couple these onsight efforts with educational outreach for K-12, undergraduate, and graduate students, including efforts that support existing programs sponsored by the state, the National Science Foundation, and other agencies. This outreach will include the public and tribal school teachers of these students, as well as college and university instructors. The goal is to establish lasting links between the classroom and NUSL, empowering teachers while enhancing science opportunities for the students. The NUSL outreach methodology will include distance education tools both for science presentations and for classroom involvement in real-time data dumps from NUSL detectors.

Among the existing programs that NUSL will offer to support are the teacher outreach efforts of the Center for Advancement of Mathematics and Science Education of Black Hills State University, a program similar to that pioneered by Lillian McDermott at the University of Washington; and the NSF-sponsored Model Institute for Excellence efforts in science, mathematics, engineering and technology involving five Great Plains tribal colleges (Oglala Lakota College on the Pine Ridge Reservation, Sinte Gleska University on the Rosebud Reservation, Si Tanka College on the Cheyenne River Reservation, Sitting Bull College on the Standing Rock Reservation and Sisseton Wahpeton Community College in northeastern South Dakota). The former program focuses on the professional development of K-12 teachers, improvement of instructional materials, and research in science and mathematics teaching. The latter program, a unique initiative among the nation's 31 tribal colleges, seeks to integrate traditional Native American values into new programs of study to enhance opportunities for Native American students to obtain 4-year and advanced degrees in computer science, pre-engineering, and environmental sciences. It also seeks to improve the preparation and to combat the isolation of tribal K-12 school teachers. The program is already involved in distance learning, establishing links with three neighboring tribal colleges. NUSL will also initiate new programs. It will establish an aggressive Research Experiences for Undergraduates program that will target students regionally (both state and tribal institutions) and nationally. It will work with regional research universities to enhance their PhD programs and provide research opportunities for graduate students. It is anticipated that NUSL scientists will play a classroom role in nearby universities.

The National Underground Science Laboratory (NUSL) at Homestake will provide synergy and efficiency that will enable underground scientists to build on past successes and thus address a new scale of experimental challenges. The history of underground science in the United States is more than 30 years old. Shortly after World War II, American scientists such as K. Greisen at Cornell University applied the newly developed techniques of μsecond coincidence circuits to the underground study of cosmic ray muons. R. Davis, then at Brookhaven National Laboratory, moved underground science to a new level, when he installed 615 tons of perchloroethylene in the Homestake Mine about 35 years ago to search for solar neutrinos. That detector first identified the "solar neutrino problem," an inexplicably low number of observed solar neutrinos, using a highly sensitive radiochemical trace analysis technique. K. Lande and his associates at the University of Pennsylvania continue to operate this detector today, extending Davis' measurements to almost three complete solar cycles. American underground science progressed markedly in the 1980's with the development of the IMB water Cerenkov detector by F. Reines and his collaborators at the University of California-Irvine, the University of Michigan and the Brookhaven National Laboratory. The first American multi-experiment underground laboratory at Soudan MN by built in 1984-1986 by scientists and engineers at the University of Minnesota, Argonne National Laboratory, Oxford University, the Rutherford Appleton Laboratory and Tufts University. These efforts have made major contributions to the elucidation of the "atmospheric neutrino anomaly," that likely indicates mixing among the three neutrinos families

and thus non-zero neutrino mass.

Despite these accomplishments, American underground scientists have been forced to mostly choose between *ad hoc* and parasitic arrangements at underground sites in the United States, including the Homestake Mine, the Waste Isolation Pilot Plant near Carlsbad NM, the Silver King Mine in Park City UT, and the Morton Salt Mine in Fairport Harbor OH, and participation in experiments in better-developed, more capable and deeper international sites including the Creighton Mine in Sudbury Canada, the Kamioka Mine in Mozumi Japan, the National Laboratory of Gran Sasso near Assergi, Italy and the Baksan Laboratory, near Neutrino, Russia in the north Caucasus Mountains. The next generation of underground science is more technically challenging than previous studies and will require both significant resources and good planning and management for success. In contrast to the previous, serendipitous siting of detectors, NUSL will provide a single primary site where large and sophisticated instruments can be operated in an efficient, cost-effective manner.

The National Underground Science Laboratory at Homestake will

- Provide a common infrastructure including convenient access to the underground campus, modern machine shops, local administrative support, high-performance computing facilities and state-of-the-art telecommunications;
- Operate a common safety support system, including safety training and certification; design assistance; pre-installation safety audits; ongoing safety inspections; installation, monitoring and maintenance of safety systems, including smoke and fire detection, monitoring of toxic and suffocating gases and fire suppression systems; safety equipment, including hard hats, steel-toed shoes, re-breathers and respirators; underground refuge rooms with independent air supplies, food and water to support life while awaiting rescue during any emergency situations; radiation safety for accelerators and isotopes; and training and equipping underground rescue teams;
- Promote synergistic interactions among scientists working on different detectors and even in different academic disciplines in a campus-like environment that encourages easy and broad exchanges of ideas;
- Establish common facilities that can be used by different scientists in developing and operating detectors, for example, an ultra-low background counting facility for certification of ultra-low radioactivity materials;
- Create an on-site support organization at NUSL that will enable the testing and implementation of new ideas within an established and coherent scientific program;
- Provide a critical mass of exciting, "world-class" science projects, whose goals and results will stimulate outreach to the American people through direct and "distance education" contact and through the media. In addition, NUSL will operate a "destination-quality" science tourist facility and a coherent on-site and distance education enrichment program for K-12 students;
- Excite and nurture a new generation of scientists through internship programs for undergraduate students, especially students from primarily undergraduate colleges and historically under-served populations, and through dissertation research and mentoring programs for graduate students and post-doctoral fellows in a range of academic disciplines;
- Facilitate international collaboration through cooperation and exchanges with underground science laboratories outside the United States, through hosting of foreign scientific visitors and through facilitation of international scientific collaborations to address "world-class" opportunities in underground science;
- Facilitate, organize and host international scientific meetings to promote information exchange and the development of creative ideas in underground science.

3. Why Homestake?

The questions of whether and, if so, where should a national underground science laboratory be built in the United States have been examined during the past several months by an *ad hoc* Committee organized by the nuclear physics and elementary particle physics communities (Bahcall Committee). The Committee's membership and its report that strongly endorses the construction of a national underground laboratory are included in Appendix B. The Committee members voting also unanimously chose Homestake as the preferred site for the national underground laboratory primarily for the following reasons:

- The world's leading deep underground laboratory, Gran Sasso, was constructed two decades ago and has served a generation of experiments well. It provides 3,800 mwe of overburden. In these two decades the sensitivity of

experiments progressed remarkably. Lifetime limits from double beta decay experiments have improved by three orders of magnitude. The background requirements for the SNO detector—soon to yield first results —led to its construction at a depth of 6,200 m.w.e. (in the difficult environment of an active mine).

The Bahcall Committee concluded that depth was therefore the crucial question in constructing a world-leading underground science laboratory that would provide the optimal environment for the experiments the international community will undertake over the next several decades. Homestake offers depths ranging to 7,200 m.w.e., corresponding to a two-orders-of-magnitude improvement in cosmic ray muon attentuation over that possible at Gran Sasso. To approach such depths at other, undeveloped sites would entail an investment in excess of $100,000,000. Furthermore Homestake is uniquely versatile: its extensive tunnels and power and ventilation systems will allow experiments to be mounted at a range of depths between 1,500 and 7,200 m.w.e.

With recent discoveries in neutrino physics -- which suggest that important clues to physics beyond the standard model can be obtained from low-energy precision tests of symmetries—the pace of progress in this field is likely to quicken. The Bahcall Committee concluded that Homestake was a unique opportunity for securing a laboratory that could accommodate the needs of planned and anticipated experiments.

• The Homestake site offers relatively low risk because (a) both the overall site geology and the characteristics of particular rock structures are well-mapped and well-understood; (b) Homestake has an existing staff, some of whom would join NUSL and bring their knowledge and expertise to bear on NUSL's technical and engineering challenges; (c) the Black Hill's area has extremely low levels of seismic activity; and (d) Homestake and its environs have a long and well-accepted mining history, making environmental and permitting issues less contentious.

• The Homestake site offers shorter time and less capital outlay to produce initial "world-class" physics results, because of its extensive current workings. Our facilities plan, discussed in more detail below, envisions an ultra-low-background counting facility operating within 6 months of the funding of this project and installation access for initial detectors within one year. The capital outlay to reach these milestones is significantly less than the expenditures required in any equivalently deep site because of the existing quantity and quality of the Homestake underground infrastructure, the buildings and physical plant at the surface and the availability of the skilled Homestake workforce.

• The Homestake site has incredible local support and because of that support and its tourist-destination location, Homestake has enormous opportunities for educational outreach and development of public understanding of science. The local support for Homestake is documented in the section on "Local Support" below, which catalogs statements of support by members of Congress, state governmental bodies, local public officials and newspaper editorials.

The Committee's Technical Assessment Sub-Committee developed an enumeration of factors that it believed would be useful in siting a national underground laboratory. The Sub-Committee then discussed these factors with respect to four possible laboratory sites in the United States: the Waste Isolation Pilot Plant (WIPP) near Carlsbad NM, Homestake in Lead SD, Mt. San Jacinto near Palm Springs CA and the Soudan Underground Laboratory in northeastern Minnesota. The factors not discussed elsewhere in this proposal and Homestake's attributes relative to these factors are summarized below:

• *Laboratory Context:* Homestake has the second lowest cost-of-living of the four sites. Homestake has a sunny, semi-arid, high plains climate, warmed by the recompression of air down drafting from the Front Range of the Rocky Mountains. Homestake is served by jet and air commuter service to Rapid City, about 1 hour drive from the laboratory. Homestake is tied for the shortest commute time because the Laboratory is located in the city of Lead, SD. Homestake is within a 1 hour drive of South Dakota School of Mines and Technology in Rapid City and Black Hills State University in Spearfish. Homestake will provide automated, secure 24-7 self-access to the underground campus following the completion of major hoist renovations in Phase 2 of the facilities development plan discussed below. Homestake would be a facility dedicated exclusively for science and related educational functions.

• *Suitability*: Homestake is highly suitable for ultra-low background detectors because of its extreme depth; for detectors with flammables and cryogens because of its "built-to-order" flexible campus and dedicated use as a science facility; and for an ultra-large water Cerenkov detector because of its known rock competence and stability

at deep locations and its experience and facility for moving and disposing of large quantities of rock. The multiple levels of Homestake—about every 150 feet between 1000 and 8000 feet—makes this site uniquely flexible. The existence of multiple access and ventilation shafts contributes to laboratory safety, allowing experiments to be isolated and separately vented.

• *Neutrino Beam:* Homestake is located 1,290 km from Fermilab and 2,530 km from Brookhaven.

The value of these substantial assets at the Homestake site is clearly time-dependent. The more volatile asset is the staff, approximately 300 people with an accumulated working-life-long knowledge of the Homestake Mine, its operation and its potential. The Homestake Mining Corporation has decreased staffing for a number of years. Ongoing mining operations nearby in Montana have continued to attract a number of Homestake staff. Since the Homestake Mining Corporation's shutdown plans have been public for at least 6 months, community leaders expect considerable staff erosion once public schools close for the Summer of 2001, unless strong prospects exist for underground science at Homestake. With regard to physical assets, the Homestake Mining Corporation expects continued operations through Fall 2001. During the first three months of 2002, a small crew will remove lubricating and transformer oils, refrigerants, explosives and similar possible chemical contamination sources from the mine. The pumps will be then be shutdown and the mine will be allowed to flood. Although salvage of flooded mines is possible, the process is expensive and likely not feasible. Thus, at least some action during the next few months is required in order preserve the possibility of using Homestake's capabilities for a national underground science program.

4. Scientific Program

The scientific program for the National Underground Science Laboratory at Homestake will be determined by the NUSL Director with advice from a Program Advisory Committee and after consultation with funding agencies and other leaders in the various scientific communities. Without making any specific commitments, we schematically describe here a scientific planning scenario that represents a reasonable estimate of the scientific program at a future NUSL might unfold over the five years of operation (FY 2003-2007) included in this proposal.

The scientific program would likely begin with conference and associated workshops on site in Lead in Fall 2001 in order to familiarize experimenters with the NUSL site and develop a knowledge base to inform a first-cycle Call for Proposals. We expect a first-cycle proposal submission date in early 2002, followed by a several month review period. We expect approval of first cycle experiments and detectors in mid-2002 with installation beginning in late 2002 and early 2003. Experiments of the following types could be installed on such a fast-track schedule.

• Microbiology: Biology experiments require 1,000-2,000 m^3 of clean-room laboratory space for study and analysis of samples that would be collected throughout the Homestake site. The facilities required for this work include an anaerobic glove box and standard chemical and biological analysis instrumentation.

• Materials and Environmental Science: Studies in this area require precision assays of radionucleides. This work will generally occur in the Ultra-Low Background Counting Facility, a deep underground room with local shielding with ultrapure water to reduce both neutron and gamma ray backgrounds. The details of this Counting Facility are described in Section 5. It should be ready for science studies in late 2002 or early 2003. Science in this area includes single particle characterization for environmental studies, characterization of low-alpha-emitting materials for the semiconductor industry, assays of long-lived isotopes for geochronicity studies and preparation of standard reagents with known radioactivity.

• Monitoring Nuclear Tests: A particularly important topic in precision radionucleide assay is the ultra-high-sensitivity measurement of ^{133}Xe and ^{135}Xe to detect possible violations of the Comprehensive Nuclear Test Ban Treaty. Precision assay of both isotopes is required in order to differentiate between explosive nuclear fission and the accidental of gases of nuclear reactors.

• Geoscience: These activities at NUSL can begin immediately, will be ongoing and will take place through the site. A modest amount of space (<500 m^3) is required for analysis of samples and archiving of data. Studies in this area

include an evaluation of the roles of heterogeneity and scaling on underground processes, studies of migration of water and trace elements, measurements of deformations under heat and stress, and assessment of the impact of mining and operations on biological and environmental conditions. The understanding of processes, together with site features and controlled tests to represent different events, are needed to develop predictive tools including numerical models for future assessment.

• Nuclear Astrophysics: The well-known "Solar Neutrino Problem" is generally thought to point to exotic properties of neutrinos, but the discrepancy has also highlighted a weakness in the standard solar models, namely that a number of the low-energy fusion cross-sections are not actually well-measured. The necessary experiments require a high-current, low-energy accelerator in a deep underground location, in order to minimize background and thus increase sensitivity and precision. Accelerator installation at NUSL could begin in late 2002 or early 2003, with measurements beginning in mid- to late-2003. This schedule will be feasible if the proposed machine is of the type currently in use at Gran Sasso; one letter of interest proposes a more innnovative design that would require a program of research and development, and thus a delay in the accelerator construction and installationschedule.

Although other experiments might well be approved in the first proposal cycle, their likely installation date would be later in the proposal period, either because of their requirements on NUSL or because the experiments themselves will require time to assemble resources or develop detailed plans. Experiments in this category include:

• Double Beta Decay: Double beta decay detectors generally require sufficient lead time to procure isotopically-enriched materials. Their requirements on NUSL a very deep location (6,500 mwe), low radon and clean room facilities. They may also require underground storage facilities for detector materials in order to decrease concentrations of short half-life, cosmogenic isotopes, facilities for handling cryogens and, possibly, the installation of large quantities of mineral-oil based, liquid scintillator. The space requirements for double beta decay are modest, ranging from 1,000 to 5,000 m^3. We estimate that one or two double beta decay experiments could be installed beginning in late 2003 or early 2004.

• Solar neutrinos: A major contribution of NUSL will be new measurements on solar neutrinos, particularly the <1 MeV pp neutrinos. Several possible detectors in this area have modest space needs (<10,000 m^3), but do require transport and inventory of cryogenic liquids, clean room staging, low radon and materials storage to decrease cosmogenic activity. These detectors are thus most likely for installation in the 2004-2005.

• Supernova Detectors: Supernova detectors likely require large quantities of liquid scintillator operating stably for periods up to 50 years with minimal deadtime. Typical space requirements for such a detector are 15,000 m^3. NUSL could install a detector such as OMNIS in the 2004-2005 time period.

• Dark Matter Searches: Dark matter searches share many similar requirements with other detectors, including: modest space requirements (~7,500 m^3), flammable and cryogenic liquid, clean room access, low radon, storage areas to reduce cosmogenic radioactivity and access to a low background materials test facility. Since CDMS-II is currently being installed at Soudan, a next generation dark matter search is likely for installation in 2005-2006, because of the need for time to understand the current detector before designing a new one.

The Letters of Interest (see Appendix D for a summary and reference to the full text of these Letters) include several detectors that are of such size and expense that it is not feasible to fund the laboratory's portion (site preparation and detector installation) of the support costs for these detectors as part of this proposal. Like the Neutrinos at the Main Injector (NUMI, which includes the MINOS—Main Injector Neutrino Oscillation Search Far and Near Detectors) Project, at Fermilab, mega-projects at NUSL will need to secure both laboratory approval and their own funding for laboratory support. The three projects of this type included in the Letters of Interest are:

• High-Pressure Time Projection Chamber for Solar Neutrinos: requires a volume of 400,000-500,000 m^3.

• UNO: A large water Cerenkov detector for proton decay, solar and atmospheric neutrinos and supernova neutrinos. UNO requires a volume of approximately 900,000 m^3.

• LLANND: A large volume, dilute scintillator detector with science goals similar to UNO. The required volume for LLANND is about 300,000 m^3.

More details about these detectors are included in the Letters of Interest cited in Appendix D and available on a website. Since these detectors are complex and require significant resources, they are not likely for installation prior to 2005-2006.

The NUSL scientific staff in the Office of the Associate Director—Science will (a) participate in detector collaborations, (b) work as liaison scientists in support of approved detectors, (c) work on the development of instrumentation and other techniques generally relevant to underground science and (d) generally promote progress in underground science through theoretical studies, interactions with the theoretical and experimental communities by making presentations, writing review papers or books, organizing conferences and other, similar work. NUSL will follow the model of other national laboratories such as Fermilab or Brookhaven in which a few scientists are assigned broad full-time responsibilities, but most scientists work half-time as direct participants in underground science research and half-time in "service functions" as liaison scientists or similar roles. NUSL's scientific program will also include support of post-doctoral research associates and some graduate research assistants from universities working at NUSL and ancillary scientific activities such as work by liaison engineers and computer and network staff.

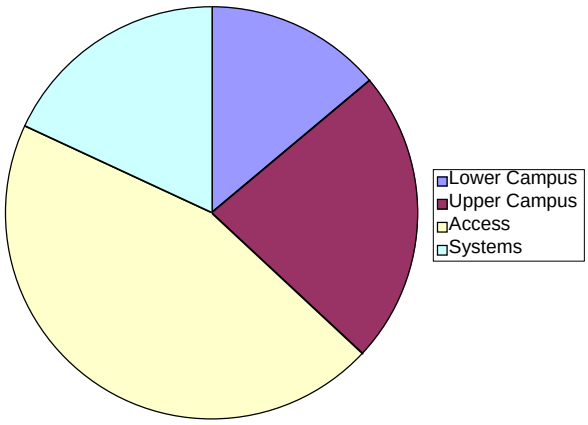
After submission of this Proposal, we expect to commence two activities that will further inform both the national and international science communities and the funding agencies regarding the future development of NUSL at Homestake. First, we will hold an international conference near the Homestake site to provide a forum for potential NUSL users to both discuss ideas for new detectors and learn more about the site. We expect to particularly encourage participation by scientists from communities outside nuclear and particle physics, in order to better scope the broad science implications of NUSL. We further expect to edit the Proceedings of this conference to provide a similar but broader and more detailed "snapshot" of underground science than is provided by the Letters of Interest summarized in Appendix D. Secondly, we expect to organize "working groups" of scientists and other faculty from both inside and outside South Dakota to further define plans for developing NUSL at Homestake. Suitable engineering support will be recruited to facilitate these planning efforts. The results of these studies will be incorporated in a Technical Design Report that will provide a basis for an initial "Temple" review of the NUSL at Homestake project.

Table 3—Summary of Major Development Tasks for NUSL at Homestake

Task	Location/Type	Estimated Cost[1]
Laboratory excavations and finishes	Lower Campus	$12,130,000
Control and scientist support facilities	Lower Campus	$3,980,000
Facilities for Detector Mechanical Support Systems	Lower Campus	$1,110,000
Ultra-low background counting facility and equipment	Lower Campus	$2,900,000
Refuge Room and Sump	Lower Campus	$400,000
Cosmogenic Decay Storage Areas	Lower Campus	$250,000
Total for Lower Campus		**$20,770,000**
Demolish and clear existing structures	Upper Campus	$5,000,000
Renovate existing structures for science, administration	Upper Campus	$5,000,000
New building for science, administration	Upper Campus	$6,125,000
New near-underground space for outreach	Upper Campus	$14,000,000
Receiving and warehousing space	Upper Campus	$3,750,000
Total for Upper Campus		**$33,875,000**
Road Improvements and Parking	Access	$3,000,000
Immediate Shaft and Cage Improvements	Access	$8,500,000
Drifts at 7400 level	Access	$20,210,000
Ramp system improvements	Access	$1,500,000
Yates shaft improvements	Access	$30,710,000
Underground materials handling and transport systems	Access	$1,625,000
Total for Access		**$65,545,000**
Lower Campus System Upgrades	Systems	$22,110,000
Upper Campus System Upgrades	Systems	$3,250,000
Lower Campus Isolation Systems	Systems	$500,000
Sealing Unused Underground Areas	Systems	$400,000
Total Systems		**$26,260,000**
Sub-Total Laboratory Development		**$146,450,000**
EDIA (12%)		**$17,574,000**
Contingency (25%)		**$36,612,500**
Total for Laboratory Development		**$200,636,500**

[1]Estimated costs are in FY2003 dollars.

Figure 3—Distribution of Development Costs for the National Underground Science Laboratory at Homestake



5. Homestake Facilities Development Plan

The Homestake Facilities Development Plan is carefully structured to achieve a number of compatible goals centered on the NUSL mission of hosting a new generation of "world-class" science and involving the American people and people of the world in that science through multiple outreach mechanisms. The specific goals of the Facilities Development Plan include:

- Enabling a new generation of sensitive science detectors in the least possible time at the lowest feasible cost;
- Supporting an exciting and effective outreach program with multiple modalities and audiences;
- Making optimal use of the existing human and physical assets at Homestake;
- Limiting ongoing maintenance responsibilities and thus minimizing operating costs;
- Protecting the Black Hills environment and the Homestake historical heritage.

Transition: The transition of the Homestake Mine from minerals extraction to science will be challenging and, in its full extent, will require much of the five years of this proposed grant. The short-term transition, preserving the human and physical resources across the ownership transition is essential, must be accomplished in a timely manner, will likely be the most difficult and inefficient phase. It is not possible to blast rock to extract gold at full capacity one day and construct a next generation science laboratory on the next day. The Homestake Mining Corporation reports it has been advised by counsel to carefully control its participation in transition planning in order to limit the Corporation's possible future liabilities when NUSL is in operation. On the other hand, the Lead and Black Hills communities and the United Steelworkers of America, who represent the Homestake non-exempt employees, enthusiastically support NUSL and are preserving and transferring knowledge and expertise regarding the Homestake Mine. Nonetheless, the proposed budget includes funds to employ future NUSL workers, who are laid-off by the Homestake Mining Corporation prior to the title transfer, and to inventory and assess the physical plant and equipment transferred to NUSL on the title closing date. Selected miners and supervisors will be retrained during this interim period to improve their civil construction skills, including more expertise in the skills required to install and maintain electrical, HVAC, plumbing, communications and other systems. Once the title is transferred to the State of South Dakota and ongoing maintenance operations are stabilized, NUSL management will focus on implementing the Homestake Facilities Development Plan. This plan has four major components: the Lower Campus, the Upper Campus, the Access and the Systems (electrical, pumping and water treatment, ventilation, communications and safety).

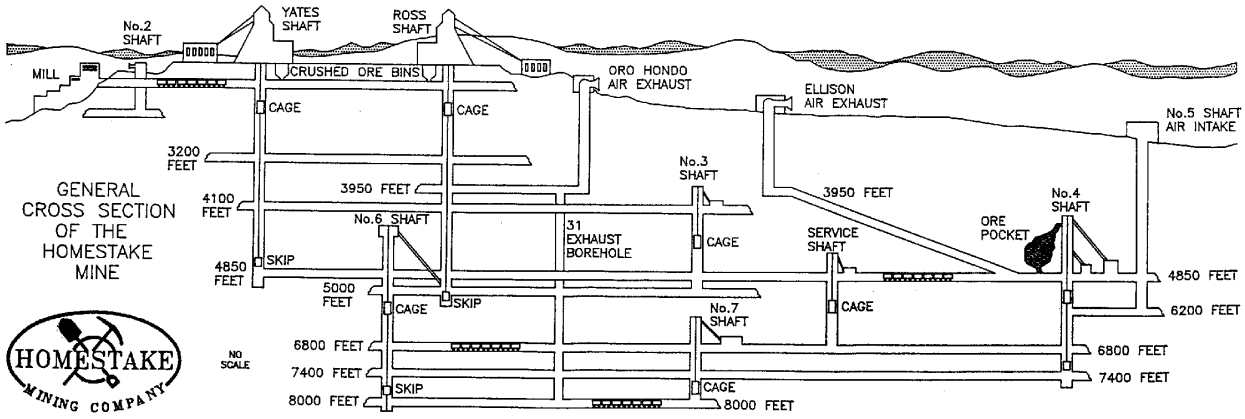


Figure 4—A schematic side view of the Homestake Mine complex. Primary access is through the Yates and Ross shafts, both of which are downdraft shafts. Air is exhausted through the Oro Hondo and Ellison shafts. The No. 5 shaft is also an air intake.

Lower Campus: The Lower Campus represents the main thrust of NUSL's program. Functionalities required on the Lower Campus include: detector space, including space for electronics, data acquisition, purification, de-gassing and other detector-related systems; detector assembly, installation, and testing areas; areas for detector control and supervision; areas for visitors and outreach programming; workspace for scientists and students; site operations staff workspace; space for ancillary services, such as a "lunchroom" and lavatories; space for "refuge" rooms, a first-aid

facility and other safety systems; and space for electrical, HVAC, communications and other support systems. One large experimental hall, a low background counting facility and support space will be built initially in the Lower Campus. After this phase, the laboratories and support areas in the Lower Campus will be "built-to-order" in order to minimize cost and maximize functionality for individual detectors.

The overall layout of the Lower Campus is defined, in part, by the existing geography of the Homestake Mine, depicted in the schematic diagram above. Personnel and equipment access to the underground at Homestake is primarily through the Yates and Ross shafts, shown on the left side of the diagram. The two shafts are approximately 1,000 m apart and the Lower Campus will generally occupy the volume between these two shafts and within approximately 250 m of the vertical plane defined by them. Other shafts are used for ventilation or emergency access. The cross-sectional dimensions of the Yates and the Ross shafts are approximately 29 feet by 15 feet and 20 feet by 14 feet, respectively. Both the Yates and the Ross shafts drop from the surface to the 4,850 foot level. The Davis neutrino detector continues to operate at this level near the bottom of the Yates shaft. A major drift (15 feet by 15 feet in cross-section), equipped with an electric trolley line, connects the two shafts at this level. From here, there are two means of access to the lower levels. The No. 6 winze begins about 100 m horizontally from the bottom of the Ross shaft and continues down to the 8,000 foot level, which is the bottom of the mine. The second access between the 4,850 foot level and the 8,000 foot is a series of sloped ramps.

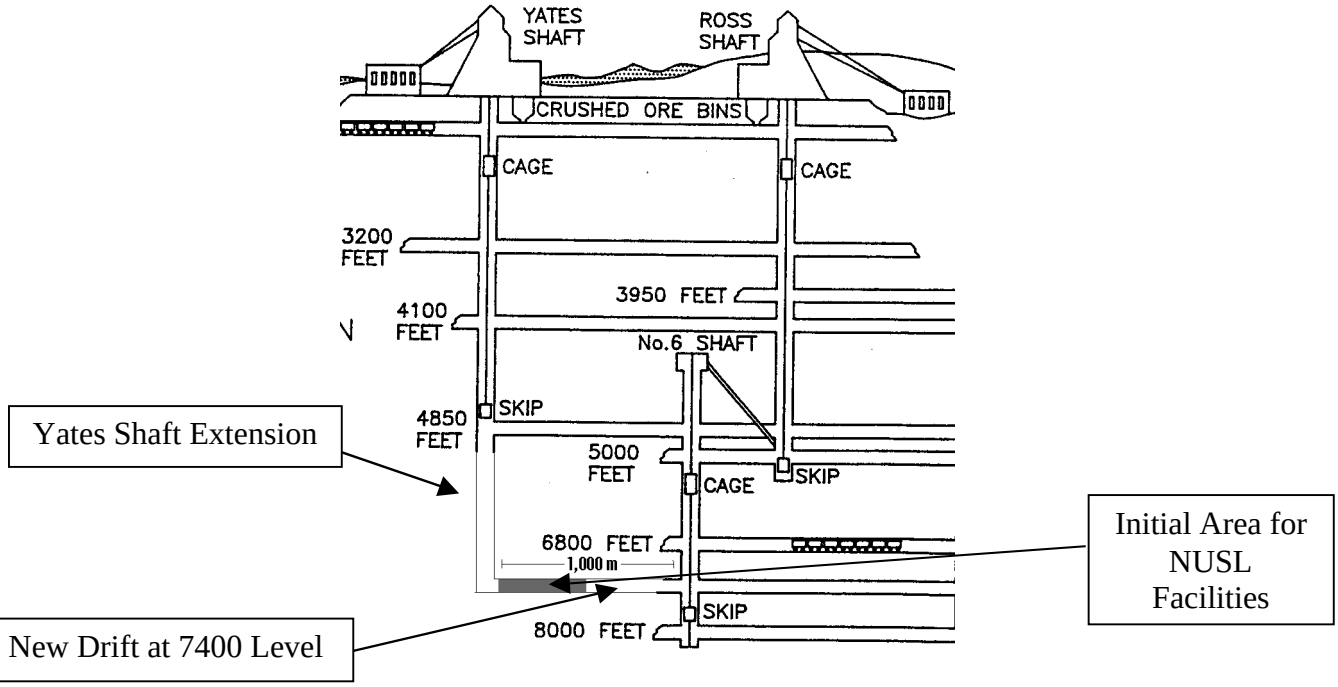


Figure 5—An expanded view of the area of the Homestake Mine that will be the primary focus for NUSL. The facilities development plan concentrates laboratories and support spaces at the 7400 foot level in the 1,000 m between the extension of the Yates shaft and the existing No. 6 winze.

The conceptual plan for development of the Lower Campus concentrates activities at the 7,400 foot level (6,700 mwe), the deepest level with well-developed infrastructure and workings and, therefore, extensive existing knowledge about rock mechanics properties. Detectors with special depth requirements could be located at five other levels, ranging in depth from as shallow as 700 mwe to as deep as 7,200 mwe (the bottom of the mine). The first step in the development of the Lower Campus is to drive a main access drift 5.5 m by 5.5 m in cross-section at 7,400 foot level from the No. 6 winze to a point directly below the Yates shaft. Hence, this new drift will be connected to the existing ramp system and the No. 6 winze. A smaller ventilation drift (3.6 m by 3.6 m in cross-section) would also be developed, mostly parallel to this new main access drift, but separated from it by about 200 m. The next steps would be to excavate one large experimental hall at the 7,400 foot level, approximately 20 m by 100 m by 20 m high, an multi-floor office and computer complex (approximately 20 m by 36 m by 20 m high), a

mechanical support room (approximately 23 m by 29.5 m by 8.5 m high), a combined refuge room and sump (approximately 10 m by 12 m by 10 m high) and a low background counting facility described below. An artist's conception of how the laboratory might look is shown in the figure on the next page. The large experimental hall would be flexibly allocated for small experiments and for staging and assembly of experiments located in other areas. The office and computer complex would be built out as a 38,200 gross sq. ft., multi-story "office-type" work area for scientific and technical support offices and workspaces. Existing openings would also receive minimal preparation as long-term storage areas for reducing cosmogenic radioactivity in ultra-low background materials. Following this initial space development, additional laboratories and support facilities will be custom-built based on proposals approved by the Program Advisory Committee. We have budgeted for custom-built detector laboratory space aggregating 42,500 m^3, which would be developed during the five years of this proposal (See table in Appendix D for estimates of laboratory volumes required for specific detectors.). The excavation of chambers for very large experiments such as the UNO proton decay detector may also occur within this same time period, but this project would require supplemental funding.

The requirements of approved experiments and the following principles will determine the exact layout of the Lower Campus:

(a) *Rock properties*—Existing geological data will be supplemented by new civil-engineering-oriented rock coring to select detector chamber areas with strong, homogenous rock that will require minimal ground support. Cavities will be oriented with their major axes parallel to the direction in which the rock is weakest, so that the cavities walls that require the most ground support have the smallest area.

(b) *Compactness and Efficiency*—Underground rooms are easiest and cheapest to design and build when the spacing between rooms (undisturbed rock) is at least three to four times the transverse span of each room. On the other hand, an efficient Lower Campus layout minimizes the horizontal distances among the shaft accesses, the laboratory locations and the support services. The Lower Campus layout needs to satisfy both these criteria with a series of parallel rooms spaced at three to four times their transverse dimension.

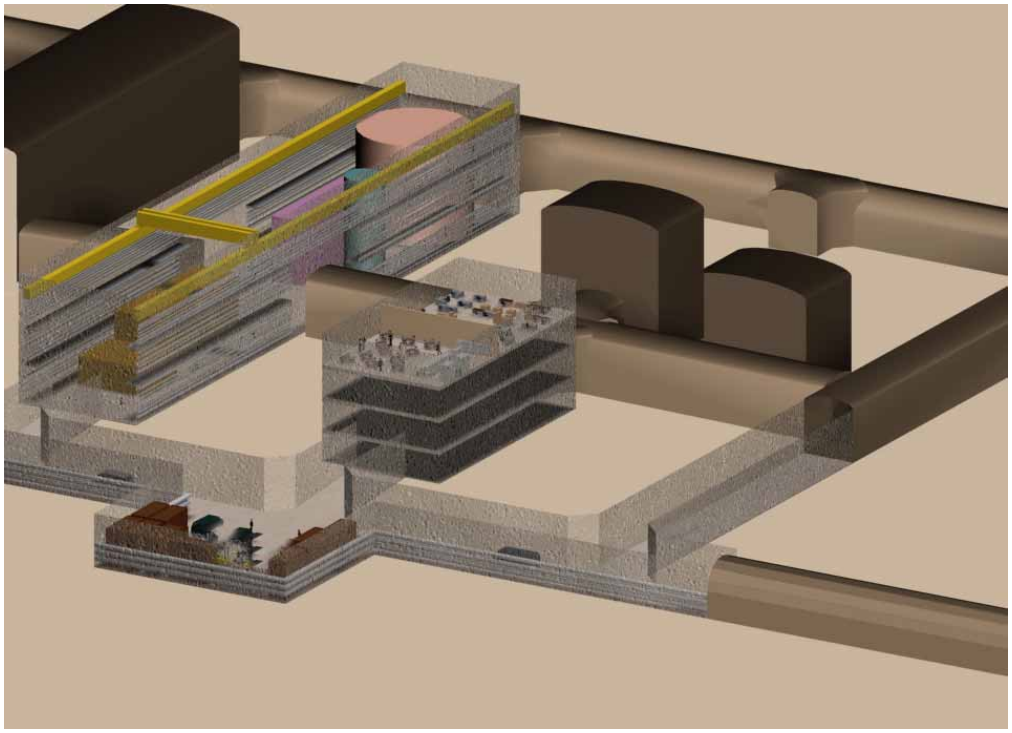


Figure 6—An artist's conception of the NUSL facilities. A multi-story work area is in the center of this sketch. The 20 m by 100 m by 20 m high flexible laboratory is behind and to the left of the work area. The dark, "rural mailbox" shaped structures are additional detector laboratories. This compact layout is intended to facilitate work by scientists and support staff.

(c) *Ventilation and Safety:* Safety considerations suggest independent laboratories for major experiments with fire-rated (and, in some cases, blast-rated) separations and closures. Laboratories designed for detectors with significant inventories of liquids will generally be accessed near the top, above the liquid level. All laboratories will have two or more means of egress, with at least one egress leading upstream in the ventilation system. The ventilation system will provide direct access for air to each laboratory without the fresh air passing first through another laboratory. Easy access to self-contained, fire and blast-rated closure rescue rooms will be linked to all occupied spaces in the Lower Campus.

• *Low Background Counting Facility:* The next generation of double beta decay, dark matter, and solar neutrino experiments will require construction materials of unprecedented radiopurity. Verifying the activity level of such materials requires the availability of both low-background high-resolution germanium counting systems. Such systems must be able to count small to modest size samples, as well as being usable as a large "whole-body" counting facility which would be capable of handling large, meter-sized materials that will be required in building the large volume next generation detectors. Such a facility is also required for extremely low-level trace materials analysis such as the Naval Research Laboratory's PIsCES (Precision Isotope Counting Experimental Setups), which are increasingly useful in environmental and nuclear anti-proliferation studies. There is also a clear need for low-background counting facilities to serve the increasing demand from a wide variety of applied and commercial applications, including fabrication of electronics materials.

For most materials, the chief contributors to internal radioactivity are decays of naturally occurring radionucleides in the ^{238}U and ^{232}Th decay chains as well as decays of ^{40}K. Current low-background germanium counting systems have a sensitivity to U and Th of 100-300 pg/g. Most of these existing systems also have quite limited volume, on the order of 0.02 m^3. However, many of the new experiments require material purity at or below the 10 pg/g level and have far larger quantities of material that will need to be tested. We propose to build at NUSL a state of the art, ultra low background counting facility that would allow one to reach a sensitivity 5-10 ppt, for large .3-.6 m^3 volume material, within 1-2 days of counting.

To reach such levels of sensitivity will require special consideration of all potential sources of backgrounds. There are three primary background sources:

• *Prompt through-going cosmic ray muons* - In addition to the muon itself, prompt activity includes short-lived radioactive spallation products, gammas, and fast neutrons. The overhead burden at NUSL will effectively shield the vast majority of muons, eliminating this background source.

• *Longer lived cosmogenic radioactivity* - This activity is induced by the through-going cosmic ray muons. Again the overhead burden eliminates any in-situ creation of activity. By careful selection of shielding materials one can verify that intrinsic cosmogenic activity of construction materials is also not a problem.

• *Natural radioactivity* - This arises primarily from the ^{238}U and ^{232}Th decay chains and from ^{40}K. The main difficulty is shielding the low-energy 1-2 MeV gammas (Compton scattering results in a nearly continuous low energy gamma ray spectrum) and neutrons. The main source of natural radioactivity is in the surrounding rock. Homestake rock typically contains 1-5 μg/g of ^{238}U and 2-7 μg/g of ^{232}Th.

The Ultra Low Background Counting Facility (ULBCF) will initially include six conventional low-background Germanium counting systems, a scintillator based "whole-body" detector, and space for dedicated prototype R&D measurement systems. The lab will operated by NUSL for the benefit of underground science and will be open to researchers from around the world. We envision a laboratory of 4 m by 4 m by 16 m (long) dimensions. This room will be encased in a special low-activity water shield in order to minimize effects from external sources of radioactive backgrounds. A minimum of 4 m of high purity water (≤0.1 pg/g Th and U) will stand between the rock walls and the laboratory walls. If deemed necessary after a more detailed study, this water shield will be outfitted as an active PMT-based cosmic ray veto capability. The laboratory will be operated as a CLASS 1000 – 3000 level clean room to ensure that mine dust cannot contaminate the counting equipment or samples. Furthermore, the air from the surface will be filtered with an active charcoal system to reduce the incoming naturally occurring radon. One end of the room will be dedicated to the "whole-body" counter. The inner chamber of this system will be encased in a special low-activity material (acrylic or a plastic) isolation box in order to reach counting sensitivity levels of 5 pg/g for large samples.

Upper Campus: The mission of the Upper Campus is to provide office and support facilities for scientific staff, visiting scientists and students, to provide office and workspace for laboratory administrative and technical support

staff, and to provide program and support space for the outreach program. The Upper Campus will consist both of some surface buildings, including renovation of some existing structures, and near-surface underground space, primarily for outreach educational and tourist functions. The rationale for using near-surface underground space is (a) provide all visitors—even those who choose not to visit the deep underground laboratory levels—with an "underground" experience and (b) better match the NUSL construction needs with the skills set of the NUSL staff and facilitate efficient use of NUSL staff, in conjunction with laboratory construction deep underground. Access to the near-surface underground space will be provided using standard elevators and, possibly, a spiraling downward exhibit ramp; emergency access from this space will be provided via horizontal or nearly horizontal tunnels, which take advantage of the sloping terrain. Use of near-surface underground space for this purpose will also decrease ongoing energy costs.

The Upper Campus structures and underground space will be designed during the first year of this project using standard architectural program techniques. Here we discuss a schematic design. Cost estimates in the budget discussion are based on gross square footage and typical cost per square foot for office/laboratory construction in Lawrence County SD. The NUSL operational approach will be to provide easy 24/7 access deep underground and to concentrate most scientific and technical support facilities underground near the detectors. Nonetheless, the Homestake site provides spectacular views of the surrounding terrain and it will be useful to provide some facilities at the surface, particularly for administrative staff.

Scientific office and support facilities: Scientific space in the Upper Campus will be consist of approximately 20,000 asf (assignable square feet) for flexibly-assigned office space, seminar rooms and about a 1,000 volume library, equipped with terminals and printers for online access to scientific journals and preprints.

Administrative work areas: Approximately 5,000 asf in the Upper Campus will be used for administrative staff workspace.

Technical support space: Most technical support work areas will be located near detectors deep underground and close to detector areas. Approximately 5,000 asf will be utilized in the Upper Campus for technical support staff workspace and approximately 20,000 asf of air-conditioned space and another 20,000 asf of non-air-conditioned space will be used for receiving, staging and storing or detector and other materials as they arrive at NUSL.

Outreach: Based on experience at the Soudan Underground Mine State Park in Minnesota, the initial visitor design capacity will be 1,500 persons per day with a maximum capacity of 750 visitors on-site at any particular time. Of these 750 visitors, about 500 will be in the Upper Campus facilities; the others will primarily be in the Lower Campus with the remaining visitors touring the historic trails and using the picnic area outside. Outreach space for this number of visitors will be 40,000 asf, including exhibit space, flexible "classroom"-type space, workspace for outreach staff and auditorium space for multi-media presentations. During the first year of this project, we expect to examine the feasibility of building the world's first underground IMAX theater at Homestake using some combination of public and private financing and corporate or other contributions. The IMAX theater is not included in the space assignments described here.

The assignable space described above aggregates 70,000 sq. ft. of high-quality space and 20,000 sq. ft. of air-conditioned and a similar amount of non-air-conditioned "warehouse" space. Using an gsf/asf (gsf is "gross square feet") ratio of 2 for the conventional space and 1.25 for the "warehouse" space suggests a gross square footage requirement of 140,000 gsf of conventional space and 50,000 gsf of "warehouse" space, half of which is non-air-conditioned. The scientific, administrative and technical support areas and 25% of the outreach space will be located above ground, totaling 80,000 gsf. Near-surface, underground outreach space will total 60,000 gsf or 10,000 m^3, assuming 5 m ceiling heights.

Access: Access begins at the property boundary and includes Upper Campus road and parking layouts, access to the surface and underground portions of the Upper Campus, shaft access to the Lower Campus and access drifts in the Lower Campus. The access system will be designed to both facilitate access for authorized persons and to deter access for others.

Upper Campus Environs: The Upper Campus roadways will be redesigned to facilitate convenient and, to the extent feasible, separated access for staff and visiting scientists, delivery traffic and tourist and other outreach traffic. The natural slope of the terrain will likely produce a design that segregates the incoming traffic at different elevations at the point at which it reaches the focus of the Upper Campus near the headframe of the Yates Shaft. Access to the Ross Shaft headframe area will be limited to staff, visiting scientists and deliveries. In total, on-site NUSL will require 350 spaces of on-site parking, including parking facilities for school and other buses, motorcycles and bicycles. An additional 200 parking spaces will be identified in Lead and shuttle buses will be used to meet summer-

peak outreach parking requirements. The project will seek non-science funds to develop on-site picnic facilities and historically-interpretative walking and hiking trails.
Upper Campus Access: The Upper Campus will be designed for differentiated access (likely at different elevation levels) for visitors; staff and visiting scientists; and materials and equipment. All personnel access will be handicapped-accessible. Staff and visiting scientist will travel within the Upper Campus complex using walkways, stairs and elevators. Incoming materials and equipment will have direct access to warehouse and storage areas on semi-trailers with enclosed, heated unloading areas. Forklifts will be able to move incoming material and equipment from the receiving and warehousing areas directly to the Ross shaft on a separate materials access level not used for personnel access by either staff or visitors. Visitor access to the near-surface underground interpretative area will possibly be via a downward, handicapped accessible exhibit spiral.
Access to and in the Lower Campus: Access to the Lower Campus will be through the Yates and Ross shafts to the 4,850 foot level and then through the No. 6 winze (near the Ross shaft) and a series of downward-inclined ramps to the 7,400 foot level. Initial work will improve these accesses to provide clean and convenient transport for personnel and equipment. At the 4,850 foot level, an existing transverse drift outfitted with rails links the two shafts. A similar drift 5.5 m by 5.5 m in cross-section, intended for rubber-tired vehicles, will be constructed from the No. 6 winze to a point directly under the Yates shaft and connecting to the ramp system. These two drifts will provide the main access paths to the detector laboratories and support spaces. In 2003, the Yates shaft will be extended to the 7,400 foot level. Once the shaft is extended, the Yates shaft and hoist will be reconfigured to a 15-ton capacity freight hoist approximately 7 m by 5 m in cross-section and two high-speed, double-deck personnel hoists, similar in size to conventional elevators. The Yates shaft will then provide the primary access to NUSL for both personnel and equipment. Development at the 8,000 foot level would remain a future option with access via the No. 6 winze and a new raise or ramp.

Systems: Systems include facilities for electrical power distribution, pumping and water treatment, ventilation, communications and safety. Because Homestake is currently an ongoing activity, much of the Homestake systems infrastructure is in good condition and has modern capabilities. For example, fiber optic cable is installed throughout the Lower and Upper Campuses. Ventilation and safety systems are operated using the same state-of-the-art, commercial industrial automation software that operates the CDF detector at Fermilab. Nonetheless, science at Homestake will require extensive renovation and improvement of this infrastructure. A major step in this activity will be a shrinking of underground physical plant by walling off unused drifts to block ventilation to unused areas while maintaining drainage. Walls will be designed to permit re-access at a later time, so that unused areas can be later re-used for excavation rock disposal. Variable speed controls will be installed on ventilation fans to reduce power consumption. Water inflows will be identified and measured and water sources will be diverted to reduce pumping costs. The mine safety systems will be assessed and upgraded for the new requirements on numbers of people underground and special materials that will be required for some detectors. The communications systems both internal to the mine and between the mine and the local POP will be assessed and upgraded to meet NUSL's data transmission requirements.

6. Project Management

General Considerations: The management plan is designed to maximize not only the scientific, but also the educational and outreach impact of NUSL. The envisioned management is a partnership between the National Science Foundation, the state of South Dakota and its universities (and also universities in neighboring states), and the national and international underground science community. An individual with an outstanding reputation in underground science and in project management, chosen in an international search, will be responsible for directing the laboratory, including construction and operation. The Director will be directly accountable to the managing board, the Consortium for Underground Science (CUS). The Director will delegate various responsibilities to Associate Directors and others, including an Associate Director for Construction, an Associate Director for Operations, and an Associate Director for Outreach. These individuals will have special responsibilities for interfacing with the South Dakota Board of Regents and its institutions in completing the tasks required for the success of the Homestake Laboratory.

The Associate Director for Construction will ensure that the construction of the laboratory and its surface campus is done according to best practices and with prudent cost controls. The Director will make use of periodic outside

reviews, similar to the Temple reviews often used in large projects, to monitor construction progress. The Director's Advisory Board will also include individuals experienced in large-project construction.

CUS, the proposed management body, will be constituted as a tax-exempt, limited-liability organization representing the interests of the National Science Foundation, the national and international science communities, and the State of South Dakota, its board of Regents, and its universities. Five members of CUS will be appointed by the group of research institutes responsible for the present proposal [incuding Columbia, Institute for Nuclear and Particle Astrophysics and Cosmology—INPAC (which represents the UC campuses and laboratories), Minnesota, Pennsylvania, Princeton, and Washington]; five members will represent the three South Dakota research universities (the South Dakota School of Mines & Technology, South Dakota State University, and the University of South Dakota), the South Dakota Board of Regents, and the Governor's office; and five member will be appointed by the NSF (or by nationally representative scientific bodies it should designate). CUS will also include a representative of the four neighboring states closest to Homestake -- North Dakota, Montana, Wyoming, and Nebraska -- all of which are EPSCoR states. The Laboratory will provide a focus for enhancing science generally in the region, and will encourage cooperation among these and other EPSCoR states (e.g., Idaho, Kansas) on projects related to NUSL.

This structure takes into account the special contributions various communities will make to NUSL. The scientific planning for NUSL, the proposing, defending, and execution of new experiments, and the communication of new results, through scientific papers and conferences, is the responsibility of the national and international scientific community. While initially most of this resonsibility with be carried by institutions from outside the region, South Dakota and regional institutions will play increasing roles as their science departments strengthen in response to NUSL and as student outreach efforts succeed. The State of South Dakota will contribute knowledge and concern about the local population, land, and environment. The State will secure title to the surface and underground property at Homestake. The Regents and their institutions will participate in the major functions of site operation, site maintenance, and facilities development for science, outreach, and administration. A Work Breakdown Structure (WBS), Budget, and Budget Explanation detailing these responsibilities are included in this proposal. State institutions, such as the Governor's Office for Tribal Affairs and the Black Hills State University Center for the Advancement of Mathematics and Science Education, are crucial to the outreach and diversity goals of this proposal, as described below and elsewhere.

The National Science Foundation will have oversight responsibility for NUSL and its operations. This proposal provides a role for NSF in appointing members to CUS to ensure that CUS properly represents the entire scientific community (including international scientists, scientists from other national laboratories, and the full range of interested university groups). The Foundation will provide guidance on the proposed management plan and will periodically review NUSL operations and science. It will help coordinate participation of other agencies, such as the Department of Energy and the Department of Defense, in NUSL underground science experiments. Its existing regional offices—such as the state EPSCoR offices and its tribal college Model Institutions for Excellence efforts in science and engineering—will be involved in NUSL outreach and diversity efforts.

The Associate Director for Outreach will coordinate outreach, education, and diversity efforts of NUSL. The Homestake site is important historically to the region: the mine has been operated continuously for 126 years, and predates the state of South Dakota. Native Americans have even longer connections to the Black Hills: NUSL will be respectful of this history in its outreach. The envisioned components include a major visitor center in which the culture and history of the region will be combined with science, providing an educational experience for visiting K-12 students, South Dakota citizens, and tourists to the Black Hills. The education and outreach project will partner with existing state and regional programs. As discussed elsewhere in this proposal, two outstanding opportunities are the Center for the Advancement of Mathematics and Science Education at Black Hills State University (the University closest to Homestake) and Model Institutes for Excellence effort in computer science, pre-engineering, and environmental science at Sinte Gleska College (Rosebud Reservation) and Oglala Lakota College (Kyle, SD). The education and outreach project will also involve programs initiated by NUSL, including the Research Experiences for Undergraduates and graduate student efforts discussed elsewhere. We anticipate that NUSL will establish ongoing relations with many state and regional institutions -- civic groups, business interests, tribal councils, alumni groups, historical societies -- interested in outreach, education, scientific diversity, and historical preservation.

NUSL will play the role of a partner in major experiments conducted at the Laboratory. The collaboration spokesperson will work with NUSL, prior to submission of the experimental proposal, to evaluate the capacity of NUSL to accommodate and mount the new experiment. The Director, with the concurrence of CUS in the case of major experiments, will provide the collaboration with a technical assessment of NUSL's capacity to help with the

proposed experiment. The collaboration will have the usual responsibilities to defend the proposal in the standard review process; the resulting funding will go to the collaboration. NUSL may submit a coordinated proposal if the proposed experiment requires substantial excavation or other significant NUSL costs. The Director is responsible for ensuring the health and safety of all activities within NUSL.

The Director will have the support of an Advisory Board and, once NUSL is operational, a Users Group. Invitations have been extended to six potential Advisory Board members: Gary Feldman (Harvard; not confirmed), Carole Anne Heart (Director, National Indian Education Association), Steve Koonin (Caltech), Neal Lane (Rice), Jay Marx (LBNL), Art McDonald (Queens), and William Press (LANL).

Specific Considerations: Certain specifics of the management plan and responsibilities have been discussed by the scientists who authored this proposal and Governor William Janklow (and his representatives) and Senator Tom Daschle (and his representatives). The following agreement, supporting the above plan, was reached:

• The Board of Regents of South Dakota will receive all funding and will have, together with the National Science Foundation, the right of concurrence on the appointment of the Director of the National Underground Science Laboratory (NUSL). The Board of Regents will delegate responsibility for the management of the laboratory to a Science Board, described below. However, it shall be the responsibility of the Board of Regents to ensure that the activities of the Science Board conform with the Constitution, laws, and regulations of the State of South Dakota.

• The Science Board of the consortium, consisting of representatives of 16 entities described below, will appoint the Director and the senior science staff, and will establish their terms of employment. The Science Board, usually acting through the Director of the NUSL, will be responsible for the direction of the laboratory and for the allocation of all funds for the NUSL received by the Regents for contracts initiated by the Board or through association with the Board. The interim Director will be Professor Wick Haxton, University of Washington. An international search for a full time Director will be initiated as soon as the Science Board is constituted. The interim Science Spokesman will be John Bahcall, Institute for Advanced Study, Princeton, who will serve for a term to be determined by the Science Board and the Director.

• The membership of the Science Board will contain five members from South Dakota ((SDSM&T, the University of South Dakota, and South Dakota State, the Board of Regents, and the Governor). Five members will be designated by the consortium of out-of-state universities that wrote the pending NUSL-Homestake proposal. Five members will be appointed by the NSF to represent others in the scientific community. One member will be appointed by a consortium of EPSCoR states neighboring South Dakota. Science board members will serve three year terms, with reappointment allowed. The initial terms of members shall be staggered in order to ensure institutional memory on the Board. The Board will elect its own chair.

• The Associate Director for Construction will be appointed by the Science Board and will be responsible for construction and maintenance of the National Laboratory. The interim Associate Director for Construction will be Professor Marvin Marshak of the University of Minnesota. The Associate Director for Construction will interface with South Dakota institutions in a manner that is mutually agreeable to the Science Board and the Board of Regents of South Dakota. The Board of Regents shall ensure that the activities of the Associate Director are consistent with the Constitution, laws, and regulations of South Dakota.

•The Associate Director for Outreach and Education will be appointed by the Science Board after consultation with the Laboratory Director and in close coordination with the Board of Regents and the five South Dakota members of the Board, as well as the regional Representative.

• Funding for new experiments in the NUSl that require additional laboratory development, operation, or maintenance costs will be received by the Regents and allocated by the Science Board. Funding that is specific to an individual experiment will be received in the usual way, directly by the investigators of that experiment.

• The Interim Director, and later the full-time Director, shall be consulted in discussions regarding the indemnification process.

• In order to facilitate day-to-day interactions between the national science community and the scientists and institutions of South Dakota and in order to benefit science, mathematics, and other academic activities throughout the educational systems of South Dakota, the Governor of South Dakota will designate an individual who will be responsible for ensuring an optimal working relationship between the national science community and the scientists and institutions of South Dakota. This individual will be someone easily accessible to the scientists, and with whom the scientists can develop a sense of shared goals, mutual trust, and respect. The Governor's representative and the Interim Director will formulate a set of guidelines for facilitating and optimizing the activities of the NUSL.

An important point is that this project structure does not replace or interfere with the usual agency and community refereeing process. Clearly it is important, as the time a large project is proposed, to determine whether NUSL has the capacity to mount the experiment in a timely fashion: issues of competition between various proposals for space as well as safety will inevitably arise. The NUSL process -- submitting proposal plans through the director's office to the Board – will address such technical issues from the perspectives of NUSL capabilities and collaboration strength. The agencies will then be able to address the scientific merit of the project proposal, having in hand a technical assessment of aspects related to NUSL.

7. Outreach and Education

NUSL at Homestake provides unparalleled opportunities for "wider impact'" or outreach/education both on site and via distance education. Here we discuss the potential impact on multiple communities: (a) general public; (b) K–12 students in state and tribal schools; (c) Native Americans in tribal colleges; (d) the general undergraduate community, regionally and nationally; (e) public and tribal school teachers; (f) graduate students researchers; and (g) the US and international science communities.

• *General Public:* Three million visitors come to the Black Hills annually, some of whom are interested in the Native American and gold mining history of the region, and many of whom might have an interest in science, especially if science is well-presented and well-publicized. NUSL therefore has the potential to directly contact more Americans than any other pure-science research site in the United States. (Presumably, Cape Kennedy is a technology rather than science site.) The science at NUSL is compelling and of great popular interest—the origin of the Cosmos and the nature of the dark matter and dark energy it contains, the nature of biological life forms in extreme environments, the fundamental forces that govern our world, the origin of the elements, and the geology and geophysics of the Black Hills. The Soudan Mine, which is smaller and more remote, hosts about 40,000 visitors per year. The current Homestake Mine conducts tours for visitors interested in the history of the mine and of gold mining generally. We believe that the potential for NUSL is clearly in excess of 100,000 visitors per year. We plan an initial capacity of 1,500 visitors per day.

The Upper Campus plan includes space for an interactive display museum in the near-surface underground—some visitors will limit their penetration into the earth to 200 feet. The displays will touch on the history of the Black Hills and Homestake—the geologic processes that produced the Black Hills, the land's importance to Native Americans, the gold rush, the development of the west, and finally the birth of neutrino astrophysics. They will also capture the excitement of the science program now housed by NUSL. During the term of this Proposal, we expect to develop capacity for 1,000 people per day to visit the deep underground laboratories in which science is actually done. The underground will be equipped with separate tourist access drifts and viewing galleries overlooking laboratories, separated from the detectors when necessary by fire-rated glass. In addition to the "in-person" program for the public, we expect to explain unerground science to people not able to visit, through the media and via the World Wide Web.

During the first year of operation NUSL will join with local civic and education leaders to explore the feasibility of forming a public-private partnership to finance and operate the world's only underground IMAX theater. The cost of the theater is not included in this proposal. The worldwide IMAX repetoire includes a number of films that treat scientific topics relevant to NUSL. There is also an existing IMAX film on gold mining.

• *K-12 students:* There are many examples of outreach centers in the US that are used effectively to interest K-12 students in science. NUSL would host classroom groups and, more importantly, help classroom teachers integrate the visit into the broader context of the classroom by making available preparatory materials and follow-up science

experiences. NUSL intends to partner with state and regional experts in K-12 education, such as the Black Hills State University's Center for the Advancement of Mathematics and Science Education (a South Dakota Board of Regents Center of Excellence), to prepare materials appropriate to various age groups. (One of the Center's missions is to serve as a resource center for instructional materials; it currently distributes science curriculum kits to about 300 science teachers in western South Dakota.) These materials would be a form of distance education by NUSL, which ideally would be coupled to either a follow-up or initial visit by the students to NUSL. Similarly, the on-campus tours of NUSL would be tailored to the ages of the visiting group.

With internet connectivity it is quite possible that more advanced students could work directly with data from NUSL detectors, using apropriately designed science kits. Scientists at NUSL will be encourage to be active in school and community outreach, visiting school rooms, participating in science fairs both as mentors and judges, etc. While most Native Americans in South Dakota attend public schools, about 20% attend tribal schools. One reason for coupling the region's history to the science in the NUSL Visitor Center is to emphasize connections of Native Americans to the history of the Homestake site. Some of the tribal colleges are addressing the special problems confronting science education in tribal K-12 schools, such as geographic isolation and poor teacher preparation. NUSL would like to team with some of the tribal college educators to design apropriate distance learning and visiting experiences.

• *Undergraduates in Tribal College:* In Native American culture, the individual is viewed as a small but important part of a much greater Cosmos—a view not unlike that of a typical scientist. South Dakota Native American educators are among the nation's leaders. Carole Anne Heart, from the Rosebud Sioux reservation, is the current president of the National Indian Education Association. Two South Dakota tribal colleges, Sinte Gleska University (with about 1,000 students) and Oglala Lakota College, are leaders in tribal science and mathematics education, known for their computer science, pre-engineering, and environmental science curricula. Sinte Gleska is in the forefront of regional efforts to reform science education, a partner with the National Science Foundation and the SDSM&T in NAMSEL, the Native American Mathematics and Science Educational Leadership, a program for developing leadership capacity in teachers, for addressing the needs of Native American students, and for developing school cultures which support systematic change. Sinte Gleska and Ogala Lakota are partners in an NSF Model Institutes for Excellence (MIE) grant, which supports the science curriculum developments mentioned above, and also supports distance learning efforts that will involve three other South Dakota tribal colleges (Si Tanka College on the Cheyenne River Reservation, Sitting Bull College on the Standing Rock Reservation and Sisseton Wahpeton Community College in northeastern South Dakota). Together, these five institutions comprise the Oyate Consortium. Currently 94% of OLC and 85% of SGU graduates are employed or are seeking advanced degrees; in comparison, reservation unemployment rates frequently reach 80-85%. The goal of the MIE initiative is to integrate traditional tribal values into new programs of study for Native students. It includes new programs in environmental science, information technology, computer science, pre-engineering and life science. Some of these programs aim to prepare students for more advanced studies at other institutions, so NUSL-based relationships will help facilitate some of the MIE goals. In short, NUSL will be located in a center for progressive Native American science and mathematics education and has an opportunity, by partnering with and supporting the tribal colleges, to significantly enhance diversity in science.

Discussions are being initiated with educators in these tribal colleges to explore ways that NUSL might enhance Native American education. These colleges will be a particular focus of the Research Experiences for Undergraduates program discussed below.

• *Undergraduates and research:* The visitor programs described above for K-12 will be available for the region's undergraduates, as well. In addition NUSL will sponsor a Research Experiences for Undergraduates summer program, available to any US undergraduate, but with a special emphasis on Native American and other regional undergraduates. The residence program would be designed along the lines of other successful NSF REU programs, with national advertising, one or more directors, pairing of interested students with mentors selected from NUSL faculty and from long-term faculty visitors to NUSL, and a weekly program of faculty talks on underground science. The students will do guided research, writing up their results at the end of the summer and reporting on what they learn. Regional participants in the REU program might be able to continue their involvement during the academic year through occasional visits and the internet, particularly if a second mentor from the student's university were available to provide additional support.

NUSL may be able to enhance the academic-year experiences of regional undergraduates as well. Colleges from the EPSCoR states near NUSL (South Dakota, North Dakota, Wyoming, Montana, Nebraska, and Kansas), as well as the regional non-EPSCoR states of Colorado, Iowa, and Minnesota, will be invited to participate in Undergraduate Research Opportunity (UROP) semester programs, including courses at SDSM&T and research at NUSL. Several undergraduate institutions in this region aleady participate in UROP arrangements with Oak Ridge, Los Alamos, and other national laboratories.

• *Public and tribal school teachers:* Efforts are underway in South Dakota and regionally to improve the status and preparation of K-12 science and mathematics teachers. The Black Hills State University's Center for the Advancement of Mathematics and Science Education, in addition to developing and distributing mathematics and science learning kits to public and tribal school teachers, sponsors week-long workshops to help prepare teachers to use their materials. Similarly, NAMSEL was formed in part to combat the poor preparation of and the geographic isolation of tribal school teachers; to reduce the dependence on teacher-centered teaching strategies and materials; and to improve opportunities for inservice and follow-on training.

We believe that NUSL could be a powerfully ally of these efforts, helping them reach a scale where they can improve teacher morale and quality regionally. The K-12 visitor programs could be coupled with summer teacher courses in which interested teachers are introduced to underground science at an appropriate level, providing them with the background they need to later explain the science to their students. If done well, this could not only improve teacher preparation, but build confidence and leadership among the teachers. This could be part of the formula for systematic change sought by NAMSEL.

• *Graduate student research:* The faculty and staff doing experiments at NUSL will often be accompanied by graduate students and postdoctoral research associates. NUSL will create an exciting environment for young researchers by sponsoring seminars, inviting sabbatical and short-term visitors including theoreticians, and sponsoring occasional workshops. It will be an active participant in national efforts, offering to host activities like the Summer School in Nuclear Physics. NUSL faculty may, through the Consortium for Underground Science, hold concurrent faculty appointments in CUS universities. This would allow staff scientists to attract and supervise graduate students.

• *U.S. and International Science Communities:* To the extent possible, NUSL will adopt the "open data" policies typical in the astronomy and physics communities and will provide a website from which data can be downloaded. This policy is intended to stimulate correlative and, eventually, collaborative research, and will remove barriers to student use of data.

8. Local Participation

The local awareness and support for the National Underground Laboratory at Homestake in South Dakota generally and, particularly, "West River" South Dakota is extremely high. For example, in March 2001, the *Rapid City Journal* (www.rapidcityjournal.com; choose "archive" and search on "homestake") published 19 stories or editorials regarding NUSL, more than one every second day. The Journal editorialized as follows on March 5, 2001, "An underground lab is needed because the United States does not have a facility for studying neutrinos and other particle physics. The rock above the lab will shield experiments from subatomic particles that are present above ground. The only underground labs similar to what is proposed at Homestake are in other countries."

The following individuals and groups have written letters, passed resolutions or made proclamations in support of NUSL:

United States Senator Tom Daschle, United States Senator Tim Johnson, United States Representative John Thune, South Dakota Governor William Janklow, Lead 2000 Committee, City of Lead, Lawrence County, City of Deadwood, Black Hills Community Development, Inc., Lead Area Chamber of Commerce, Rapid City Area Chamber of Commerce, The Chamber, Belle Fourche, Sturgis Industrial Expansion Corporation, Rapid City Area Economic Development Partnership, Edgemont Area Chamber of Commerce, Lead-Deadwood School District #40-1, Lead-Deadwood Ministerial Association, Spearfish School District #40-2, South Dakota Workforce Development Council, Wells Fargo Bank South Dakota, One-Stop Career Center,

Historic South Dakota Foundation, Neighborhood Housing Services of the Black Hills, Inc., Black Hills Pioneer Editorial, South Dakota Representative Matt Michels, Deadwood City Commission.

The South Dakota Legislature introduced and passed Senate Bill 255 in one day on March 21, 2001, which authorizes South Dakota Governor Bill Janklow to accept transfer of the Homestake beginning July 1, 2001. Governor Janklow signed SB255 into law on March 28, 2001.

Senator Tom Daschle and his staff, along with representatives of the State of South Dakota have been working with the Homestake Mining Corporation to arrange details of the land transfer. Sen. Daschle and Rep. Thune have publicly indicated willingness to introduce into both Houses of Congress a Homestake Indemnification bill that would address concerns of both the Homestake Mining Corporation and the State of South Dakota regarding long-term liabilities associated with NUSL.

Black Hills Power and Light has agreed to provide a concessionary “development rate” for electrical power of approximately $.025 per kilowatt hour, while NUSL is “under construction.”

9. Planning and Interim Needs, 2001-2002

The announcement that mining operations would cease at Homestake on December 31, 2001, was made on September 11, 2000. This event gave the science comunity and the state of South Dakota only 15 months to prepare for the takeover of the mine. Since September 2001, the community has produce the Bahcall Committee report, which discussed both the science and site opportunities for a US underground laboratory, unanimously selecting Homestake as the preferred option. The nuclear physics Long Range Plan Process, carried out by NSAC and by the Division of Nuclear Physics, APS, culminated in March, 2001, with a strong endorsement of the Bahcall report. A letter from NSAC supporting the conversion of Homestake to a national underground science laboatory is included as Appendix G. The case for a national underground science laboratory will also be made at Snowmass this summer, as HEPAP begins its planning process.

The proposers intend to continue to strengthen the present proposal as new work on NUSL is done. A committee is being formed to construct a representative five-year science plan for NUSL. Important input to this process will come from a conference on underground science that is being planned for early fall. Collaborations are being formed between underground scientists and the scientists, engineers, and educators of South Dakota and the region to plan how construction, operations, and outreach can best be organized. The results of these discussions will be made available to the NSF as supplementary input.

The process of building collaborations between the nationa and international underground science community and South Dakota/regional scientists and educators requires many face-to-face interactions. This process has begun with an initial visit and planned future visits to South Dakota by members of the proposing team. Discussions are underway with Dr. David Benfield, who directs the South Dakota EPSCoR office, to arrange a series of seminars throughout South Dakota and the region by leading underground scientists. The goal is to bring the regional universities and communities ``up to speed'' on underground science; to learn about the science and engineering capabilities of the state and regional universities; and to develop plans for cooperative efforts to advance NUSL.

The NUSL project, submitted for consideration as a 2003 MRE proposal, has to overcome interim funding difficulties. Approximately $4 million is needed to maintain the mine during the interim period and prevent significant and costly to remediate damage to the mine itself and its systems infrastructure. An additional $3.5 million will be needed to retain 35 engineers and miners from the current Homestake staff during the interim period; a great deal of preparatory work can be done during this time. If no funds are available for mining personnel during the interim period, one of Homestake's important assets will be lost, the skilled work force familiar with the mine and its operations.

10. Results from Previous NSF Support

Wick Haxton:
Research Experiences for Undergraduates
Grant PHY-9502584 (February 15, 1995 - January 31, 1998)

Grant PHY-9732143 (March 1, 1998 - February 28, 2001)

This grant supports the University of Washington Research Experiences for Undergraduates program. It is one of the most successful in the US, drawing approximately 230 applicants each year. Participation by women has been strong: they comprise 40% of the applicants and participants. The program is in its seventh year. Haxton has been the director throughout.

National Summer School in Nuclear Physics
Grant PHY-9424452 (February 1, 1995 - January 31, 2001)
Grant PHY-0088940 (June 1, 2000 - May 31, 2005)

Haxton is PI, and the INT holds the grant, for the National Summer School in Nuclear Physics, a school for advanced graduate students and beginning postdocs. Many of the nation's young nuclear scientists attend this school. It has a Steering Committee appointed by the DNP, American Physical Society. The school is in its 13th year. The INT and host universities also provide support.

Janet Conrad:

During the past five years, Janet Conrad has focused her research, which is entirely NSF supported, on neutrino physics. As a member of the NuTeV deep inelastic neutrino scattering experiment at Fermilab[1], she has overseen the refurbishing of the Lab E calorimeter and construction of a novel decay region upstream of the calorimeter. Using these detectors, she and her group have performed searches for decays of exotic neutral particles produced in the beam[2]. She is also the co-spokeperson for the MiniBooNE neutrino oscillation experiment at Fermilab[3]. This experiment is designed to decisively confirm or refute the $\nu_\mu \rightarrow \nu_e$ oscillation signal observed by the LSND experiment.[4] The detector and beamline are under contruction and data taking will begin in early 2002.

[1] http://www-e815.fnal.gov
[2] A. Vaitaitis, *et al.,* "Search for Neutral Heavy Leptons in the NuTeV High-Energy Neutrino Beam," Phys. Rev. Lett. 83 (1999) 4943; J. Formaggio, *et al.,* "Search for a 33.9-MeV/c^2 Neutral Particle in Pion Decay," Phys. Rev. Lett. 84: (2000) 4043; T. Adams, *et al.,* "Observation of Anomalous Dimuon Events in the NuTeV Decay Detector," hep-ex/0009007.
[3] http://www-boone.fnal.gov
[4] http://www.neutrino.lanl.gov/LSND/

Sherry Farwell:

a. **ATM-9625141**, $379,321, 06/15/96-05/31/00
b. A Mobile Test Gas Generator Facility for the Atmospheric Chemistry Community
c. *Summary of Results:*

This project had three main objectives: 1) to continue the optimization, testing, and validation of an automated sulfur gas dilution system (ASGDS) for the reliable production of pptv-levels of sulfur dioxide in air mixtures containing various suites of potential measurement interferent gases, 2) to unitize this improved test gas generator facility in a second rigorous intercomparison experiment similar to the former NSF Gaseous Sulfur Intercomparison Experiment (GASIE-1) and 3) to exploit the fundamental design of this novel gas dilution system for the preparation of other test gases at known pptv concentrations in air-based matrices. One of the measurement instruments evaluated during GASIE-1 was a diffusion denuder, total sulfur chemiluminescence detector operated by scientists from the University of Alaska. During GASIE-1, this particular instrument exhibited significant problems when various interferent gases such as water vapor were added to the test gas mixtures.

GASIE-2 was designed to re-evaluate the performance of a modified version of this diffusion denuder, total sulfur chemiluminescence instrument by challenge gases prepared by the ASGDS. Sulfur dioxide at concentrations ranging from 17 to 182 pptv was employed in a double-blind experimental design and two independent referees analyzed the resulting data. GASIE-2 was declared a success due to the comparative performances of the dynamic dilution apparatus, its associated quality assurance measurement system, and the diffusion denuder, total sulfur chemiluminescence detector.

d. *Publications resulting from this award*:

1. D. R. Crosley, P. D. Goldan, D. K. Hicks, R. L. Benner, D. L. MacTaggart, W. L. Bamesberger, and S. O. Farwell, "Gas-Phase Sulfur Intercomparison Experiment #2: Analysis and Conclusions", *J. Geophys. Res., 105, 19,787, 2000.*
2. J. R. Burdge, D. L. MacTaggart, and S. O. Farwell, "Realistic Detection Limits from Confidence Bands", *J. Chem. Ed., 76, 434, 1999.*
3. J. R. Burdge, D. L. MacTaggart, Z. Cai, T. K. Haakenson, W. L. Bamesberger, and S. O. Farwell, "A Continuous Monitor-Sulfur Chemiluminescence Detector System for the Measurement of Total Gaseous Sulfur Species in Air", *Atmos. Environ., 33, 625, 1999.*
4. D. L. MacTaggart and S. O. Farwell, "Realistic Detection Limits", *Amer. Environ. Lab., 10, 4, 1998.*

a. **ATM-9601951**, $118,200, 06/15/96-05/31/99
b. Acquisition of a Real-Time API-TOFMS Monitor for Use with a Mobile Test Gas Generation Facility
c. *Summary of Results:*

This MRI instrumentation grant allowed the purchase and installation of an atmospheric pressure ionization-time of flight mass spectrometer (API-TOFMS) for subsequent use as an on-line analyzer for test gas mixtures. The instrument acquired was a Sensar TOF2000 with an atmospheric pressure corona discharge ionization source and an off-axis time-of-flight mass analyzer. Initial experimental results with this commercial ionization source demonstrated detectability in the low ppbv range for different sulfur-containing gases. For the detection of various sulfur, nitrogen, and halogen gases at low pptv concentrations, the instrument is operated in a negative ion mode with a different ionization source. This new Ni-63 ionization source was designed in our research laboratory at SDSM&T. The performance of the Ni-63 API-TOFMS instrument has been characterized using known gas mixtures prepared by our programmable dynamic dilution system.

One graduate student at SDSM&T completed a Ph.D. dissertation in December 2000 on the application of the atmospheric-pressure ionization mass spectrometer for the real-time monitoring of analyte concentrations in the test gas mixtures prepared by the dynamic dilution system.

Professors Marshak's and Professor Wilkerson's research are supported by DOE. They have not received NSF support during the past 5 years.

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"Future Atmospheric Neutrino Detectors", A. Geiser, Nuclear. Physic B (Proc. Suppl) 91 (2001)147-155. e-Print Archive: hep-ex/0009060

7. Long baseline neutrino oscillation detectors

"Neutrino beams from muon storage rings: characteristics and physics potential", S. Geer, Phys.Rev.D57:6989-6997,1998.

"Long baseline physics with a muon storage ring neutrino source", V. Barger, S. Geer, K. Whisnant, e-Print Archive: hep-ph/9906487.

"Long baseline study of the leading oscillation at a neutrino factory", V. Barger, S. Geer, R. Raja, K. Whisnant, e-Print Archive: hep-ph/9911524.

"Oscillation Measurements with Upgraded Conventional Neutrino Beams", V. Barger, et. al. e-Print Archive: hep-ph/0103052

"Status of the MINOS Experiment" S. G. Wojcicki, Nuclear Physics B (Proc. Suppl.) 91 (2001) 216-222.

"Status of the K2K" K. Nakamura, Nuclear Physics B (Proc. Suppl.) 91 (2001) 203-209.

8. Supernova neutrinos and detectors

"Supernova Neutrino Detection", Kate Scholberg Nuclear Physics B (Proc. Suppl.) 91 (2001) 331-337. e-Print Archive: hep-ex/0008044

"What We Might Learn from a Futre Supernova Neutrino Signal? Petr Vogel, 8th International Workshop on Neutrino Telescopes, Venice, Italy, 23-26 Feb 1999. e-Print Archive: astro-ph/9904338.

"Prospects for Detecting Supernova Neutrino Flavor Oscillations". George M. Fuller, Wick C. Haxton, Gail C. McLaughlin. Phys. Rev. D 59,1999. e-Print Archive: astro-ph/9809164.

"Observation of a Neutrino Burst in Coincidence with Supernova SN1987A in the Large Magellanic Cloud. R.M. Bionta et. al. Phys. Rev. Lett. 58, 1494, 1987.

9. Geosciences

Amy, P., and D. Haldeman (Editors), 1997. "The Microbiology of the Terrestrial Deep Subsurface". CRC Press, Boca Raton, FL.

Faybishenko, B., P. A. Witherspoon, and S. Benson (Editors), 2000: "Dynamics of Fluids in Fractured Rock", Geophysical Monograph 122, American Geophysical Union, Washington, DC.

Glaser, S. D. and D. N. Doolin, 1999. "New Directions in Rock Mechanics – A Forum Sponsored by the American Rock Mechanics Association", A Report to the National Science Foundation, Department of Civil and Environmental Engineering, University of California, Berkeley, CA.

National Research Council, 2000. "Seeing into the Earth – Noninvasive Characterization of the Shallow Subsurface for Environmental and Engineering Application", National Academy Press, Washington, DC.

Wang, J. S. Y., 1991. "Flow and Transport in Fractured Rocks". U.S. National Report to International Union of Geodesy and Geophysics. Reviews of Geophysics, Supplement, pp. 254-262.

10. Precision Radioassay

Solid State Gamma-Ray Detection
G. Heusser, "Low Radiation Background Techniques", Ann. Rev. Nucl. Part. Sci. 45 (1995) 543-90.

Gas Proportional Detectors and Techniques
W. Hampel et. al. incl. F. X. Hartmann, G. Heusser, T. Kirsten, F. v. Feilitzsch, GALLEX Collaboration), "Gallex Solar Neutrino Observations: Results for Gallex III)", Phys. Lett. B388 (1996) 384-396.

Underground Low Background Scintillation Detection
G. Bellini, et. al. incl. F. X. Hartmann, W. Hampel, G. Heusser, T. KIrsten, F. v. Feilitzsch, Borexino Collaboration, "Ultra-low background measurements
in a large volume underground detector", Astrop. Phys. 8 (1998) 141.

Neutron Activation
T. Goldbrunner et. al. incl. F. v. Feilitzsch, "New Records on Low Activity Measurements with Neutron Activation Analysis", Proc. of Int. Conf. on Adv.
Tech. and Part. Phys., Como, Oct 7-11, 1996, Nucl. Phys. B (Proc. Suppl.) 61B (1998) 176

11. Underground Microbiology

J. K. Fredrickson and T. C. Onstott, *Microbes Deep inside the Earth*, Scientific American, v. 275, No. 4, p. 68-73.
D. R. Lovley and F. H. Chapelle, Reviews of Geophysics 33: 365-381 (1995).
K. Pedersen, FEMS Microbiol. Rev. 20: 399-414 (1997).
F. S. Colwell et al., FEMS Microbiol. Rev. 20: 425-435 (1997).
K. O. Stetter et al., Nature 365: 743-745 (1993).

Biographical Sketch: Wick C. Haxton

A. Professional Preparation

University of California, Santa Cruz	Physics & Mathematics	B.S 1971
Stanford University	Physics Thesis: Semileptonic Weak Interactions	Ph.D. 1976
Universität Mainz, Institut für Kernphysik	Postdoctoral Research Associate	1975-77
Los Alamos Scientific Laboratory	Postdoctoral Staff Member, J.R. Oppenheimer Fellow, and Staff Member	1977-85

B. Appointments

Adjunct Professor Astronomy, University of Washington, 1994-present
Director, National Institute for Nuclear Theory (INT), September 1991-present
Professor of Physics, University of Washington, 1987-present
Associate Professor of Physics, University of Washington, 1984-87

C. Publications

Most closely related to proposed project:

"Neutrino Physics," Am. J. of Physics 68 (2000) 15 (with B. Holstein).

"Prospects for Detecting Supernova Neutrino Flavor Oscillations," Phys. Rev. D59, 085005 (1999).

"Cross Section Uncertainties in the Gallium Neutrino Source Experiments," Phys. Lett. B431, 110 (1998).

"Neutrino-induced nucleosynthesis and the site of the r-process," Phys. Rev. Lett. 78, 2694 (1997) (with Langanke et al.).

"Salty Water Cerenkov Detectors for Solar Neutrinos," Phys. Rev. Lett. 76, 1562 (1996).

Other significant publications:

"Morphing the Shell Model into an Effective Theory," Phys. Rev. Lett. 84 (2000) 5454 (with C.-L. Song).

"^{3}He Transport in the Sun and the Solar Neutrino Problem," Phys. Rev. Lett. 77, 4286 (1996) (with Andrew Cumming).

"The Solar Neutrino Problem," Ann. Rev. Astron. and Astrophys. 33, 459 (1995).

"Landau-Zener Treatments of Solar Neutrino Oscillations," Phys. Rev. D51, 4028 (1995) (with M. Bruggen and Y.-Z. Qian).

"The Very Low Energy Solar Flux of Electron and Heavy-Flavor Neutrinos and Antineutrinos," Phys. Lett. B 486 (2000) 263 (with Wei Lin).

D. Synergistic Activities

- Co-founder and current PI of the National Summer School in Nuclear Physics, now in its 13th year, which attempts to enhance the appreciation of young researchers for the breadth and diversity of the field.
- Founder and director of the Univ. of Washington Physics Research Experiences for Undergraduates program, now in its seventh year, which draws about 230 applications each year and has had an excellent record of attracting women physicists.
- Developed the web-based course "Nuclear Astrophysics" at the University of Washington.
- Member of the Type II Supernova Consortium that is integrating expertise from computer science, astrophysics, and nuclear physics in preparation for massively parallel two-dimensional hydrocode developments.
- Director of the Institute for Nuclear Theory, the DOE's national outreach center in this discipline. Approximately 350 visitors are drawn each year to INT programs, workshops, and schools.

E. Collaborators & Other Affiliations

Collaborators:

B. Barrett (Univ. of Arizona); J. Ginocchio (Los Alamos National Laboratory); N. Hata, (Princeton); K. Lande (Univ. of Pennsylvania); K. Langanke (Aarhus University); Y. Qian (Caltech); M. Savage (Univ. of Washington); P. Vogel (Caltech); D.C. Zheng (unknown).

Graduate and Postdoctoral Advisors:

Thesis Advisor: T.W. Donnelly (MIT)
Postdoc Advisors: D. Drechsel (Mainz) and J. Ginocchio (LANL)

Thesis Advisor and Postgraduate-Scholar Sponsor:

Students:

Cheng Pang Liu (Univ. of Washington); Thomas Luu (Univ. of Washington); Travis Norsen (Univ. of Washington); Marina Hruska (Univ. of Washington); Chang-Liang Song (IBM San Jose); Kar Lee (unknown).

Postdocs†:

Gail McLaughlin (TRIUMF); Yong Qian (Caltech); Antje Hoering (Univ. of Washington)

† The INT hosts many postdocs – I have listed only those with whom I collaborated in the last five years.

Biographical Sketch: Janet M. Conrad

A. Professional Preparation:

Swarthmore College,	Physics,	B.A.,1981–1985
Oxford University,	High Energy Physics,	M.Sc., 1985–1987
Harvard University,	High Energy Physics,	Ph.D., 1986–1993

B. Professional Appointments:

Associate Professor, Columbia University, 1999–present
Assistant Professor, Columbia University, 1995–1999
Postdoc. Research Assoc., Columbia University, 1993–1995

C. Publications

Related to the Project:

- "A Feasibility Study of a Neutrino Source Based on a Muon Storage Ring," N. Holtkamp, *et al.*, Submitted to Phys. Rev. ST Accel. Beams.
- "A proposal for an experiment to measure $\nu_\mu \to \nu_e$ oscillations and nu_μ disappearance at the Fermilab Booster: BooNE," The BooNE Collaboration (E. Church *et al.*,) LA-UR-98-352, Fermilab experiment 898. Available at http://www-boone.fnal.gov/.
- "A High Statistics Search for ν_e ($\bar{\nu}_e$) $\to \nu_\tau$ ($\bar{\nu}_\tau$) Oscillations," The CCFR/NuTeV Collaboration (D. Naples, *et al.*). Phys. Rev. D59 (1999) 3110.
- "A High Statistics Search for ν_μ ($\overline{\nu_\mu}$) $\to \nu_e$ ($\overline{\nu_e}$) Oscillations in the Small Mixing Angle Regime," The CCFR/NuTeV Collaboration (A. Romosan *et al.*) *Phys. Rev. Lett.* 78 (1997) 2912.
- "A Limit on $\nu_\mu(\overline{\nu_\mu}) \to \nu_\tau(\overline{\nu_\tau})$ Oscillations from a Precision Measurement of ν – nucleon Neutral Current Interactions," The CCFR/NuTeV Collaboration (K. McFarland, *et al.*), Phys. Rev. Lett 75 (1995) 3993.

Other Selected Publications:

- "A First Measurement of Low x Low Q^2 Structure Functions in Neutrino Scattering," The NuTeV Collaboration, (B. Fleming, *et al.*), accepted to Phys. Rev. Lett. (2001). hep-ex/0011094.
- "Search for a 33.9-MeV/c^2 Neutral Particle in Pion Decay," The NuTeV Collaboration (J. Formaggio, *et al.*), Phys. Rev. Lett. 84: (2000) 4043.
- "Search for Neutral Heavy Leptons in the NuTeV High-Energy Neutrino Beam," The NuTeV Collaboration (A. Vaitaitis, *et al.*), Phys. Rev. Lett. 83 (1999) 4943.
- "Precision Measurements with High Energy Neutrino Beams," J. Conrad, M. Shaevitz, Rev. Mod. Phys. 70 (1998) 1341.

- "Improved Determination of α_s from Neutrino - Nucleon Scattering," The CCFR/NuTeV Collaboration (W. Seligman, *et al.*), Phys. Rev. Lett. 79 (1997) 1213

D. Synergistic & Outreach Activities:

- Publication of a free booklet for the public, "Neutrinos Matter," developed under NSF-PHY-9733023. This has been used extensively to educate South Dakotans about the Homestake project.
- Presently mentoring high school students Jessica Falco, Seth Flaxman, and Ruchard Page and high school teacher Len Bugel.
- Presentation at the Australian Institute of Physics Meeting of Women in Physics, on "Ideas for Increasing the Fraction of Women in Physics," Adelaide, December 2000.
- Presentation of a series of Public Lectures on Neutrinos. Most Recent lecture was given to K-12 teachers at the Symposium on the Nature of Science, Fermilab.
- Production of a set of posters explaining neutrino oscillations. Presently on display at Holton-Arms women's high school.

E. Collaborators and Other Affiliations:

Collaborators: The MiniBooNE Collaboration: see http://www-boone.fnal.gov/collaboration.html
The CCFR/NuTeV Collaboration: see http://www-e815.fnal.gov/people.html
The Neutrino Factory Collaboration: see http://www.cap.bnl.gov/mumu/info/members.html
ISCAP (at Columbia): A. Crotts, B. Greene, L. Hui, D. Kabat, S. Westerhoff.

Graduate and Postdoctoral Advisors:
Postdoc: M. Shaevitz, Columbia University
Ph.D.: F. Pipkin (deceased), R. Wilson, Harvard University
M.Sc.: P. Renton, Oxford University.

Graduate and Postdoctoral Advisees:
Thesis students at Columbia: L. Borissov, B. Fleming, J. Formaggio, J. Monroe, M. Sorel
Past students (present location): J.H. Kim (Irvine), C. McNulty (industry), A. Romosan (Berkeley), W. Seligman (Columbia), A. Vaitaitis (industry)
Present Postdocs at Columbia: L. Coney, E. Zimmerman
Past postdocs (present location): P. Spentzouris (FNAL), E. Stern (industry)

BIOGRAPHICAL SKETCH

Sherry Owen Farwell, Ph.D.
Dean of Graduate Education and Sponsored Programs
South Dakota School of Mines and Technology
Rapid City, South Dakota 57701-3995
Phone: (605) 394-2493
Email: Sherry.Farwell@sdsmt.edu

Date and Place of Birth

June 1, 1944 Miles City, Montana

Educational Background

B.S., Chemistry, SD School of Mines and Technology	1966
M.S., Analytical Chemistry, SD School of Mines and Technology	1969
Ph.D., Analytical Chemistry, Montana State University	1973
Post-Ph.D., Atmospheric Chemistry, Washington State University	1974

Summary of Professional Experience

Analytical Chemist, John Deere Co., Dubuque, IA	1966-67
Analytical Chemist, Tektronix, Inc., Beaverton, OR	1969
Assistant Research Chemist, Air Pollution Research Section, Washington State University	1975-77
Assistant Professor, Department of Chemistry, Washington State University	1976-77
Associate Prof./Professor, Department of Chemistry, University of Idaho	1977-95
NORCUS Senior Research Associate, Battelle PNL, Atmospheric and Earth Science, Richland, WA	1987
Program Director, Atmospheric Chemistry Program, National Science Foundation	1993-95
Director of South Dakota Space Grant Consortium	1995-present
Co-Director of South Dakota EPSCoR Program	1995-present
Dean of Graduate Education and Sponsored Programs, South Dakota School of Mines and Technology	1995-present

Professional Organizations

American Chemical Society
Association of Official Analytical Chemists
Sigma Xi
American Society for Testing Materials
American Geophysical Union
Air and Waste Management Association

Selected Recent Publications and Presentations

Author of 12 book chapters, over 66 refereed journal articles, and 125 presentations at scientific meetings. Seven selected publications include:

"Gas-Phase Sulfur Intercomparison Experiment 2", J. Geophys. Res., 2000, Vol 105(D15):19,787.

"Realistic Detection Limits from Confidence Bands", J. Chem. Ed., 1999, Vol. 76:434.

"A Continuous Monitor-Sulfur Chemiluminescence Detector System for the Measurement of Total Gaseous Sulfur Species in Air", Atmos. Environ., 1999, Vol. 33:625.

"Generation and Evaluation of Test Gas Mixtures for the Gaseous Sulfur Intercomparison Experiment (GASIE)" (With D.L. MacTaggart, T.J. Haakenson, W.L. Bamesberger, and W.D. Dorko). J. Geophys. Res., 1997. Vol. 102(D13):16,237

"Results of the Gas-Phase Sulfur Intercomparison Experiment (GASIE): Overview of experimental setup, results, and general conclusions" (With H.A. Stecker et al.). J. Geophys. Res., 1997. Vol. 102(D13):16,219

"Modern Gas Chromatographic Instrumentation" in Analytical Instrumentation Handbook, 2nd edition, Marcel Dekker, Inc., 1997, Chapter 23, pp. 1205-1285.

"A Modified Microcomputer-Controlled Proportioning Valve Instrument for Programmable Dilution of Gases", Instrumentation Science and Technology, 1995, Vol. 23:277.

Synergistic Activities

As Dean of Graduate Education, provide guidance and oversight to the educational programs of over 300 graduate students in engineering and physical science.

As Director of the SD Space Grant Consortium, plan and participate in numerous educational outreach programs that transmit the excitement of space and earth science to students of all ages and races in SD.

As Co-Director of the NSF SD-EPSCoR program, design and implement specific projects that both strengthen the research capacity of SD universities/colleges and promote quality educational opportunities in science, mathematics, and technology.

As Director of the NASA SD-EPSCoR program, stimulate research and educational partnerships between SD universities, technological businesses, state government agencies, and federal agencies.

As Board Member of the Western Research Alliance, promote technology transfer, entrepreneurship, SBIR/STTR opportunities, and regional economic development.

Grants and Contracts

Principal Investigator on 42 previous research grants and contracts funded by various federal, state, industrial and private sources. Total financial support for these previous research projects exceeded $6 million. Currently funded by two NSF awards for $2,661,816, three NASA awards for $1,137,500, and two University of North Dakota UMAC-PARC awards ($147,500).

Honors and Awards

Honorary Lifetime ASTM Membership for Meritorious E-19 Service
Distinguished University of Idaho Faculty Award
Phi Kappa Phi Distinguished Faculty Award
University of Idaho International Honor Roll

Recent Research Collaborators

W. Lee Bamesberger, Washington State University
Patrick R. Zimmerman, South Dakota School of Mines & Technology
Paul L. Smith, South Dakota School of Mines & Technology
Bradly Baker, South Dakota School of Mines & Technology
Paul D. Goldan, NOAA Aeronomy Laboratory
David R. Crosley, SRI International
William D. Dorko, NIST
Douglas MacTaggart, Trace Minerals Analytical Laboratory

Recent Graduate Students and Postdoctoral Scholars

Tim Haakenson	Brenda Waller	Brian Hart
Julie Burdge	Greg Blanchard	Lori Blanchard
Tim Attig	Kristin Gaines	Douglas MacTaggart
William Chatham	Charles Barinaga	Shaowen Wu
Max Dolenc	Joel Chavez	Richard Kagel
Carla Kagel	John Jolley	Steven Fernandez
John Fellman	Jim Johnson	Jack Felkey
Dennis Gage	Fritz Grothkopp	Daniel Liebowitz
Steve Gluck	Ann Sherrard	Teresa Corbin
Lisa Teeslink	Amanda Song	Bradly Baker

Total graduate students advised from 1975-01 59
(approximately 1/3 have been female students)
Total research associates sponsored from 1975-01 8

Graduate and Postdoctoral Advisors

Professor Lowell Dieter (M.S.)
Professor Richard Geer (Ph.D.)
Professor Donald F. Adams (Post-Ph.D.)

Biographical Sketch: Marvin L. Marshak

a. Professional Preparation

A.B. (Physics)—Cornell University, Ithaca, NY, 1967
M.S. and Ph.D. (Physics)—University of Michigan, Ann Arbor, MI, 1969 and 1970
Postdoctoral Research Associate—University of Minnesota, Minneapolis MN, 1970-1974

b. Appointments

Morse-Alumni Distinguished Teaching Professor of Physics, University of Minnesota, 1996-present
Director of Residential College, University of Minnesota, 1994-1996, 1997-present
Faculty Legislative Liaison, University of Minnesota, 1997-present
Senior Vice-President for Academic Affairs, University of Minnesota, 1996-1997
Head, School of Physics and Astronomy, University of Minnesota, 1986-1996
Professor of Physics, University of Minnesota, 1983-1996
Director of Graduate Studies in Physics, University of Minnesota, 1983-1986
Associate Professor Physics, University of Minnesota, 1978-1983
Assistant Professor of Physics, University of Minnesota, 1974-1978

c(i). Related Publications

1. *SEARCH FOR NUCLEON DECAY WITH FINAL STATES LEPTON+ ETA**0, ANTI-NEUTRINO ETA**0, AND ANTI-NEUTRINO PI+,0 USING SOUDAN-2.* Soudan 2 Collaboration (D. Wall *et al.*). **Phys.Rev.D62:092003,2000**

2. *SEARCH FOR NUCLEON DECAY INTO LEPTON + K0 FINAL STATES USING SOUDAN-2.* By Soudan 2 Collaboration (D. Wall *et al.*). **Phys.Rev.D61:072004,2000**

3. *THE OBSERVATION OF A SHADOW OF THE MOON IN THE UNDERGROUND MUON FLUX IN THE SOUDAN-2 DETECTOR.* By Soudan 2 Collaboration (J.H. Cobb *et al.*). **Phys.Rev.D61:092002,2000**

4. *THE ATMOSPHERIC NEUTRINO FLAVOR RATIO FROM A 3.9 FIDUCIAL KILOTON YEAR EXPOSURE OF SOUDAN-2.* By Soudan-2 Collaboration (W.W.M. Allison *et al.*). **Phys.Lett.B449:137-144,1999**

5. *SEARCH FOR THE PROTON DECAY MODE PROTON TO NEUTRINO K+ IN SOUDAN-2.* By Soudan-2 Collaboration (W.W.M. Allison *et al.*). **Phys.Lett.B427:217-224,1998**

c(ii). Other Publications

1. *THE LARGE MOMENTUM TRANSFER REACTION C-12(P,2P + N) AS A NEW METHOD FOR MEASURING SHORT RANGE N N CORRELATIONS IN NUCLEI.* By J. Aclander, J. Alster, D. Barton, G. Bunce, A. Carroll, N. Christensen, H. Courant, S. Durrant, S. Gushue, S. Heppelmann, E. Kosonovsky, I. Mardor, Y. Mardor, M. Marshak, Y. Makdisi, E.D. Minor, I. Navon, H. Nicholson, E. Piasetzky, T. Roser, J. Russell, M. Sargsian, C.S. Sutton, M. Tanaka, C. White, J.Y. Wu (Tel Aviv U. & Brookhaven & Minnesota U. & Penn State U. & Mount Holyoke Coll. & Massachusetts U., North Dartmouth). 1999. **Phys.Lett.B453:211-216,1999**

2. *SEARCH FOR THE PROTON DECAY MODE PROTON TO NEUTRINO K+ IN SOUDAN-2.* By Soudan-2 Collaboration (W.W.M. Allison *et al.*). **Phys.Lett.B427:217-224,1998**

3. *MEASUREMENT OF QUASIELASTIC C-12 (P, 2P) SCATTERING AT HIGH MOMENTUM TRANSFER.* By Y. Mardor, J. Aclander, J. Alster (Tel Aviv U.), D. Barton, G. Bunce, A. Carroll (Brookhaven), N. Christensen, H. Courant (Minnesota U.), S. Durrant, S. Gushue (Brookhaven), S. Heppelmann (Penn State U.), E. Kosonovsky, I. Mardor (Tel Aviv U.), M. Marshak (Minnesota U.), Y. Makdisi (Brookhaven), E.D. Minor (Penn State U.), I. Navon (Tel Aviv U.), H. Nicholson (Mount Holyoke Coll.), E. Piasetzky (Tel Aviv U.), T. Roser (Brookhaven), J. Russell (Massachusetts U., North Dartmouth), C.S. Sutton (Mount Holyoke Coll.), M. Tanaka (Brookhaven), C. White (Minnesota U.), J.Y. Wu (Penn State U.). Oct 1997. **Phys.Lett.B437:257-263,1998**

4. *A STUDY OF COSMIC RAY COMPOSITION IN THE KNEE REGION USING MULTIPLE MUON EVENTS IN THE SOUDAN-2 DETECTOR.* By Soudan-2 Collaboration (S.M.S. Kasahara *et al.*).**Phys.Rev.D55:5282-5294,1997**

5. *MEASUREMENT OF THE ATMOSPHERIC NEUTRINO FLAVOR COMPOSITION IN SOUDAN-2.* By W.W.M. Allison, G.J. Alner, D.S. Ayres, W.L. Barrett, C. Bode, P.M. Border, C.B. Brooks, J.H. Cobb, D.J.A. Cockerill, R.J. Cotton, H. Courant, D.M. Demuth, T.H. Fields, H.R. Gallagher, C. Garcia-Garcia, M.C. Goodman, R.N. Gray, K. Johns, T. Kafka, S.M.S. Kasahara, W. Leeson, P.J. Litchfield, N.P. Longley, M.J. Lowe, W.A. Mann, M.L. Marshak, E.N. May, R.H. Milburn, W.H. Miller, L. Mualem, A. Napier, W. Oliver, G.F. Pearce, D.H. Perkins, E.A. Peterson, D.A. Petyt, L.E. Price, D.M. Roback, K. Ruddick, D. Schmid, J. Schneps, M.H. Schub, R.V. Seidlein, M.A. Shupe, A. Stassinakis, N. Sundaralingam, J. Thomas, J.L. Thron, V. Vasilev, G. Villaume, S.P. Wakely, D. Wall, S.J. Werkema, N. West, U.M. Wielgosz (Argonne & Minnesota U. & Oxford U. & Rutherford & Tufts U. & Western Washington U.). **Phys.Lett.B391:491-500,1997**

d. Synergistic Activities

• Founded and has directed for six years the University of Minnesota Residential College, a program that now includes 450 undergraduate students and integrates academic and residential activities. Mr. Marshak has taught innovative seminars for Residential College students including *The Art and Science of Color* (jointly with a Studio Arts professor), *The Deep Underground Sky* (neutrinos for the non-expert) and *America Emerges from Isolation: The History of the Manhattan Project*.

• For the past three years represented the 3,000 members of the University of Minnesota faculty in interactions with the Governor and Legislature of Minnesota. In this position, he has promoted public dialogue in Minnesota regarding the balance of access and excellence in public, land-grant, research university higher education.

• Served the University of Minnesota as its Senior Vice-President and Chief Academic Officer during the 1996-1997 conflict between the University Regents and faculty regarding policies on faculty tenure. As part of the solution to this conflict, he publicly articulated the importance of academic freedom to the University of people of Minnesota and the direct link between tenure and academic freedom. He also participated in the management of the University's reorganization of its biological sciences programs and the $225 million sale of the University Hospital to a non-profit, vertically-integrated health care organization.

• Played a significant role in raising $4 million to endow a Theoretical Physics Institute, in recruiting outstanding faculty, principally from the Soviet Union, and in organizing the Institute, which has played a major role in the recent development of elementary particle and condensed matter physics. He also raised approximately $0.5 million to endow the Abigail and John Van Vleck Lectureship in Physics, which has attracted nearly 20 Nobel-laureate lecturers.

• Often served as a Visiting Scientist in K-12 schools, principally in a program sponsored by the Science Museum of Minnesota and the Blandin Foundation.

e(i) Collaborators

J. Aclander, (Tel-Aviv), Y. Aleshin, (ITEP-Moscow), K. Alexandrov, (Lebedev), W. Allison, (Oxford), J. Alster, (Tel-Aviv), D. Anderson, (Fermilab), C. Arroyo, (Stanford), F. Avignone, (South Carolina), S. Avvakumov, (Stanford), D. Ayres, (Argonne), J. Bahcall, (IAS), B. Baller, (Fermilab), B. Barish, (Caltech), P. Barnes, (Livermore), G. Barr, (Oxford), W. Barrett, (Western Washington), D. Barton, (Brookhaven), R. Bernstein, (Fermilab), G. Bock, (Fermilab), D. Boehnlein, (Fermilab), D. Bogert, (Fermilab), P. Border, (Minnesota), C. Bower, (Indiana), L. Buckley-Geer, (Fermilab), G. Bunce, (Brookhaven), A. Byon-Wagner, (Fermilab), F. Calaprice, (Princeton), A. Carroll, (Brookhaven), S. Chernichenko, (Pittsburgh), S. Childress, (Fermilab), B. Choudhary, (Caltech), N. Christensen, (Minnesota), J. Cobb, (Oxford), J. Conrad (Columbia), D. Cossairt, (Fermilab), H. Courant, (Minnesota), A. De Santo, (Oxford), D. Demuth, (Minnesota), P. Dervan, (UC London), V. Ditlov, (ITEP-Moscow), M. Diwan, (Brookhaven), P. Doe, (U. Washington), S. Durrant, (Brookhaven), R. Edgecock, (Rutherford), O. Egorov, (ITEP-Moscow), A. Erwin, (Wisconsin), D. Fassouliotis, (Athens), G. Feldman, (Harvard), T. Fields, (Argonne), T. Gaisser (Bartol), H. Gallagher, (Minnesota), A. Golutvin, (ITEP-Moscow), M. Goodman, (Argonne), N. Grossman, (Fermilab), V. Gudkov, (South Carolina), S. Gushue, (Brookhaven), Y. Gutnikov, (Pittsburgh), A. Habig, (UM Duluth), D. Harris, (Fermilab), E. Harris, (Sussex), P. Harris, (Sussex), E. Hartouni, (Livermore), R. Hatcher, (Stanford), W. Haxton (U. Washington), R. Heinz, (Indiana), K. Heller, (Minnesota), S. Heppelmann, (Penn State), Y. Huang, (Caltech), J. Hylen, (Fermilab), M. Ignatenko, (Fermilab), G. Irwin, (Stanford), C. James, (Fermilab), T. Joffe-Minor, (Argonne), D. Johnson, (Fermilab), T. Kafka, (Tufts), S. Kasahara, (Minnesota), E. Katsavounidis, (Caltech), V. Khovanski, (ITEP-Moscow), H. Kim, (Caltech), V. Kochetkov, (ITEP-Moscow), G. Koizumi, (Fermilab), S. Kopp, (Texas-Austin), E. Kosonovsky, (Tel Aviv), M. Kostin, (Texas-Austin), D. Krakauer, (Argonne), A. Kulik, (Pittsburgh), K. Lang, (Texas-Austin), R. Lee, (Harvard), K. Lesko, (LBNL), P. Litchfield, (Rutherford), J. Liu, (Beijing), J. Liu, (Texas-Austin), N. Longley, (Macalster), P. Lucas, (Fermilab), Y. Makdisi, (Brookhaven), V. Makeev, (Fermilab), W. Mann, (Tufts), A. Marchionni, (Fermilab), I. Mardor, (Tel Aviv), Y. Mardor, (Tel-Aviv), J. McDonald, (Pittsburgh), E. Melnikov, (Pittsburgh), G. Merson, (Lebedev), M. Messier, (Harvard), D. Michael, (Caltech), R. Milburn, (Tufts), L. Miller, (James Madison), E. Minor, (Penn State), S. Mishra, (South Carolina), J. Morfin, (Fermilab), L. Mualem, (Minnesota), S. Mufson, (Indiana), M. Murtagh, (Brookhaven), J. Musser, (Indiana), A. Napier, (Tufts), D. Naples, (Pittsburgh), I. Navon, (Tel Aviv), C. Nelson, (Fermilab), J. Nelson, (Minnesota), H. Newman, (Caltech), F. Nezrick, (Fermilab), H. Nicholson, (Mt. Holyoke), W. Oliver, (Tufts), V. Onuchin, (Pittsburgh), V. Paolone, (Pittsburgh), A. Para, (Fermilab), T. Patzak, (Tufts), G. Pearce, (Rutherford), C. Peck, (Caltech), E. Peterson, (Minnesota), D. Petyt, (Rutherford), K. Phillips, (Macalster), E. Piasetzky, (Tel Aviv), A. Pla-Dalmau, (Fermilab), R. Plunkett, (Fermilab), E. Pozharova, (ITEP-Moscow), L. Price, (Argonne), G. Rameika, (Fermilab), A. Read, (Fermilab), D. Reyna, (Argonne), K. Robinson, (LBNL), C. Rosenfeld, (South Carolina), T. Roser, (Brookhaven), K. Ruddick, (Minnesota), J. Russell, (U. Massachusetts), V. Ryabov, (Lebedev), R. Saakyan, (UC London), B. Sadoulet (UCB), J. Schneps, (Tufts), P. Schoessow, (Argonne), V. Semenov, (Pittsburgh), V. Shamanov, (ITEP-Moscow), W. Smart, (Fermilab), V. Smirnitsky, (ITEP-Moscow), P. Smith, (Sussex), V. Smotriaev, (ITEP-Moscow), H. Sobel (UCI), N. Solomey, (IIT), R. Soltz, (Livermore), N. Starkov, (Lebedev), C. Sutton, (Mt. Holyoke), R. Talaga, (Argonne), M. Tanaka, (Brookhaven), E. Tetteh-Larkey, (Texas A&M), J. Thomas, (UC London), M. Thomson, (Cambridge), J. Thron, (Argonne), N. Tobien, (Fermilab), D. Tovee, (UC London), I. Trostin, (ITEP-Moscow), V. Tsarev, (Lebedev), G. Tzanakos, (Athens), G. Unel, (Northwestern), J. Urheim, (Minnesota), A. Usachev, (Pittsburgh), M. Vassiliou, (Athens), M. Velasco, (Northwestern), C. Velissaris, (Wisconsin), V. Verebryusov, (ITEP-Moscow), B. Viren, (Brookhaven), L. Wai, (Stanford), J. Wang, (LBNL), C. Ward, (Cambridge), D. Ward, (Cambridge), D. Wark, (Rutherford), R. Webb, (Texas A&M), A. Weber, (Oxford), A. Wehmann, (Fermilab), N. West, (Oxford), C. White, (IIT), M. Wiescher (Notre Dame), J. Wilkerson, (U. Washington), R. Winston, (Chicago), S. Wojcicki, (Stanford), D. Wright, (Livermore), J. Wu, (Penn State), X. Xia, (Beijing), J. Yun, (Fermilab)

e(ii) Graduate and Post-doctoral Advisors: Alan Krisch (U. Michigan); Keith Ruddick (U. Minnesota)

e(iii) Thesis Students: 15 overall; last 5 years: David DeMuth, University of Minnesota-Crookston, Hugh Gallagher, University of Minnesota; **Post-doctoral Scholar Sponsor:** 5 overall; none in last 5 years

Biographical Sketch: John F. Wilkerson

A. Professional Preparation

University of North Carolina, Chapel Hill	Physics	B.S. 1977
University of North Carolina, Chapel Hill	Physics	M.S. 1979
University of North Carolina, Chapel Hill	Physics Thesis: Isospin Mixing in Light Nuclei	Ph.D. 1982
Los Alamos National Laboratory	Postdoctoral Research Fellow	1982-85

B. Appointments

Associate Chair, Physics Department, University of Washington, 1999-present
Professor of Physics, University of Washington, 1994 - present
Staff Member, Los Alamos National Laboratory, 1985 - 1994

C. Publications

Most closely related to proposed project:

"Neutrino", J.F. Wilkerson, **McGraw-Hill Encyclopedia of Science and Technology**, Eighth Edition (1997).

"Measurement of the solar neutrino capture rate by SAGE and implications for neutrino oscillations in vacuum", Phys. Rev. Lett. **83** 4686 (1999) (with J.N. Abdurashitov et al.).

"The Sudbury Neutrino Observatory", Nucl. Inst. Meth. **A449** 172 (2000) (with J. Boger et al.).

"The Russian-American Gallium Experiment (SAGE) Cr-neutrino Source Measurement", Phys. Rev. Lett. **77**, 4708, (1996). (with J.N. Abdurashitov et al.).

"Low-background ^{3}He proportional counters for use in the Sudbury Neutrino Observatory", IEEE Trans. Nucl. Sci. **46**, 873 (1999) (with ," M.C. Browne et al.).

Other significant publications:

"Limit on Electron Antineutrino Mass from Observation of the Beta Decay of Molecular Tritium", Phys. Rev. Lett. **67**, 957 (1991) (with R.G.H. Robertson et al.).

"New limit on the D coefficient in polarized neutron decay", Phys Rev **C62**, 055501 (2000) (with L. J. Lising, et al.).

"Solar Fusion Cross Sections," Rev. Mod. Phys., **70**, 1265 (1998) (with E.G. Adelberger et al.).

"Correspondence of Electron Spectra from Photoionization and Nuclear Internal Conversion", Phys. Rev. Lett. **67**, 2291 (1991) (with D.L. Wark et al.).

"Isospin-Nonconserving Particle Decays in Light Nuclei", Nuclear Physics **A549** 223 (1992) (with T.M. Mooney et al.).

D. Synergistic Activities

- As University of Washington Physics Department Associate Chair for Graduate Affairs, have directed and overseen the department's graduate student program 1999-present.

- Regularly mentor high school students from around the Puget Sound area. Inaugural participant in the Los Alamos National Laboratory high school outreach program, overseeing numerous high school students.
- Assist with the University of Washington Physics Research Experiences for Undergraduates program. In 1985, initiated summer program of hiring collage undergraduates into the Physics Division Sub-atomic Physics Group.
- One of initiators of the Washington Large Cosmic Ray Timing Array (WALTA) outreach project at the University of Washington. The program's goal is enhanced science education for teachers and students in the Seattle area by encouraging direct participation and collaboration in real science experiments.
- Presented lectures on "Experimental Neutrino Physics" at TASI Summer School, July 2000, on "Solar Neutrinos" at the SLAC Summer Institute Summer School, August 2000, "Weak Interactions in Nuclear Physics" at the National Summer School in Nuclear Physics, June 1993, scheduled to lecture on "Neutrino Physics" at the National Summer School in Nuclear Physics, June 2000.

E. Collaborators and Other Affiliations

Collaborators:

emiT*:* B. K. Fujikawa, S. J. Freedman (Univ. of California-Berkeley/LBNL); G. L. Jones (Hamilton College); T. J. Bowles, G. L. Greene (LANL); A. Garcia (Notre Dame), L. J. Lising (Univ. of Maryland); T. E. Chupp, K. P. Coulter (Univ. of Michigan); J. M. Adams, M. S. Dewey, J. S. Nico, A. K. Thompson, F. E. Wietfeldt (NIST); H. P. Mumm, R.G.H. Robertson (Univ. of Washington).

SAGE: J. N. Abdurashitov,V. N. Gavrin, V. V. Gorbachev, T. V. Ibragimova, A. V. Kalikhov, N. G. Khairnasov, T. V. Knodel S. V. Girin, I. N. Mirmov, A. A. Shikhin, E. P. Veretenkin, V. M. Vermul, V. E. Yants, G. T. Zatsepin (Institute for Nuclear Research); T. J. Bowles, W. A. Teasdale (LANL); M. L. Cherry (LSU); J. S. Nico (NIST); B. T. Cleveland, R. Davis, Jr., K. Lande (Univ. of Pennsylvania); S. R. Elliott (Univ. of Washington).

SNO*:* J. Boger, R.L. Hahn, M. Yeh (BNL); F. Dalnoki-Veress, J. Farine, D.R. Grant, C.K. Hargrove, I. Levine, K. McFarlane, A.T. Noble, D. Sinclair, M. Starinsky (Carleton Univ.); E.D. Hallman, S. Luoma, M.H. Schwendener, R. Tafirout, C.J. Virtue (Laurentian Univ.); Y.D. Chan, X. Chen, K.T. Lesko, A.D. Marino E.B. Norman, C.E. Okada, A.W.P. Poon, R.G. Stokstad (LBNL); T.J. Bowles, M.R. Dragowsky, A. Hamer, A. Hime, J.B. Wilhelmy, J.M. Wouters (LANL); S. Biller, M.G. Bowler, J. Cameron, B. Cleveland, X. Dai, G. Doucas, J. Dunmore, H. Fergani K. Frame, N.A. Jelley, S. Majerus, N. McCauley, G. McGregor, D.L. Wark, N. West, J. Wilson (Univ. of Oxford); M.G. Boulay, M. Chen, F.A. Duncan, E.D. Earle, H.C. Evans, G.T. Ewan, A.L. Hallin, P.J. Harvey, J.D. Hepburn, H.W. Lee, J.R. Leslie, H.B. Mak, A.B. MacDonald, B.A. Moffat, B.C. Robertson, P. Skensved (Queen's Univ.); J. Heise, R.L. Helmer, T. Kutter, C.W. Nally, C.E. Waltham (Univ. of British Columbia); P. Jagam, J. Law, I.T. Lawson, J.J. Simpson (Univ. of Guelph); E.W. Beier, D.F. Cowen, W. Frati, W.?. Heintzelman, P.T. Keener, J.R. Klein, C.C.M. Kyba, M.S. Neubauer, S.M. Oser, V.L. Rusu, R.G. Van de Water, R. Van Berg (Univ. of Pennsylvania); T.V. Bullard, T.H. Burritt, G.A. Cox, P.J. Doe, C.A. Duba, S.R. Elliott, A.A. Hamian, R. Hazama, K.M. Heeger, M. Howe, J.L. Orrell, R.G.H. Robertson, K.K. Schaffer, M.W.E. Smith (Univ. of Washington).

KATRIN: Guido Drexlin, Klaus Eitel, Markus Steidl, Hans Bluemer (Karlsruhe); Vladimir Lobashev (Institute for Nuclear Research); Jochen Bonn, Ernst Otten, Christian Weinheimer (Mainz); Alexander Osipowicz (Fuldu Univ.); Dragoun Otokar (Univ. of Prague); R.G.H. Robertson (Univ. of Washington).

DAPS: F.McGirt, K. Moore, J. Moses (LANL).

Graduate and Postgraduate Advisors:

Thesis Advisor: Edward J. Ludwig (UNC)
Postdoc Advisors: T.J. Bowles (LANL) and R.G.H. Robertson (Univ. of Washington)

Thesis Advisor and Postgraduate-Scholar Sponsor:

Students:

Michael C. Browne (Los Alamos National Laboratory), Eric G. Wasserman (Personify), Q. Rushdy Ahmad (Sapient, Corp.) Pieter H. Mumm (Univ. of Washington), J.L. Orrell (Univ. of Washington), Kareem Kazkaz (Univ. of Washington), G. Adam Cox (Univ. of Washington).

Postdocs:

D.L. Wark (Rutherford Laboratory/Univ of Sussex), William Hamilton (Oak Ridge National Laboratory), Steven R. Elliott (Univ. of Washington), Jeff S. Nico (NIST), J.V. Germani (WRQ Corp.), Reena Meijer-Drees (Brooks Automation), T.D. Steiger (Cymer), Araz A. Hamian (Univ. of Washington), R. Hazama (Univ. of Washington).

SUMMARY PROPOSAL BUDGET — YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **University of Washington**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Wick C Haxton**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Wick C Haxton - none**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Janet M Conrad - none**	**0.00**	**0.00**	**0.00**	**0**	
3. **Sherry O Farwell - none**	**0.00**	**0.00**	**0.00**	**0**	
4. **Marvin L Marshak - none**	**0.00**	**0.00**	**0.00**	**0**	
5. **Senior Personnel - Total**	**84.00**	**0.00**	**0.00**	**782,500**	
6. (**1**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**6**) TOTAL SENIOR PERSONNEL (1 - 6)	**84.00**	**0.00**	**0.00**	**782,500**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**1**) POST DOCTORAL ASSOCIATES	**6.00**	**0.00**	**0.00**	**22,500**	
2. (**11**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**132.00**	**0.00**	**0.00**	**584,500**	
3. (**0**) GRADUATE STUDENTS				**0**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**9**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**225,000**	
6. (**66**) OTHER				**2,955,000**	
TOTAL SALARIES AND WAGES (A + B)				**4,569,500**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**1,370,850**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**5,940,350**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **Equipment** $ **2,750,000**					
TOTAL EQUIPMENT				**2,750,000**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**34,800**	
2. FOREIGN				**17,400**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**870,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**40,000**	
3. CONSULTANT SERVICES				**100,000**	
4. COMPUTER SERVICES				**70,000**	
5. SUBAWARDS				**15,644,290**	
6. OTHER				**2,000,000**	
TOTAL OTHER DIRECT COSTS				**18,724,290**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**27,466,840**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **Off-campus (Rate: 15.0000, Base: 9072453)**					
TOTAL INDIRECT COSTS (F&A)				**1,360,868**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**28,827,708**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **28,827,708**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*: **Wick C Haxton** DATE

ORG. REP. TYPED NAME & SIGNATURE* DATE

FOR NSF USE ONLY

INDIRECT COST RATE VERIFICATION

Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

Other Senior Personnel

Name - Title	Cal	Acad	Sumr	Funds Requested
Wilkerson, John F - none	**0.00**	**0.00**	**0.00**	**0**

SUMMARY PROPOSAL BUDGET — YEAR 2

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **University of Washington**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Wick C Haxton**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Wick C Haxton - none**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Janet M Conrad - none**	**0.00**	**0.00**	**0.00**	**0**	
3. **Sherry O Farwell - none**	**0.00**	**0.00**	**0.00**	**0**	
4. **Marvin L Marshak - none**	**0.00**	**0.00**	**0.00**	**0**	
5. **Senior Personnel - Total**	**156.00**	**0.00**	**0.00**	**1,557,875**	
6. (**1**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**6**) TOTAL SENIOR PERSONNEL (1 - 6)	**156.00**	**0.00**	**0.00**	**1,557,875**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**2**) POST DOCTORAL ASSOCIATES	**24.00**	**0.00**	**0.00**	**92,700**	
2. (**15**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**174.00**	**0.00**	**0.00**	**792,585**	
3. (**0**) GRADUATE STUDENTS				**0**	
4. (**4**) UNDERGRADUATE STUDENTS				**32,960**	
5. (**11**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**283,250**	
6. (**71**) OTHER				**3,229,050**	
TOTAL SALARIES AND WAGES (A + B)				**5,988,420**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**1,796,526**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**7,784,946**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **Equipment** $ **2,850,000**					
TOTAL EQUIPMENT				**2,850,000**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**38,334**	
2. FOREIGN				**19,167**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**1,052,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**49,000**	
3. CONSULTANT SERVICES				**105,400**	
4. COMPUTER SERVICES				**117,000**	
5. SUBAWARDS				**47,272,340**	
6. OTHER				**2,100,000**	
TOTAL OTHER DIRECT COSTS				**50,695,740**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**61,388,187**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **Off-campus (Rate: 15.0000, Base: 11265847)**					
TOTAL INDIRECT COSTS (F&A)				**1,689,877**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**63,078,064**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **63,078,064**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*: **Wick C Haxton** DATE

ORG. REP. TYPED NAME & SIGNATURE* DATE

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INDIRECT COST RATE VERIFICATION

Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET COMMENTS - Year 2

Other Senior Personnel

Name - Title	Cal	Acad	Sumr	Funds Requested
Wilkerson, John F - none	**0.00**	**0.00**	**0.00**	**0**

SUMMARY PROPOSAL BUDGET — YEAR 3

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **University of Washington**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Wick C Haxton**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Wick C Haxton - none**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Janet M Conrad - none**	**0.00**	**0.00**	**0.00**	**0**	
3. **Sherry O Farwell - none**	**0.00**	**0.00**	**0.00**	**0**	
4. **Marvin L Marshak - none**	**0.00**	**0.00**	**0.00**	**0**	
5. **Senior Personnel - Total**	**192.00**	**0.00**	**0.00**	**1,827,403**	
6. (**1**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**6**) TOTAL SENIOR PERSONNEL (1 - 6)	**192.00**	**0.00**	**0.00**	**1,827,403**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**3**) POST DOCTORAL ASSOCIATES	**36.00**	**0.00**	**0.00**	**143,222**	
2. (**19**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**228.00**	**0.00**	**0.00**	**1,065,675**	
3. (**4**) GRADUATE STUDENTS				**42,436**	
4. (**8**) UNDERGRADUATE STUDENTS				**67,898**	
5. (**16**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**424,362**	
6. (**78**) OTHER				**3,596,452**	
TOTAL SALARIES AND WAGES (A + B)				**7,167,448**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**2,150,232**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**9,317,680**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **Equipment** $ **2,950,000**					
TOTAL EQUIPMENT				**2,950,000**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**46,189**	
2. FOREIGN				**23,095**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**1,234,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**58,000**	
3. CONSULTANT SERVICES				**110,872**	
4. COMPUTER SERVICES				**139,000**	
5. SUBAWARDS				**40,721,466**	
6. OTHER				**2,200,000**	
TOTAL OTHER DIRECT COSTS				**44,463,338**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**56,800,302**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **Off-campus (Rate: 15.0000, Base: 13128833)**					
TOTAL INDIRECT COSTS (F&A)				**1,969,325**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**58,769,627**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **58,769,627**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*: **Wick C Haxton** DATE

ORG. REP. TYPED NAME & SIGNATURE* DATE

FOR NSF USE ONLY

INDIRECT COST RATE VERIFICATION

Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET COMMENTS - Year 3

Other Senior Personnel

Name - Title	Cal	Acad	Sumr	Funds Requested
Wilkerson, John F - none	**0.00**	**0.00**	**0.00**	**0**

SUMMARY PROPOSAL BUDGET

YEAR 4

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **University of Washington**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Wick C Haxton**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Wick C Haxton - none**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Janet M Conrad - none**	**0.00**	**0.00**	**0.00**	**0**	
3. **Sherry O Farwell - none**	**0.00**	**0.00**	**0.00**	**0**	
4. **Marvin L Marshak - none**	**0.00**	**0.00**	**0.00**	**0**	
5. **Senior Personnel - Total**	**240.00**	**0.00**	**0.00**	**2,177,261**	
6. (**1**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**6**) TOTAL SENIOR PERSONNEL (1 - 6)	**240.00**	**0.00**	**0.00**	**2,177,261**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**4**) POST DOCTORAL ASSOCIATES	**48.00**	**0.00**	**0.00**	**196,691**	
2. (**27**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**324.00**	**0.00**	**0.00**	**1,540,199**	
3. (**12**) GRADUATE STUDENTS				**131,127**	
4. (**8**) UNDERGRADUATE STUDENTS				**69,935**	
5. (**16**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**437,091**	
6. (**85**) OTHER				**3,982,990**	
TOTAL SALARIES AND WAGES (A + B)				**8,535,294**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**2,560,586**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**11,095,880**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **Equipment** $ **3,050,000**					
TOTAL EQUIPMENT				**3,050,000**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**52,192**	
2. FOREIGN				**26,096**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**1,416,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**67,000**	
3. CONSULTANT SERVICES				**116,918**	
4. COMPUTER SERVICES				**161,000**	
5. SUBAWARDS				**50,334,084**	
6. OTHER				**2,300,000**	
TOTAL OTHER DIRECT COSTS				**54,395,002**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**68,619,170**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **Off-campus (Rate: 15.0000, Base: 15235080)**					
TOTAL INDIRECT COSTS (F&A)				**2,285,262**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**70,904,432**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **70,904,432**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*: **Wick C Haxton** DATE

ORG. REP. TYPED NAME & SIGNATURE* DATE

FOR NSF USE ONLY

INDIRECT COST RATE VERIFICATION

Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET COMMENTS - Year 4

Other Senior Personnel

Name - Title	Cal	Acad	Sumr	Funds Requested
Wilkerson, John F - none	**0.00**	**0.00**	**0.00**	**0**

SUMMARY PROPOSAL BUDGET

YEAR 5

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **University of Washington**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Wick C Haxton**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Wick C Haxton - none**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Janet M Conrad - none**	**0.00**	**0.00**	**0.00**	**0**	
3. **Sherry O Farwell - none**	**0.00**	**0.00**	**0.00**	**0**	
4. **Marvin L Marshak - none**	**0.00**	**0.00**	**0.00**	**0**	
5. **Senior Personnel - Total**	**276.00**	**0.00**	**0.00**	**2,462,051**	
6. (**1**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**6**) TOTAL SENIOR PERSONNEL (1 - 6)	**276.00**	**0.00**	**0.00**	**2,462,051**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**5**) POST DOCTORAL ASSOCIATES	**48.00**	**0.00**	**0.00**	**253,239**	
2. (**29**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**342.00**	**0.00**	**0.00**	**1,704,583**	
3. (**16**) GRADUATE STUDENTS				**180,081**	
4. (**10**) UNDERGRADUATE STUDENTS				**90,041**	
5. (**18**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**506,479**	
6. (**93**) OTHER				**4,440,132**	
TOTAL SALARIES AND WAGES (A + B)				**9,636,606**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**2,890,982**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**12,527,588**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **Equipment** $ **3,150,000**					
TOTAL EQUIPMENT				**3,150,000**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**57,289**	
2. FOREIGN				**28,645**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**1,598,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**76,000**	
3. CONSULTANT SERVICES				**123,040**	
4. COMPUTER SERVICES				**183,000**	
5. SUBAWARDS				**36,817,941**	
6. OTHER				**2,400,000**	
TOTAL OTHER DIRECT COSTS				**41,197,981**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**56,961,503**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **Off-campus (Rate: 15.0000, Base: 16993560)**					
TOTAL INDIRECT COSTS (F&A)				**2,549,034**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**59,510,537**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **59,510,537**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*: **Wick C Haxton** DATE

ORG. REP. TYPED NAME & SIGNATURE* DATE

FOR NSF USE ONLY

INDIRECT COST RATE VERIFICATION

Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET COMMENTS - Year 5

Other Senior Personnel

Name - Title	Cal	Acad	Sumr	Funds Requested
Wilkerson, John F - none	**0.00**	**0.00**	**0.00**	**0**

SUMMARY PROPOSAL BUDGET

Cumulative

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Washington

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1.	**0.00**	**0.00**	**0.00**	$ **0**	$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**0**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**5**) POST DOCTORAL ASSOCIATES	**48.00**	**0.00**	**0.00**	**253,239**	
2. (**29**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**342.00**	**0.00**	**0.00**	**1,704,583**	
3. (**16**) GRADUATE STUDENTS				**180,081**	
4. (**10**) UNDERGRADUATE STUDENTS				**90,041**	
5. (**18**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**506,479**	
6. (**93**) OTHER				**4,440,132**	
TOTAL SALARIES AND WAGES (A + B)				**7,174,555**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**2,890,982**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**10,065,537**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **$ 3,150,000**					
TOTAL EQUIPMENT				**3,150,000**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**57,289**	
2. FOREIGN				**28,645**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**1,598,000**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**76,000**	
3. CONSULTANT SERVICES				**123,040**	
4. COMPUTER SERVICES				**183,000**	
5. SUBAWARDS				**36,817,941**	
6. OTHER				**2,400,000**	
TOTAL OTHER DIRECT COSTS				**41,197,981**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**54,499,452**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**0**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**54,499,452**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **54,499,452**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked / Date Of Rate Sheet / Initials - ORG

NSF Form 1030 (10/99) Supersedes all previous editions

C***SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)**

Work Breakdown Structure, Budget and Budget Explanation

Overview: The Project Description justifies and outlines the following management structure: The performing organization for this proposal is the South Dakota Board of Regents. The Regents will normally delegate management of the Laboratory to the Consortium for Underground Science, whose structure is described in the Project Description section on Project Management. The Consortium will assign various responsibilities for operations, management and construction at NUSL to the Board of Regents' universities.

The overall Work Breakdown Structure is as follows:

1. Site Development for Science
2. Site Development for Outreach
3. Science Operations
4. Outreach Operations
5. Site Operations and Administration
6. Site Maintenance
7. Detector Operations
8. Consortium Operations

The Budget tables and the Budget Explanation are organized according to this Work Breakdown Structure. All salary and wage rates are inflated from the stated amounts in FY2003 at 3% per year.

Facilities Development Budget: The Site Development Budgets are shown below in Tables B1 and B2. These tables estimate the costs of constructing facilities, regardless of whether the work is done by "in-house" staff or "contracted out." The estimated cost for each item in the Site Development Budget is shown at the left of each table. The bases for estimating these costs are discussed item-by-item in the text following the two tables. The other columns of Tables B1 and B2 distribute the site development costs for each item over the five years of this proposal period and apply a 3% per year inflationary increase to determine "then year" costs. In the rightmost column, the "then year" costs are aggregated for each item. At the bottom of each of Table B1 and Table B2, the site development costs are allocated between "in-house" and "contracted out" effort. The "in-house" effort is then further detailed in Tables B3 and B4, which estimate costs for WBS Items 1 and 2, respectively.

Operations Budgets: Table B5 through B10 list costs for WBS Items 3 through 8, respectively. The costs listed in Table B10 (WBS 8.0 Consortium Operations) are funded through the indirect costs on WBS Items 3 (Science Operations), 4 (Outreach Operations) and 7 (Detector Operations). The indirect costs on WBS Items 1 (Site Development for Science), 2 (Site Development for Outreach), 5 (site Operations and Administration) and 6 (Site Maintenance) will be assigned to the South Dakota institutions that perform the work.

Aggregate Budget: Table B11 aggregates the costs listed in Tables B1 through B9. Note that Table B10 is included in Table B11 only through the indirect costs in other tables. Table B11 provides the basis for the entries in the NSF Budget forms included in this proposal.

Notes: Notes to each table are included directly following the table.

Table B1: Site Development Budget for Science

Item		Total	FY2003		FY2004		FY2005		FY2006		FY2007		FY2003-2007
			F	Total	F	Total	F	Total	F	Total	F	Total	Total
	Lower Campus												
1	Lab Excavations and Finishes	$11,630,000	0.1	$1,163,000	0.2	$2,395,780	0.2	$2,467,653	0.3	$3,812,525	0.2	$2,617,933	$12,456,891
2	Control and Scientist Support Facilities	$3,980,000	0.2	$796,000	0.5	$2,049,700	0.3	$1,266,715					$4,112,415
3	Facilities for Detector Support Systems	$1,110,000	0.5	$555,000	0.5	$571,650							$1,126,650
4	Ultra-Low Bkgd. Facility/Equipment	$2,900,000			1.0	$2,987,000							$2,987,000
5	Refuge Room/Sump	$400,000	1.0	$400,000									$400,000
6	Cosmogenic Decay Storage Areas	$250,000	1.0	$250,000									$250,000
	Total for LC	**$20,270,000**		**$3,164,000**		**$8,004,130**		**$3,734,368**		**$3,812,525**		**$2,617,933**	**$21,332,956**
	Upper Campus												
7	Demolish and Clear Existing Structures	$5,000,000	0.2	$1,000,000	0.2	$1,030,000	0.3	$1,591,350	0.3	$1,639,091			$5,260,441
8	Renovate Existing Structures for Science, Administration	$5,000,000			0.2	$1,030,000	0.5	$2,652,250	0.3	$1,639,091			$5,321,341
9	New Science and AdministrationBldg.	$6,125,000			0.2	$1,261,750	0.3	$1,949,404	0.5	$3,346,476			$6,557,630
10	New Underground Space for Outreach												
11	Receiving and Warehousing	$3,750,000			0.2	$772,500	0.3	$1,193,513	0.5	$2,048,863			$4,014,876
	Total for UC	**$19,875,000**		**$1,000,000**		**$4,094,250**		**$7,386,516**		**$8,673,521**			**$21,154,287**
	Access												
12	Road Improvements and Parking	$1,500,000			0.2	$309,000	0.2	$318,270	0.3	$491,727	0.3	$506,479	$1,625,476
13	Immediate Shaft and Cage Improvements	$8,500,000	0.2	$1,700,000	0.5	$4,377,500	0.3	$2,705,295					$8,782,795
14	Drifts at 7400 Level	$20,210,000	0.2	$4,042,000	0.6	$12,489,780	0.2	$4,288,158					$20,819,938
15	Ramp System Improvements	$1,500,000	0.2	$300,000	0.8	$1,236,000							$1,536,000
16	Yates Shaft Improvements	$30,710,000					0.2	$6,516,048	0.3	$10,067,294	0.5	$17,282,188	$33,865,529
17	Underground Handling & Transport	$1,625,000	0.2	$325,000	0.2	$334,750	0.2	$344,793	0.2	$355,136	0.2	$365,790	$1,725,469
	Total Access	**$64,045,000**		**$6,367,000**		**$18,747,030**		**$14,172,563**		**$10,914,157**		**$18,154,457**	**$68,355,207**
	Systems												
18	Lower Campus System Upgrades	$21,500,000	0.1	$2,150,000	0.2	$4,429,000	0.2	$4,561,870	0.3	$7,048,089	0.2	$4,839,688	$23,028,647
19	Upper Campus System Upgrades	$3,000,000	0.1	$300,000	0.1	$309,000	0.3	$954,810	0.3	$983,454	0.2	$675,305	$3,222,570
20	Lower Campus Isolation Systems	$500,000	0.1	$50,000	0.2	$103,000	0.2	$106,090	0.3	$163,909	0.2	$112,551	$535,550
21	Sealing Unused Areas	$400,000	0.4	$160,000	0.4	$164,800	0.2	$84,872					$409,672
	Total Systems	**$25,400,000**		**$2,660,000**		**$5,005,800**		**$5,707,642**		**$8,195,453**		**$5,627,544**	**$27,196,439**
	Sub-Total	**$129,590,000**		**$13,191,000**		**$35,851,210**		**$31,001,089**		**$31,595,655**		**$26,399,935**	**$138,038,889**
22	**EDIA (12%)**	**$15,550,800**		**$1,582,920**		**$4,302,145**		**$3,720,131**		**$3,791,479**		**$3,167,992**	**$16,564,667**
23	**Contingency (25%)**	**$32,397,500**		**$3,297,750**		**$8,962,803**		**$7,750,272**		**$7,898,914**		**$6,599,984**	**$34,509,722**
	Total Laboratory	**$177,538,300**		**$18,071,670**		**$49,116,158**		**$42,471,492**		**$43,286,047**		**$36,167,910**	**$189,113,278**
24	**Subtract WBS-1**			**$3,621,600**		**$3,669,141**		**$3,718,108**		**$3,768,544**		**$3,820,494**	**$18,597,887**
	Sub-Contracted			**$14,450,070**		**$45,447,017**		**$38,753,384**		**$39,517,503**		**$32,347,417**	**$170,515,391**

Table B2: Site Development Budget for Outreach

Item		Total	FY2003		FY2004		FY2005		FY2006		FY2007		FY2003-2007
			F	Total	F	Total	F	Total	F	Total	F	Total	Total
	Lower Campus												
1	Lab Excavations and Finishes	$500,000	0.1	$50,000	0.2	$103,000	0.2	$106,090	0.3	$163,909	0.2	$112,551	$535,550
2	Control and Scientist Support Facilities												
3	Facilities for Detector Support Systems												
4	Ultra-Low Bkgd. Facility/Equipment												
4	Refuge Room/Sump												
5	Cosmogenic Decay Storage Areas												
6	**Total for LC**	**$500,000**		**$50,000**		**$103,000**		**$106,090**		**$163,909**		**$112,551**	**$535,550**
	Upper Campus												
7	Demolish and Clear Existing Structures												
8	Renovate Existing Structures for Science, Administration												
9	New Science and AdministrationBldg.												
10	New Underground Space for Outreach	$14,000,000	0.1	$1,400,000	0.1	$1,442,000	0.1	$1,485,260	0.5	$7,649,089	0.2	$3,151,425	$10,800,514
11	Receiving and Warehousing												
	Total for UC	**$14,000,000**		**$1,400,000**		**$1,442,000**		**$1,485,260**		**$7,649,089**		**$3,151,425**	**$15,127,774**
	Access												
12	Road Improvements and Parking	$1,500,000			0.2	$309,000	0.2	$318,270	0.3	$491,727	0.3	$506,479	$1,625,476
13	Immediate Shaft and Cage Improvements												
14	Drifts at 7400 Level												
15	Ramp System Improvements												
16	Yates Shaft Improvements												
17	Underground Handling & Transport												
	Total Access	**$1,500,000**		**$0**		**$309,000**		**$318,270**		**$491,727**		**$506,479**	**$1,625,476**
	Systems												
18	Lower Campus System Upgrades	$610,000	0.1	$61,000	0.2	$125,660	0.2	$129,430	0.3	$199,969	0.2	$137,312	$653,371
19	Upper Campus System Upgrades	$250,000	0.1	$25,000	0.1	$25,750	0.3	**$79,568**	**0.3**	**$81,955**	**0.2**	**$56,275**	**$268,547**
20	Lower Campus Isolation Systems												
21	Sealing Unused Areas												
	Total Systems	**$860,000**		**$86,000**		**$151,410**		**$208,997**		**$281,924**		**$193,588**	**$921,918**
	Sub-Total	**$16,860,000**		**$1,536,000**		**$2,005,410**		**$2,118,617**		**$8,586,649**		**$3,964,042**	**$18,210,718**
22	**EDIA (12%)**	**$2,023,200**		**$184,320**		**$240,649**		**$254,234**		**$1,030,398**		**$475,685**	**$2,185,286**
23	**Contingency (25%)**	**$4,215,000**		**$384,000**		**$501,353**		**$529,654**		**$2,146,662**		**$991,011**	**$4,552,680**
	Total Laboratory	**$23,098,200**		**$2,104,320**		**$2,747,412**		**$2,902,506**		**$11,763,709**		**$5,430,738**	**$24,948,684**
24	**Subtract WBS-2**			**$910,100**		**$922,089**		**$934,424**		**$947,128**		**$960,214**	**$4,673,955**
	Sub-Contracted			**$1,194,220**		**$1,825,323**		**$1,968,082**		**$10,816,581**		**$4,470,524**	**$20,274,729**

Notes for Tables B1 and B2:

Line 1: Laboratory Excavations and Finishes—This item includes the cost of excavating one 40,000 m^3 general purpose laboratory and five individual detector laboratories aggregating 42,500 m^3. It also includes the cost of rockbolting and shotcreting the ceiling and walls of each laboratory, as necessary, and the cost of a poured concrete floor in each laboratory. The systems outfitting required to bring bring electrical, HVAC, communications and safety systems into each laboratory is covered in Item 18. Laboratory cranes and other materials handling equipment are included in Item 17. Costs for excavation and ground support are based on Homestake experience, modified by the increased rockbolting and shotcreting requirements for civil construction. Concrete floor and outfitting costs are based on costs for the MINOS Far Detector Laboratory construction at Soudan, scaled for laboratory configuration and size, inflation and Davis-Bacon wage differentials.

Line 2: Control and Science Support Facilities—The Facilities Plan envisions the construction of a 38,200 gsf, five-story science office and work area "building" adjacent to the 40,000 m^3 general purpose laboratory. This cost estimate assumes the same excavation, rock bolting, shotcreting and concrete floor costs as laboratory cavern volume, but then adds $50 per gsf for interior structural support, floors, walls, HVAC, plumbing, electrical, communications and safety systems and finishes. This item also includes the cost of domestic water supply and sewage treatment to reduce volume prior to conveyance to the surface and disposal in the municipal sewage system.

Line 3: Facilities for Detector Support Systems—Detectors will likely require purification, non-interruptible power and other mechanical and electrical support systems. This item includes the cost of excavating and finishing space for such systems, but not for the systems themselves, which will be considered detector costs. Estimates are based on the same assumptions as the cost of preparing laboratory space, scaled to a floor area of 7,320 gsf and a volume of 5,800 m^3, i.e. a ceiling height of 8.5 m.

Line 4: Ultra-Low Background Counting Facility and Equipment—An ultra-low background counting facility is the first detector laboratory that will be developed at HNUL. This item includes excavation and preparation of a 6 m by 6 m by 4 m high room surrounded on all sides by 4 m of ultrapure water to reduce neutron and shielding backgrounds as well as $0.5 million for initial instrumentation of the facility.

Line 5: Refuge Room and Sump—Although HNUL will maintain two and eventually three independent exits from the 7400 foot level, a sealable refuge room with an independent air supply and stored food and water will provide an additional safety option. The refuge room will have a floor area of 120 m^2 and be stocked with food for 100 people for 5 days. The water shielding in the low background counting facility will provide more than sufficient water. Normally, this area will be used as a sump, collecting any water runoff at the 7400 foot level, so that it can be pumped to the surface.

Line 6: Cosmogenic Decay Storage Areas—Low background detectors generally benefit from storage of fabrication materials deep underground for periods of at least 6 months in order to reduce cosmogenic backgrounds. These funds will enable refurbishment of existing cavities at or around the 7400 foot level for this purpose.

Line 7: Demolish and Clear Existing Structures—The Homestake site includes a number of warehouse and shop structures of little historical or practical value. This item will fund the demolition and removal of these structures, as well as the landscaping and re-vegetation of the site as a scientific laboratory and site of major public interest.

Line 8: Renovate Existing Structures for Science, Administration—The mine administration building, the mine safety building and, possibly, the mine foundry building have practical and/or historic value and can be renovated for use for science and administrative and technical functions. This item will fund renovation of 25,000 gsf at $200 per gsf. This unit price is higher than the unit price for new construction because of the inefficiencies and hidden costs that are always associated with renovations.

Line 9: New Building for Science and Administration—An additional 35,000 gsf for science, technical and administrative support on the Upper Campus will be provided in a new structure estimated at a cost of $175 per sq. ft. This relatively high unit price is intended to construct a high-quality with a design life of 50 years and a "signature" appearance that is appropriate for an important American science site.

Line 10: New Underground Space for Outreach—This proposal envisions on and off-site public outreach as a highly important function for HNUL. The initial design capacity is 1,500 people per day with a peak capacity of 750 people on site, 500 people indoors on the Upper Campus at one time. The design in this proposal envisions 80,000 gsf at $175 per sq. ft. Ninety percent of this space would be used for direct public contact, the remaining space would house staff for both on-site and off-site outreach programs.

The public visit to HNUL is intended to be a "destination experience," although many visitors would combine a day at HNUL with visits to other important sites in the Black Hills. While the visitor experience at HNUL would

focus on science, the interpretative program would also highlight the relationship of Homestake to Native American culture, expansion in the American West and the development of American technology. Because the essence of Homestake is the underground environment, we believe it is appropriate to place most or all of the outreach facilities underground, so that every visitor will have an underground experience. Most of the outreach space will be in the near-surface underground, so that emergency egress can be provided by short horizontal or near horizontal tunnels, which exit the ground because of the slope of the terrain.

The final design for the outreach space will emerge from the usual architectural/engineering design process. Conceptually, we envision a very small surface structure with limited office space leading visitors directly to a downward-ramping, handicapped-accessible helix, which will present visitors with a variety of interpretative and interactive displays as they slowly spiral down into the depths of the earth to seek answers to the mysteries of the Cosmos. An open core of the helix will provide a light shaft reaching to the sky over an underground food service area. The underground level will contain additional interpretative space, classroom-type space for orienting school groups, a gift shop, space for lavatories and other services and a ticket-selling and organizing area for deep underground tours. The additional interpretative space would include a multi-media presentation area to orient HNUL visitors. During the design process, we intend to investigate the financial and programmatic feasibility of constructing the world's only underground IMAX theater with programming similar to that of the IMAX theater at Cape Kennedy. A feasible IMAX theater plan would likely include corporate sponsorship. The IMAX theater is *not* included in this proposal.

Line 11: Receiving and Warehousing—Space is required for receiving, checking and inventorying detector elements and other equipment and supplies as they arrive. This space will include an indoor loading dock, capable of handling a semi-trailer and a direct, enclosed freight-only access to the Yates Shaft. The cost includes 25,000 gsf of air-conditioned and 25,000 gsf of unheated warehouse space at an average cost of $75 per sq. ft.

Line 12: Road Improvements and Parking—HNUL will generate two to three times as much traffic as recent operations at the Homestake Mine. Furthermore, visitor traffic will primarily consist of people unfamiliar with the area, some of whom will arrive in buses, motorhomes, trailers and other large vehicles. For these reasons, significant improvements are required in the roadway layout and in the number and size of parking spaces. The exact Upper Campus layout will emerge from a design process by qualified professionals. Conceptually, we envision a roadway scheme that will separate staff and visiting scientist, public visitors and freight traffic, likely leading them at different elevation levels along the hillside to their designated entrance to HNUL in the vicinity of the Yates shaft. On-site parking will be limited to about 300 vehicles, which will likely be sufficient nine months of the year. HNUL will seek to make off-site parking and shuttle bus arrangements with the City of Lead and, possibly, the City of Deadwood, in order to accommodate peak summer visitor traffic.

Line 13: Immediate Shaft and Cage Improvements—The major cost in this item is the improvement of the Yates shaft from the surface down to the 4,850 foot level. This process will replace wooden supports with steel sets, leaving most of the current shaft cross-section open for a new hoist and cage, that will accommodate 20 foot sea containers. Replacement of wooden sets will increase the safety of the shaft by removing combustible material and will eliminate the necessity to constantly flow water down the shaft in order to lubricate and humidify the wooden sets. These funds will also permit sealing and other cosmetic improvements to the cages in both the Yates and Ross shafts, in order to move equipment and personnel underground in cleaner and more pleasant surroundings. These costs are based on estimates by Dynatec, Ltd., a major North American mining contractor (see Appendix C).

Line 14: Drifts at the 7400 Level—The main development at the 7400 foot level will include a ~1,000 m drift 5.5 m by 5.5 m in cross-section and a roughly parallel drift 3.6 m by 3.6 m in cross-section for a return flow of ventilation. This item also includes an aggregate of 300 m of each of these two drift sizes for two-way access to each detector laboratory. The cost estimated here for the main access drift includes finishing to the highest civil construction standards with good ground support, a strong shotcrete lining, high-intensity lighting and a smooth concrete roadway and covered drainage ditch. Because the smaller drift will be used principally for ventilation and emergency egress, the design finish level is to a lower standard. The cost estimates are based on Homestake experience and cost estimates by Dynatec with regard to excavation and basic ground support and from experience at Soudan with respect to finish and systems.

Line 15: Ramp System Improvements—There are two current accesses from the 4850 foot level—the current bottom of the Yates and Ross shafts—to the 7400 foot level, where the main science laboratory development will occur. One access is the No. 6 winze. The other is a system of downward sloping ramps. This item is intended to improve the existing ramp system with rock stabilization as necessary, removal of tights, some lighting and signage, grading of the roadway and channeling of drainage. The goal would be a roadway system navigable by standard

low-emission diesel, four-wheel drive vehicles at speeds of 5-10 mph. The ramp system would also be used to transport large and heavy items from the bottom of either shaft to the 7400 foot, main laboratory level. The ramp system improvement work would be done with in-house staff. The cost estimates are based on an engineering inspection of the existing system and previous underground construction experience.

Line 16: Yates Shaft Improvements—This item includes considerable work to significantly increase the functionality of the Yates shaft for both science and outreach missions of HNUL. First, a 2 m diameter raise will be bored upward from the 7400 foot level to the 4850 foot level. Then the shaft will be bored downward fullsize from the 4850 level back to the 7400 level. The muck from both these operations will be loaded at the 7400 foot level, the bottom of the new shaft, and hauled down the new transverse drift described in Item 14 and then up the ramp system and, possibly up the Ross shaft, and distributed in unused areas of the mine. The new portion of the shaft will be lined with steel sets, so that the entire shaft will not contain combustible material. When the Yates shaft is finished full cross-section from surface to the 7400 foot level, the existing cage and hoist system will be removed and replaced with a freight hoist capable of handling standard 20 foot sea containers with a weight capacity of 15 tons and a smaller, high speed personnel hoist. The drives for the new hoisting system will be installed in a new hoist house with a new headframe. This item also includes the cost of a new shaft station at the 7400 foot level. The costs of this entire set of improvements have been estimated by Dynatec, Ltd.

Line 17: Underground Materials Handling and Transport Systems—Underground materials handling includes the cost of transport vehicles for equipment in the horizontal drifts and bridge cranes and other rigging equipment in the detector laboratories. This item also includes the cost of standard low-emission diesel-powered, 4-wheel drive vehicles for transport of personnel equipment in the underground drifts and in the ramp system. These cost estimates are based on experience with the cost of materials handling equipment in the Soudan Laboratory and list prices for vehicles.

Line 18: Lower Campus System Upgrades—Item 1 includes only the cost of excavating and surface finishing of the underground laboratories and support space. This item cover the cost of electrical, HVAC, plumbing, safety, communications, clean room and other systems in the entire Lower Campus area including the detector laboratories and the support space. The costs have been estimated from experience with "outfitting" costs for the MINOS Far Detector Laboratory at Soudan, scaled to the size of HNUL and modified by Davis-Bacon wage differentials. Clean room costs, not relevant at Soudan, have been estimated from catalog prices for pre-assembled clean rooms with an allowance for increased installation costs of working underground.

Line 19: Upper Campus System Upgrades—The Homestake Mine has reliable, redundant power supplies from multiple substations of Black Hills Power and Light. However, the on-site electrical distribution system, including step-down transformers, would benefit from some renovation. Operating costs could be decreased if the ventilation system is equipped with modern, variable speed motor controls. HNUL may wish to separate its treatment system for pumped mine water from the present system, which will continue to be owned by the Homestake Mining Corporation for the foreseeable future, in order to simplify permitting and discharge responsibility. New construction and renovation on the surface will require updated communications systems. The costs in this item are based on work by Dunham Associates, but have considerable uncertainty that can only be resolved when the conditions of the land transfer from the Homestake Mining Corporation are more clearly defined.

Line 20: Lower Campus Isolation Systems—Personnel and equipment safety will be primary concerns of HNUL. The entire Lower Campus will have a system of fire-rated and, in some cases, explosion-rated barriers with automatic closure on alarm in order to contain any event that threatens safety or personnel or equipment. This item will fund installation of barriers, doors and automatic closure systems. The cost has been estimated based on underground construction experience in human-occupied space.

Line 21: Sealing Unused Underground Areas—Both safety and operating cost considerations suggest that unused underground area should be sealed to minimize airflow to feed a spontaneous combustion fire and to keep smoke from spreading into the occupied areas of the mine. This item will fund construction of fire-rated barriers to block off unused area. These barriers will allow drainage, so that water does not build up in these areas. Some barriers will also have fire-rated and sealed doors which opened to permit access to the unused areas for future rock disposal. These costs are based on estimates by Dynatec, Ltd.

Line 22: EDIA—EDIA is calculated at 12% of the total laboratory development cost.

Line 23: Contingency—Contingency is included at 25% of the total laboratory development cost.

Line 24: Subtract WBS-1 (Science), WBS-2 (Outreach)—These Facilities tables estimate the overall cost of developing facilities for science and outreach at HNUL. WBS-1 and WBS-2 describe development activities that are carried out "in house." The WBS or "in-house" amounts are subtracted from the total facilities development amounts to determine amounts for work to be sub-contracted to outside firms.

Table B3: WBS-1 Site Development for Science

	FY2003		2004		2005		2006		2007		FY2003-2007
	N	Total	N	Total	N	Total	N	Total	N	Total	Total
Senior Personnel											
Assistant Manager	0.8	$60,000	0.8	$61,800	0.8	$63,654	0.8	$65,564	0.8	$67,531	$318,548
Total Senior Personnel		$60,000		$61,800		$63,654		$65,564		$67,531	$318,548
Other Personnel											
Postdoctoral Associates											
Other Professionals	1.6	$80,000	1.6	$82,400	1.6	$84,872	1.6	$87,418	1.6	$90,041	$424,731
Graduate Students											
Undergraduate Students											
Secretarial-Clerical	0.8	$20,000	0.8	$20,600	0.8	$21,218	0.8	$21,855	0.8	$22,510	$106,183
Other (Developers)	20	$900,000	20	$927,000	20	$954,810	20	$983,454	20	$1,012,958	$4,778,222
Total Salaries and Wages		$1,060,000		$1,091,800		$1,124,554		$1,158,291		$1,193,039	$5,627,684
Fringe Benefits (30%)		$318,000		$327,540		$337,366		$347,487		$357,912	$1,688,305
Total Salaries, Wages and FB		$1,378,000		$1,419,340		$1,461,920		$1,505,778		$1,550,951	$7,315,989
Equipment		$1,800,000		$1,800,000		$1,800,000		$1,800,000		$1,800,000	$9,000,000
Domestic Travel		$4,000		$4,000		$4,000		$4,000		$4,000	$20,000
Foreign Travel		$2,000		$2,000		$2,000		$2,000		$2,000	$10,000
Other Direct Costs											
Materials and Supplies		$200,000		$200,000		$200,000		$200,000		$200,000	$1,000,000
Publication/ Documentation / Dissemination											
Consultant Services											
Computer Services											
Sub-Awards											
Other (Utilities)											
Total Other Direct Costs											
Total Direct Costs		$3,384,000		$3,425,340		$3,467,920		$3,511,778		$3,556,951	$17,345,989
Indirect Costs (15%)		$237,600		$243,801		$250,188		$256,766		$263,543	$1,251,898
Total Direct and Indirect Costs		$3,621,600		$3,669,141		$3,718,108		$3,768,544		$3,820,494	$18,597,887

Notes: Salary and wage rates used for FY2003: Assistant Manager—$75,000; Other professional (engineer; surveyor, administrative manager, etc.)—$50,000; Developer (Miner, equipment operator, blaster, etc.)—$45,000; Secretarial-clerical: $25,000. Equipment includes drills, loaders, person lifts, graders, trucks, etc. Materials and supplies includes drill bits, explosives, blasting caps, lubricants, fuel oil, etc. Indirects are assessed on total direct cost excluding equipment.

Table B4: WBS-2 Site Development for Outreach

	2002		2003		2004		2005		2006		2002-2006
	N	Total	N	Total	N	Total	N	Total	N	Total	Total
Senior Personnel											
Assistant Manager	0.2	$15,000	0.2	$15,450	0.2	$15,914	0.2	$16,391	0.2	$16,883	$79,637
Total Senior Personnel		$15,000		$15,450		$15,914		$16,391		$16,883	$79,637
Other Personnel											
Postdoctoral Associates											
Other Professionals	0.4	$22,000	0.4	$22,660	0.4	$23,340	0.4	$24,040	0.4	$24,761	$116,801
Graduate Students											
Undergraduate Students											
Secretarial-Clerical	0.2	$5,000	0.2	$5,150	0.2	$5,305	0.2	$5,464	0.2	$5,628	$26,546
Other (Developers)	5	$225,000	5	$231,750	5	$238,703	5	$245,864	5	$253,239	$1,194,556
Total Salaries and Wages		$267,000		$275,010		$283,260		$291,758		$300,511	$1,417,539
Fringe Benefits (30%)		$80,100		$82,503		$84,978		$87,527		$90,153	$425,262
Total Salaries, Wages and FB		$347,100		$357,513		$368,238		$379,286		$390,664	$1,842,801
Equipment		$450,000		$450,000		$450,000		$450,000		$450,000	$2,250,000
Domestic Travel		$2,000		$2,000		$2,000		$2,000		$2,000	$10,000
Foreign Travel		$1,000		$1,000		$1,000		$1,000		$1,000	$5,000
Other Direct Costs											
Materials and Supplies		$50,000		$50,000		$50,000		$50,000		$50,000	$250,000
Publication/ Documentation / Dissemination											
Consultant Services											
Computer Services											
Sub-Awards											
Other (Utilities)											
Total Other Direct Costs											
Total Direct Costs		$850,100		$860,513		$871,238		$882,286		$893,664	$4,357,801
Indirect Costs (15%)		$60,000		$61,576		$63,186		$64,842		$66,550	$316,154
Total Direct and Indirect Costs		$910,100		$922,089		$934,424		$947,128		$960,214	$4,673,955

Notes: Salary and wage rates used for FY2003: Assistant Manager—$75,000; Other professional (engineer; surveyor, administrative manager, etc.)—$50,000; Developer (Miner, equipment operator, blaster, etc.)—$45,000; Secretarial-clerical: $25,000. Equipment includes drills, loaders, person lifts, graders, trucks, etc. Materials and supplies includes drill bits, explosives, blasting caps, lubricants, fuel oil, etc. Indirects are assessed on total direct cost excluding equipment.

Table B5: WBS-3 Science Operations

	FY2003		FY2004		FY2005		FY2006		FY2007		FY2003-2007
	N	Total	N	Total	N	Total	N	Total	N	Total	Total
Senior Personnel											
Laboratory Director	0.7	$122,500	0.7	$126,175	0.7	$129,960	0.7	$133,859	0.7	$137,875	$650,369
A.D.-Science			1	$154,500	1	$159,135	1	$163,909	1	$168,826	$646,370
A.D.-Operations	1	$150,000	1	$154,500	1	$159,135	1	$163,909	1	$168,826	$796,370
P.S.-Theory			1	$128,750	1	$132,613	1	$136,591	1	$140,689	$538,642
P.S-Physics	1	$125,000	1	$128,750	1	$132,613	1	$136,591	1	$140,689	$663,642
P.S.-Astrophysics	0.5	$62,500	1	$128,750	1	$132,613	1	$136,591	1	$140,689	$601,142
P.S.-Geophysics			1	$128,750	1	$132,613	1	$136,591	1	$140,689	$538,642
P.S.-Analytical Methods	0.5	$62,500	1	$128,750	1	$132,613	1	$136,591	1	$140,689	$601,142
P.S.-Biology			1	$128,750	1	$132,613	1	$136,591	1	$140,689	$538,642
Associate Scientists					1	$79,568	3	$245,864	4	$337,653	$663,084
Assistant Scientists					1	$63,654	3	$196,691	5	$337,653	$597,998
Total Senior Personnel		$522,500		$1,207,675		$1,387,127		$1,723,777		$1,994,964	$6,836,043
Other Personnel											
Postdoctoral Associates	0.5	$22,500	2	$92,700	3	$143,222	4	$196,691	5	$253,239	$708,352
Other Professionals	4.5	$247,500	6.5	$368,225	8.5	$495,971	14.5	$871,450	15.5	$959,496	$2,942,642
Graduate Students					2	$42,436	6	$131,127	8	$180,081	$353,645
Undergraduate Students			2	$32,960	4	$67,898	4	$69,935	5	$90,041	$260,833
Secretarial-Clerical	2	$50,000	4	$103,000	6	$159,135	6	$163,909	7	$196,964	$673,008
Other											
Total Salaries and Wages		$842,500		$1,804,560		$2,295,788		$3,156,888		$3,674,786	$11,774,522
Fringe Benefits (30%)		$252,750		$541,368		$688,736		$947,066		$1,102,436	$3,532,357
Total Salaries, Wages and Fringe Benefits		$1,095,250		$2,345,928		$2,984,524		$4,103,955		$4,777,222	$15,306,879
Equipment											
Domestic Travel		$15,400		$15,862		$16,338		$16,828		$17,333	$81,761
Foreign Travel		$7,700		$7,931		$8,169		$8,414		$8,666	$40,880
Other Direct Costs											
Materials and Supplies		$10,000		$15,000		$20,000		$25,000		$30,000	$100,000
Publication/Documentation/ Dissemination		$10,000		$15,000		$20,000		$25,000		$30,000	$100,000
Consultant Services		$10,000		$11,000		$12,000		$13,500		$15,000	$61,500
Computer Services		$10,000		$15,000		$20,000		$25,000		$30,000	$100,000

Table B5 (Continued)

Sub-Awards											
Other											
Total Other Direct Costs		$40,000		$56,000		$72,000		$88,500		$105,000	$361,500
Total Direct Costs		$1,158,350		$2,425,721		$3,081,031		$4,217,697		$4,908,221	$15,791,020
Indirect Costs (15%)		$173,753		$363,858		$462,155		$632,655		$736,233	$2,368,653
Total Direct and Indirect Costs		$1,332,103		$2,789,579		$3,543,185		$4,850,351		$5,644,455	$18,159,673

Notes: A.D. is Associate Director. P.S. is Principal Scientist. FY2003 salaries are Director: $175,000; Associate Director: $150,000; Principal Scientist: $125,000; Associate Scientst: $75,000; Assistant Scientist: $60,000; Postdoctoral Associate: $45,000; Other Professionals (Engineers, Technicians, etc.): $55,000; Graduate Students (FTE): $45,000; Undergraduate Students: $30,000; Secretarial-Clerical: $25,000.

Table B6: WBS-4 Outreach Operations

	FY2003		FY2004		FY2005		FY2006		FY2007		FY2003-2007
	N	Total	N	Total	N	Total	N	Total	N	Total	Total
Senior Personnel											
Laboratory Director	0.2	$35,000	0.2	$36,050	0.2	$37,132	0.2	$38,245	0.2	$39,393	$185,820
A.D.-Outreach			1.0	$82,400	1.0	$84,872	1.0	$87,418	1.0	$90,041	$344,731
Total Senior Personnel		$35,000		$118,450		$122,004		$125,664		$129,434	$530,551
Other Personnel											
Postdoctoral Associates											
Other Professionals	0.5	$25,000	1	$51,500	1.5	$79,568	2	$109,273	3	$168,826	$434,167
Graduate Students											
Undergraduate Students											
Secretarial-Clerical	1	$25,000	1	$25,750	2	$53,045	2	$54,636	2	$56,275	$214,707
Other	1	$30,000	4	$123,600	8	$254,616	12	$393,382	16	$540,244	$1,341,842
Total Salaries and Wages		$115,000		$319,300		$509,232		$682,954		$894,780	$2,521,266
Fringe Benefits (30%)		$34,500		$95,790		$152,770		$204,886		$268,434	$756,380
Total Salaries, Wages and FB		$149,500		$415,090		$662,002		$887,841		$1,163,213	$3,277,646
Equipment											
Domestic Travel		$1,400		$2,472		$3,607		$4,808		$7,203	$19,490
Foreign Travel		$700		$1,236		$1,804		$2,404		$3,602	$9,745
Other Direct Costs											
Materials and Supplies		$10,000		$12,000		$14,000		$16,000		$18,000	$70,000
Publication/Documentation/ Dissemination		$10,000		$12,000		$14,000		$16,000		$18,000	$70,000
Consultant Services		$10,000		$12,000		$14,000		$16,000		$18,000	$70,000
Computer Services		$10,000		$12,000		$14,000		$16,000		$18,000	$70,000
Sub-Awards											
Other											
Total Other Direct Costs		$40,000		$48,000		$56,000		$64,000		$72,000	$280,000
Total Direct Costs		$191,600		$466,798		$723,412		$959,053		$1,246,018	$3,586,881
Indirect Costs (15%)		$28,740		$70,020		$108,512		$143,858		$186,903	$538,032
Total Direct and Indirect Costs		$220,340		$536,818		$831,924		$1,102,911		$1,432,921	$4,124,913

Notes: A.D. is Associate Director. FY2003 salaries are Director: $175,000; Associate Director: $80,000; Other Professionals (Educators, Designers, etc.): $50,000; Secretarial-Clerical: $25,000.

Table B7: WBS-5 Site Operations and Administration

	FY2003		FY2004		FY2005		FY2006		FY2007		FY2003-2007
	N	Total	N	Total	N	Total	N	Total	N	Total	Total
Senior Personnel											
Assistant Manager	1	$75,000	1	$77,250	1	$79,568	1	$81,955	1	$84,413	$398,185
Total Senior Personnel		$75,000		$77,250		$79,568		$81,955		$84,413	$398,185
Other Personnel											
Postdoctoral Associates											
Other Professionals	2	$100,000	3	$154,500	4	$212,180	4	$218,545	4	$225,102	$910,327
Graduate Students											
Undergraduate Students											
Secretarial-Clerical	4	$100,000	4	$103,000	5	$132,613	5	$136,591	6	$168,826	$641,030
Other (Operators)	20	$900,000	20	$927,000	20	$954,810	20	$983,454	20	$1,012,958	$4,778,222
Total Salaries and Wages		$1,175,000		$1,261,750		$1,379,170		$1,420,545		$1,491,299	$6,727,764
Fringe Benefits (30%)		$352,500		$378,525		$413,751		$426,164		$447,390	$2,018,329
Total Salaries, Wages and FB		$1,527,500		$1,640,275		$1,792,921		$1,846,709		$1,938,689	$8,746,094
Equipment											
Domestic Travel		$6,000		$7,000		$8,000		$9,000		$10,000	$40,000
Foreign Travel		$3,000		$3,500		$4,000		$4,500		$5,000	$20,000
Other Direct Costs											
Materials and Supplies		$500,000		$600,000		$700,000		$800,000		$900,000	$3,500,000
Publication/Documentation/Dissemination		$10,000		$11,000		$12,000		$13,000		$14,000	$60,000
Consultant Services		$40,000		$41,200		$42,436		$43,709		$45,020	$212,365
Computer Services		$25,000		$30,000		$35,000		$40,000		$45,000	$175,000
Sub-Awards											
Other (Utilities, Insurance)		$2,000,000		$2,100,000		$2,200,000		$2,300,000		$2,400,000	$11,000,000
Total Other Direct Costs		$2,575,000		$2,782,200		$2,989,436		$3,196,709		$3,404,020	$14,947,365
Total Direct Costs		$4,111,500		$4,432,975		$4,794,357		$5,056,918		$5,357,709	$23,753,459
Indirect Costs (15%)		$616,725		$664,946		$719,154		$758,538		$803,656	$3,563,019
Total Direct and Indirect Costs		$4,728,225		$5,097,921		$5,513,511		$5,815,455		$6,161,366	$27,316,478

Notes: Salary and wage rates used for FY2003: Assistant Manager—$75,000; Other professional (engineer; surveyor, administrative manager, etc.)—$50,000; Developer (Machinery operator, equipment operator, etc.)—$45,000; Secretarial-clerical: $25,000. Materials and supplies include spare parts, lubricants, fuel oil, etc. Indirects are assessed on total direct cost excluding equipment.

Table B8: WBS-6 Site Maintenance

	FY2003		FY2004		FY2005		FY2006		FY2007		FY2003-2007
	N	Total	N	Total	N	Total	N	Total	N	Total	Total
Senior Personnel											
Assistant Manager	1	$75,000	1	$77,250	1	$79,568	1	$81,955	1	$84,413	$398,185
Total Senior Personnel		$75,000		$77,250		$79,568		$81,955		$84,413	$398,185
Other Personnel											
Postdoctoral Associates											
Other Professionals	2	$110,000	2	$113,300	2	$116,699	2	$120,200	2	$123,806	$584,005
Graduate Students											
Undergraduate Students											
Secretarial-Clerical	1	$25,000	1	$25,750	1	$26,523	1	$27,318	1	$28,138	$132,728
Other (Maintainers)	20	$900,000	20	$927,000	20	$954,810	20	$983,454	20	$1,012,958	$4,778,222
Total Salaries and Wages		$1,110,000		$1,143,300		$1,177,599		$1,212,927		$1,249,315	$5,893,141
Fringe Benefits (30%)		$333,000		$342,990		$353,280		$363,878		$374,794	$1,767,942
Total Salaries, Wages and Fringe Benefits		$1,443,000		$1,486,290		$1,530,879		$1,576,805		$1,624,109	$7,661,083
Equipment		$500,000		$600,000		$700,000		$800,000		$900,000	$3,500,000
Domestic Travel		$6,000		$7,000		$8,000		$9,000		$10,000	$40,000
Foreign Travel		$3,000		$3,500		$4,000		$4,500		$5,000	$20,000
Other Direct Costs											
Materials and Supplies		$100,000		$150,000		$200,000		$250,000		$300,000	$1,000,000
Publication/Documentation/Dissemination		$10,000		$11,000		$12,000		$13,000		$14,000	$60,000
Consultant Services		$40,000		$41,200		$42,436		$43,709		$45,020	$212,365
Computer Services		$25,000		$30,000		$35,000		$40,000		$45,000	$175,000
Sub-Awards											
Other (Utilities)											
Total Other Direct Costs		$175,000		$232,200		$289,436		$346,709		$404,020	$1,447,365
Total Direct Costs		$2,127,000		$2,328,990		$2,532,315		$2,737,014		$2,943,130	$12,668,448
Indirect Costs (15%)		$244,050		$259,349		$274,847		$290,552		$306,469	$1,375,267
Total Direct and Indirect Costs		$2,371,050		$2,588,339		$2,807,162		$3,027,566		$3,249,599	$14,043,716

Notes: Salary and wage rates used for FY2003: Assistant Manager—$75,000; Other professional (engineer; surveyor, administrative manager, etc.)—$50,000; Developer (Maintenance person, equipment mechanic, etc.)—$45,000; Secretarial-clerical: $25,000. Materials and supplies include spare parts, lubricants, fuel oil, etc. Indirects are assessed on total direct cost excluding equipment.

Table B9: WBS-7 Detector Operations

	FY2003		FY2004		FY2005		FY2006		FY2007		FY2003-2007
	N	Total	N	Total	N	Total	N	Total	N	Total	Total
Senior Personnel											
Assistant Manager					1	$79,568	1	$81,955	1	$84,413	$245,935
Total Senior Personnel						$79,568		$81,955		$84,413	$245,935
Other Personnel											
Postdoctoral Associates											
Other Professionals					1	$53,045	2	$109,273	2	$112,551	$274,869
Graduate Students											
Undergraduate Students											
Secretarial-Clerical					1	$26,523	1	$27,318	1	$28,138	$81,978
Other (Operators)			2	$92,700	5	$238,703	8	$393,382	12	$607,775	$1,332,559
Total Salaries and Wages				$92,700		$397,838		$611,927		$832,877	$1,935,341
Fringe Benefits (30%)				$27,810		$119,351		$183,578		$249,863	$580,602
Total Salaries, Wages and Fringe Benefits				$120,510		$517,189		$795,505		$1,082,739	$2,515,943
Equipment											
Domestic Travel						$4,244		$6,556		$6,753	$17,553
Foreign Travel						$2,122		$3,278		$3,377	$8,777
Other Direct Costs											
Materials and Supplies				$25,000		$50,000		$75,000		$100,000	$250,000
Publication/Documentation/Dissemination											
Consultant Services											
Computer Services				$30,000		$35,000		$40,000		$45,000	$150,000
Sub-Awards											
Other (Utilities)											
Total Other Direct Costs				$55,000		$85,000		$115,000		$145,000	$400,000
Total Direct Costs				$175,510		$608,554		$920,340		$1,237,869	$2,942,273
Indirect Costs (15%)				$26,327		$91,283		$138,051		$185,680	$441,341
Total Direct and Indirect Costs				$201,837		$699,837		$1,058,391		$1,423,549	$3,383,614

Notes: Salary and wage rates used for FY2003: Assistant Manager—$75,000; Other professional (engineer; surveyor, administrative manager, etc.)—$50,000; Developer (Maintenance person, equipment mechanic, etc.)—$45,000; Secretarial-clerical: $25,000. Materials and supplies include spare parts, lubricants, fuel oil, etc. Indirects are assessed on total direct cost excluding equipment.

Table B10: WBS-8 Consortium Operations

	FY2003		FY2004		FY2005		FY2006		FY2007		FY2003-2007
	N	Total	N	Total	N	Total	N	Total	N	Total	Total
Senior Personnel											
Laboratory Director	0.1	$17,500	0.1	$18,025	0.1	$18,566	0.1	$19,123	0.1	$19,696	$92,910
Total Senior Personnel		$17,500		$18,025		$18,566		$19,123		$19,696	$92,910
Other Personnel											
Postdoctoral Associates											
Other Professionals	0.5	$25,000	0.5	$25,750	0.5	$26,523	0.5	$27,318	0.5	$28,138	$132,728
Graduate Students											
Undergraduate Students											
Secretarial-Clerical	1	$25,000	1	$25,750	1	$26,523	1	$27,318	1	$28,138	$132,728
Other											
Total Salaries and Wages		$85,000		$87,550		$90,177		$92,882		$95,668	$451,277
Fringe Benefits (30%)		$25,500		$26,265		$27,053		$27,865		$28,700	$135,383
Total Salaries, Wages and Fringe Benefits		$110,500		$113,815		$117,229		$120,746		$124,369	$586,660
Equipment											
Domestic Travel		$1,600		$1,648		$1,697		$1,748		$1,801	$8,495
Foreign Travel		$800		$824		$849		$874		$900	$4,247
Other Direct Costs											
Materials and Supplies		$10,000		$10,300		$10,609		$10,927		$11,255	$53,091
Publication/Documentation/ Dissemination		$10,000		$10,300		$10,609		$10,927		$11,255	$53,091
Consultant Services		$40,000		$100,000		$150,000		$200,000		$250,000	$740,000
Computer Services		$20,000		$40,000							
Sub-Awards											
Other-Science		$9,600		$167,249		$354,406		$552,277		$691,678	$1,775,210
Total Other Direct Costs		$89,600		$327,849		$525,624		$774,132		$964,188	$2,681,393
Total Direct Costs		$202,500		$444,136		$645,400		$897,500		$1,091,258	$3,280,794
Indirect Costs											
Total Direct and Indirect Costs		$202,500		$444,136		$645,400		$897,500		$1,091,258	$3,280,794

Notes: FY2003 salaries are Director: $175,000; Associate Director: $80,000; Other Professionals (Administrators etc.): $50,000; Secretarial-Clerical: $25,000.

Table B11: Budget Summary

	FY2003		FY2004		FY2005		FY2006		FY2007		FY2003-2007
	N	Total	N	Total	N	Total	N	Total	N	Total	Total
Total Senior Personnel		$782,500		$1,557,875		$1,827,403		$2,177,261		$2,462,051	$8,807,084
Other Personnel		$0		$0		$0		$0		$0	$0
Postdoctoral Associates		$22,500		$92,700		$143,222		$196,691		$253,239	$708,352
Other Professionals		$584,500		$792,585		$1,065,675		$1,540,199		$1,704,583	$5,687,542
Graduate Students		$0		$0		$42,436		$131,127		$180,081	$353,645
Undergraduate Students		$0		$32,960		$67,898		$69,935		$90,041	$260,833
Secretarial-Clerical		$225,000		$283,250		$424,362		$437,091		$506,479	$1,876,180
Other (Operators)		$2,955,000		$3,229,050		$3,596,452		$3,982,990		$4,440,132	$18,203,623
Total Salaries and Wages		$4,569,500		$5,988,420		$7,167,441		$8,535,290		$9,636,607	$35,897,257
Fringe Benefits (30%)		$1,370,850		$1,796,526		$2,150,232		$2,560,586		$2,890,982	$10,769,177
Total Salaries, Wages and Fringe Benefits		$5,940,350		$7,784,946		$9,317,673		$11,095,879		$12,527,587	$46,666,435
Equipment		$2,750,000		$2,850,000		$2,950,000		$3,050,000		$3,150,000	$14,750,000
Domestic Travel		$34,800		$38,334		$46,189		$52,192		$57,289	$228,804
Foreign Travel		$17,400		$19,167		$23,095		$26,096		$28,645	$114,402
Other Direct Costs		$0		$0		$0		$0		$0	$0
Materials and Supplies		$870,000		$1,052,000		$1,234,000		$1,416,000		$1,598,000	$6,170,000
Publication/Documentation/ Dissemination		$40,000		$49,000		$58,000		$67,000		$76,000	$290,000
Consultant Services		$100,000		$105,400		$110,872		$116,918		$123,040	$556,230
Computer Services		$70,000		$117,000		$139,000		$161,000		$183,000	$670,000
Sub-Awards		$15,644,290		$47,272,340		$40,721,466		$50,334,084		$36,817,941	$190,790,121
Other (Utilities, Insurance)		$2,000,000		$2,100,000		$2,200,000		$2,300,000		$2,400,000	$11,000,000
Total Other Direct Costs		$21,526,490		$53,603,241		$47,482,622		$57,523,290		$44,433,915	$224,569,557
Total Direct Costs		$27,466,840		$61,388,187		$56,800,295		$68,619,169		$56,961,502	$271,235,992
Indirect Costs (15%)		$1,360,868		$1,689,877		$1,969,325		$2,285,262		$2,549,034	$9,854,364
Total Direct and Indirect Costs		$28,827,708		$63,078,064		$58,769,627		$70,904,432		$59,510,537	$281,090,368

Current and Pending Support: Wick C. Haxton

Current

Institute for Nuclear Theory
US Department of Energy, Grant DE-FG03-00ER41132
February 1, 2000 – February 28, 2005
Current (year 2) award: $2,095,000 (*includes equipment funds*)
Total anticipated award for 5 years: $9,825,000 (*estimated amount on original proposal, October 1999*)

National Summer School in Nuclear Physics
National Science Foundation, Grant PHY-0088940
June 1, 2000 – May 31, 2005
Total anticipated award for 5 years: $195,000

Research Experiences for Undergraduates
National Science Foundation, Grant PHY-9732143
March 1, 1998 – February 28, 2001 (*no-cost extension granted until June 30, 2001*)
Total award for 3 years: $271,000

University of Washington Physics REU Site
National Science Foundation, Grant PHY-0097551
March 1, 2001 – February 28, 2004
Total anticipated award for 3 years: $290,250

Reformulating the Shell Model and Transforming It into a Rigorous Effective Theory
UT-Battelle LLC, Subcontract No. 4000006019
November 8, 2000 – October 31, 2001
Total award: $19,453

Pending

Shedding New Light on Exploding Stars: TeraScale Simulations of Neutrino-Driven Supernovae and Their Nucleosynthesis
US Department of Energy
August 1, 2001 – July 31, 2006
Total requested funds: $628,300

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Janet Conrad**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Elementary Particle Physics Program at Columbia University/Nevis Laboratories**

Source of Support: **NSF**

Total Award Amount: $ **0** Total Award Period Covered: **11/01/01 - 10/31/04**

Location of Project: **Nevis**

Person-Months Per Year Committed to the Project. Cal:**8.00** Acad: **0.00** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Elementary Particle Physics Program at Columbia University/Nevis Labs NSF-PHY-9813383**

Source of Support: **NSF**

Total Award Amount: $ **2,840,000** Total Award Period Covered: **02/01/00 - 01/31/01**

Location of Project: **Nevis**

Person-Months Per Year Committed to the Project. Cal:**8.00** Acad: **0.00** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Muon Beam Research**

Source of Support: **Cornell #34102-6279**

Total Award Amount: $ **115,000** Total Award Period Covered: **06/01/00 - 05/31/01**

Location of Project: **Nevis**

Person-Months Per Year Committed to the Project. Cal:**1.00** Acad: **0.00** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **An Experiment to Investigate numu to nue oscillations: MiniBooNE -- NSF CAREER Grant, NSF-PHY-9733023**

Source of Support: **NSF**

Total Award Amount: $ **500,000** Total Award Period Covered: **07/01/98 - 06/30/04**

Location of Project: **Nevis**

Person-Months Per Year Committed to the Project. Cal:**8.00** Acad: **0.00** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Detector for MiniBooNE NSF-9804051**

Source of Support: **NSF**

Total Award Amount: $ **1,600,000** Total Award Period Covered: **07/15/99 - 06/30/04**

Location of Project: **Nevis**

Person-Months Per Year Committed to the Project. Cal:**8.00** Acad: **0.00** Summ: **0.00**

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Sherry Farwell	Other agencies (including NSF) to which this proposal has been/will be

Support: ☒ Expired ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: National Space Grant College & Fellowship Program

Source of Support: NASA

Total Award Amount: $540,889 Total Award Period Covered: 03/01/91-09/30/97

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☒ Expired ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Research and Hydrologic Analysis in South Dakota 2

Source of Support: US Department of Interior - Geological Survey

Total Award Amount: $2498.60 Total Award Period Covered: 05/25/95-funds expended

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☒ Expired ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Research and Hydrologic Analysis in South Dakota 3

Source of Support: US Department of Interior - Geological Survey

Total Award Amount: $2498.60 Total Award Period Covered: 07/01/95-funds expended

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☒ Expired ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Research and Hydrologic Analysis in South Dakota 4

Source of Support: US Department of Interior - Geological Survey

Total Award Amount: $2498.60 Total Award Period Covered: 08/05/95-funds expended

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☒ Expired ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: A Public Access Resource Center (PARC) Empowering the General Public to Use EOSDIS

Source of Support: University of ND (NASA)

Total Award Amount: $23,000 Total Award Period Covered: 09/01/95-08/16/96

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Sherry Farwell	Other agencies (including NSF) to which this proposal has been/will be

Support: ☒ Expired ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: A Mobile Test Gas Generation Facility for the Atmospheric Chemistry Community

Source of Support: NSF

Total Award Amount: $379,321 Total Award Period Covered: 06/15/96-05/31/00

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☒ Expired ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Acquisition of Real-Time, API-TOFMS Monitor for Use with a Mobile Test Gas Generation Facility

Source of Support: NSF

Total Award Amount: $118,200 Total Award Period Covered: 09/15/96-08/31/98

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: A Public Access Resource Center (PARC) Empowering the General Public to Use EOSDIS

Source of Support: University of North Dakota (NASA)

Total Award Amount: $81,150 Total Award Period Covered: 11/15/96-06/15/01

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: National Space Grant College & Fellowship Program

Source of Support: NASA

Total Award Amount: $807,500 Total Award Period Covered: 03/01/97-02/28/01

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☒ Expired ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Upper Missouri River Basin: Pilot Project

Source of Support: NASA (Marshall)

Total Award Amount: $800,000 Total Award Period Covered: 02/01/98-09/30/00

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Sherry Farwell	Other agencies (including NSF) to which this proposal has been/will be

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: A Public Access Resource Center (PARC) Empowering the General Public to Use EOSDIS: ESIP

Source of Support: University of ND (NASA)

Total Award Amount: $66,350 Total Award Period Covered: 03/01/98-05/15/02

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: The Graduate Research Fellowship Program: Farrah Johnson

Source of Support: NSF

Total Award Amount: $52,800 Total Award Period Covered: 09/01/99-08/31/04

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Continuing Development of a Collaborative Plan to Further Engage South Dakota in NASA's Earth System

Source of Support: NASA

Total Award Amount: $450,000 Total Award Period Covered: 07/01/99-06/30/01

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☒ Expired ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Analytical Training Program

Source of Support: Mongolian Technical University (MTU)

Total Award Amount: $14,540 Total Award Period Covered: 10/01/99-11/15/99

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: South Dakota Space Grant College and Fellowship Program

Source of Support: NASA

Total Award Amount: $212,500 Total Award Period Covered: 03/01/01-02/28/02

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Sherry Farwell	Other agencies (including NSF) to which this proposal has been/will be

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: South Dakota EPSCoR Cooperative Agreement: Year 3 of Infrastructure Improvement Project

Source of Support: SDSU (NSF)

Total Award Amount: $942,038 Total Award Period Covered: 03/01/98-08/31/01

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: South Dakota "Rushmore Initiative for Excellence in Research"

Source of Support: NSF EPSCoR

Total Award Amount: $2,293,628 (SDSM&T portion) Total Award Period Covered: 03/01/01-02/28/02

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: The Use of Remote Sensing for Monitoring, Prediction, and Management of Hydrologic, Agricultural, and Ecological Processes in the Northern Great Plains

Source of Support: NASA

Total Award Amount: $700,000 Total Award Period Covered: 07/01/01-06/30/02

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Marvin Marshak**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Research in Experimental and Theoretical Elementary Particle Physics**

Source of Support: **U.S. Department of Energy, Office of Science**

Total Award Amount: $ **2,750,000** Total Award Period Covered: **11/01/00 - 11/01/01**

Location of Project: **University of Minnesota**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **4.50** Sumr: **2.00**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **John Wilkerson**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Experimental Nuclear Physics**

Source of Support: **DOE grant DEFG 03-97ER41020**

Total Award Amount: $ **22,562,000** Total Award Period Covered: **11/01/96 - 11/30/02**

Location of Project: **Univ. of Wash, Center for Exp. Nucl. Phys. & Astrophys.**

Person-Months Per Year Committed to the Project. Cal: **2.00** Acad: **0.00** Sumr: **2.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Measurement of the Solar Neutrino Flux using the Gallium Neutrino Telescope at the Underground Baksan Neutrino Observatory**

Source of Support: **Civilian Research & Development Foundation RP2-2253**

Total Award Amount: $ **68,000** Total Award Period Covered: **10/01/00 - 03/31/02**

Location of Project: **Inst for Nucl.Res, Moscow and CENPA, Univ. of Wash., Seattle**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

H. Facilities, Equipment and Other Resources

The major facility that will be utilized in the proposed work is the Homestake Gold Mine, located in and around the City of Lead, Lawrence County, South Dakota. The Homestake Mine is currently owned by the Homestake Mining Corporation of Walnut Creek, CA. The Homestake Mining Corporation has publicly announced that it will cease mining activities at Homestake at the end of 2001 and that it is willing to donate its underground properties and a portion of its surface properties at the Homestake site to an appropriate entity for the purpose of advancing science and education. The Homestake Mining Corporation intends to retain some properties at the current Homestake site for some number of years for the purposes of environmental remediation. The Corporation has also publicly stated that it has no interest in further mining or any activities other than environmental remediation at the Homestake site.

The Homestake Mine has approximately 800 km of underground tunnels ("drifts") and four main shafts, two of which—the Yates shaft and the Ross shaft—are equipped with hoisting machinery capable of moving personnel, equipment and excavated rock. The other shafts are used solely for ventilation. For more than 30 years, the Homestake Mine has hosted the Davis (now Lande) solar neutrino detector consisting of ~600 tons of perchloroethylene. Thus, the science capabilities of the Homestake site have been clearly demonstrated. This proposal describes a plan to vastly enhance those capabilities to explore new levels of detector sensitivity relevant to a broad range of scientific questions.

I. Special Information and Supplementary Documentation

Rationale for Performance Off-Campus:

The vast majority of the work under this project will be performed at the Homestake Mine Site in and around the City of Lead, Lawrence County, South Dakota. The deep underground locations available at Homestake are essential to the underground science described in this Proposal, as discussed in the Project Description. Most activities of the Consortium for Underground Science (CUS) will be focused at Homestake. For administrative efficiencies, CUS may choose another location for its address of record. The University of Washington, an institution experienced in the administration of large research projects, has consented to act as Interim Fiscal Agent for CUS. Of course, its address of record is located at some distance from the Homestake site.

Environmental Impact:

Mining activities by their very nature often have substantial environmental impacts. The Homestake Mining Corporation has publicly announced a substantial fund for ongoing environmental remediation related to its activities in Lawrence County SD. Although the exact inventory of the land and property transfer is not yet defined, we believe that the surface areas that will become the Homestake NUSL have relatively small ongoing environmental problems. We also believe that the Homestake NUSL activities themselves will have few, if any, environmental consequences. State of South Dakota environmental regulation personnel have given very preliminary consideration to these concerns. When the Homestake property transfer and any collateral issues are resolved, we intend to do an environmental assessment and seek a finding of "no impact" under both state and federal environmental regulations.

Research in a Location Eligible To Be A Registered Historic Place:

The Homestake Gold Mine has been in operation for 125 years. However, because of the nature of a mining operation, the structures that now exist on the site are of various ages, with an average age that is a small fraction of 125 years. Thus, a detailed historical survey will be required in order to determine the preservation eligibility status of particular features at Homestake. The Consortium for Underground Science will organize such a survey, in collaboration with the State Historic Preservation Office, as part of developing a Technical Design Report for this project. The information developed in this study will also be used to design a historic walking trail, as a small part of the outreach activities envisioned in this proposal.

Research Involving Hazardous Materials:

The work proposed here uses relatively small amounts of hazardous materials such as solvents and explosives that are common in civil construction both above and under ground. The use of such materials will be controlled by appropriate law and regulations and by appropriate policies of CUS and its Interim Fiscal Agent. Certain detectors, not directly included the scope of this Proposal, may use unusual quantities of hazardous materials. Any such detector will be subject to extensive safety reviews and audits in order to assure compliance with all applicable laws and regulations, as well as worldwide "best practices." Based on the nature of the proposed activities and the precedent of the Soudan Underground Laboratory in Minnesota, we expect to seek regulation under the Occupational Safety and Health Act and regulations and similar South Dakota laws and regulations, rather than regulation as a mine under the Mine Safety and Health Administration.

List of Appendices

Appendix A

Underground Science*

John Bahcall[1], Barry Barish[2], Frank Calaprice[3], Janet Conrad[4], Peter J. Doe[5], Thomas Gaisser[6], Wick Haxton[7], Kevin T. Lesko[8], Marvin L. Marshak[9], Kem Robinson[8], Bernard Sadoulet[10], Henry Sobel[11], Michael Wiescher[12], Stan Wojcicki[13], John Wilkerson[5]

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Why should one build a laboratory deep underground? To study the fundamental laws of physics, such as those governing the stability of the proton and the particle-antiparticle properties of the neutrino? To probe the interior of the sun? To record some of the most spectacular explosions in the universe in ways that complement optical and gravitational wave observations? To determine the nature of the dark matter that pervades the universe?

Underground science spans an astonishing range of disciplines. It addresses all of the questions listed in the previous paragraph and many more topics that fascinate physicists, astronomers, and cosmologists. Underground science also includes a vast range of both fundamental and practical subjects outside the pure physical sciences, including the behavior and evolution of life forms in exotic environments, the characteristics and stability of geologic structures, the evaluation of groundwater resources, the monitoring of nuclear weapons tests, and the vulnerability of microelectronics and other materials to cosmic radiation.

Why should one build a laboratory deep underground now? Over the past few years an intellectual revolution has begun at the intersection of astronomy, astrophysics, and cosmology with subatomic physics. Underground experiments—many of which embody elements of both astronomical observation and conventional particle/nuclear physics—are playing a crucial role in this revolution. Extraordinary technical advances, driven in part by detector advances originating in nuclear and particle physics, are allowing observers to probe the universe in new ways and with vastly increased precision. We are now testing the structure of the universe a few hundred thousand years after the big bang and the nature of the dark matter and energy that govern the expansion of the universe, with prospects for understanding the implications for the underlying "theory of everything."

The vitality of this intersection between accelerators, underground science, and the physics of the cosmos derives not only from the importance and breadth of the scientific questions being asked, but also from the rich cross-fertilization of ideas and techniques. Two outstanding examples are neutrino physics and dark matter searches:

• Neutrino physics is among the fastest evolving scientific fields today. Neutrinos are fundamental, neutral, weakly interacting particles, which come in three flavors: electron neutrinos, muon neutrinos and tau neutrinos. In the "standard model" of particle physics, neutrinos are massless and the three flavors are distinct particle states. In this theory, one neutrino flavor will not convert, or "oscillate" to another flavor with time. However, neutrino oscillations are expected from quantum mechanics if neutrino flavor eigenstates are mixtures of the mass eigenstates and if neutrinos have mass. Recently, experiments searching for

*The authors of this report served from 11/2000 to 3/2001 as members of a committee, appointed by the Institute of Nuclear Physics, the University of Washington, that reviewed the prospects for underground science. The initial drafts for several sections were written by distinguished scientists with special expertise who volunteered their efforts. We are grateful to C. Burgess, F. Hartmann, M. Gai, H. Gursky, T. Onstott, J. Wang, and P. Zimmerman for their important contributions.

"neutrino oscillations" have provided evidence for neutrino mass and mixing of flavor states in atmospheric and solar neutrino experiments. Now, at accelerators, a new generation of neutrino experiments is underway to further understand these beyond-the-standard-model neutrino properties. Taken as a whole, this group of experiments may give us our first clue as to what must be added to the surprisingly precise standard model of particle physics, as well as telling us whether neutrinos have sufficient mass to affect our models of the universe.

• As we try to understand the cosmology of the universe, one of the most vexing questions is: What is the dark matter that forms most of the matter of the universe? It seems likely that the dark matter is made up of new particles, which have not yet been produced in any laboratory. Non-accelerator experiments have pursued this question over the last decade. These highly precise searches employ new detector technology in order to maximize sensitivity to interactions with the dark matter particles. Complimenting this work, recent accelerator experiments have indicated that new physics, which could explain dark matter may be within reach of the next set of high energy experiments.

Neutrinos and dark matter represent only two sub-fields within the rich scientific program of a new underground laboratory.

Why should one build a deep laboratory in the U.S.? First, we have new possibilities for laboratories of great promise. Second, the European and Japanese facilities are highly subscribed. American scientists, whether they work on the frontier of nonproliferation activities or on fundamental research, have to locate their experiments in Italy or Japan, leading to added cost and complication. The U.S. now has an opportunity to lead underground science internationally by building the next-generation underground laboratory, one that will build on the European and Japanese experience and continue the emerging intellectual revolution in astro-particle and astro-nuclear physics.

We begin by describing in Section I the nature of the solar neutrino opportunity and then discuss in Section II the possibility of further constraining neutrino properties through observations of neutrino-less double beta-decay. Next we outline in Section III the role of underground experiments in detecting particle dark matter. We describe in Section IV the motivation and possibilities for a new generation of detectors testing nucleon stability. In Section V, we discuss future possibilities for underground studies of atmospheric neutrinos and in Section VI consider the related question of future long baseline neutrino experiments. We describe in Section VII the special requirements of neutrino observatories for detecting neutrinos from galactic supernovae. In Section VIII, we discuss precision techniques for measuring fusion reactions at temperatures characteristic of stellar interiors, exploiting the low-background environment of a deep laboratory. In the last three sections we describe the unique experiments that can be done underground in geoscience (Section IX), materials development and technology (Section X), monitoring nuclear weapons tests (Section XI), and microbiology (Section XII).

Each of these fields is on the frontier of science where the pace of new discoveries will be accelerated by the availability of a state-of-the-art underground laboratory.

I. Solar Neutrinos

The field of neutrino astrophysics began with the study of solar neutrinos. The history of this subject demonstrates the rapidly accelerating pace of technical innovation in underground science, the increasing breadth of the scientific issues, and the deepening connections with both conventional astrophysics and accelerator experiments.

Neutrinos that are created in the sun offer a unique opportunity to study both electroweak physics and nuclear fusion in the interior of our best known star. Within the sun, energy is generated by a chain of nuclear processes, which is described by the "standard solar model." Experimental tests of the standard solar model, including measurement of solar sound speeds, are in good agreement with the model. Therefore, we can use this model to predict the rate of production of electron neutrinos from the sun. These solar electron neutrinos have relatively low energy compared to accelerator-produced neutrinos, ranging from less than 1 MeV to about 20 MeV.

The "solar neutrino problem" is that experiments sensitive to electron neutrinos observe a lower rate than is predicted by the standard solar model. An elegant solution to the dilemma is that the neutrinos are converting, or ``oscillating,'' from electron neutrino flavor to some other neutrino flavor to which the detectors are insensitive.

The great distance, 10^8 km, between the nuclear accelerator in the solar interior combined with the relatively low energy of the neutrinos produced in the sun imply that squared neutrino mass differences as small as $\$10^{-12}$ eV^2 can be studied with solar neutrinos: solar neutrino experiments are truly very long baseline oscillation experiments. Moreover, as the neutrinos pass through $>10^{10}$ g–cm^2 of matter before exiting the sun, interaction with matter can affect their propagation, magnifying the consequences of neutrino mixing.

The first indication of the solar neutrino problem came from radiochemical experiments. These are experiments, which integrate the rate of solar neutrinos over months and hence are called “passive” detectors. More recently, “active” detectors, which can reconstruct the kinematics of a solar neutrino interaction on an event-by-event basis, have confirmed the deficit of electron neutrinos from the sun.

The first solar neutrino experiment reported results in 1968, using data gathered in a newly excavated cavern within the Homestake gold mine in Lead, South Dakota. The passive Homestake detector, consisting of 615 metric tons of the cleaning fluid, perchloroethylene, produced over a three-decade period a precise constraint on the higher energy components of the solar neutrino flux, revealing a factor-of-three shortfall that gave rise to the solar neutrino problem. A decade ago, two similar radiochemical experiments, one conducted within a mountain in the Caucasus region of Russia (the Baksan Observatory) and the other in the Gran Sasso Underground National Laboratory in Italy, began taking data. Because these two experiments used a different material, gallium, in their detectors, they were sensitive to lower energy solar neutrinos than Homestake. These were also the first experiments to be tested with intense ~megaCurie laboratory neutrino sources, demonstrating that the systematic uncertainties in radiochemical experiments could be well-understood. As with the Homestake experiment, the gallium experiments also observed a deficit of electron neutrinos.

The era of active solar neutrino detection began in 1987 with the Kamioka experiment: a water Cerenkov proton-decay detector located in the Mozumi Mine in the Japanese Alps. The Kamioka detector provided sensitivity to higher energy neutrino-electron scattering events. As in the previous cases, this experiment observed an overall deficit of solar neutrinos. As an important byproduct, the active detection allowed the historic first detection of neutrinos from a core-collapse supernova in 1987.

Concurrent with these pioneering experiments, developments in other areas enhanced the significance of the observed deficit. In particular, advances in solar seismology led to precise determinations of the speed of sound as a function of solar radius, which is predicted by the standard solar model. These results confirmed the predictions to 0.1% rms, throughout the sun, and strongly disfavoring nonstandard solar models. Also, the theoretical discovery that solar matter could enhance oscillations produced new particle physics scenarios that are consistent with all the available measurements in particle physics and in astronomy. Finally, as discussed later in this paper, the discovery of atmospheric neutrino oscillations made oscillation-based explanations of the solar neutrino problem increasingly plausible.

Physicists studying solar neutrinos reached a consensus that the solar neutrino ``problem'' was really a unique opportunity to learn new electroweak physics. This prospect motivated three new detectors that are remarkable for their size and sophistication, and thus for the demands they make on underground technology. Super-Kamiokande is the successor to the Kamioka experiment, with almost 100 times the mass of the original Homestake experiment and a solar neutrino event rate of many thousands of events per year. The Super-Kamiokande experiment has produced important constraints on the spectrum of high-energy solar neutrinos and on the day-night effects associated with neutrino propagation through the earth. The Sudbury Neutrino Observatory (SNO) is using a 1,000 tons of heavy water to distinguish electron-type neutrinos from other flavors generated by oscillations. This experiment is being conducted at great depth (6800 ft) in a nickel mine in Sudbury, Ontario, under unprecedented clean-room conditions, in order to minimize backgrounds. The results may tell us if a fourth, beyond-the-standard-model neutrino is contributing to solar neutrino oscillations. A third detector, BOREXINO, employs 1,000 tons of organic scintillator. Under construction in the Gran Sasso National Underground Laboratory in Italy, BOREXINO is the first active detector designed to detect low-energy ^{7}Be solar neutrinos.

At present, active detectors for solar neutrinos have only measured recoil electron energies for the rare part of the solar neutrino flux produced by ^{8}B beta-decay. This is less than $\$10^{-4}$ of the total flux. More than \$98% of the solar neutrino flux is predicted to have energies less than 1 MeV. To date, only passive detectors have been able to access these lower energies. The fundamental *p-p* neutrinos, which have energies less than 0.4 MeV, are predicted to constitute more than 90% of the total solar neutrino flux and it is important that the solar neutrinos in this range be studied in a variety of experiments with event-by-event reconstruction capability. The goals are to measure the total flux below 1 MeV in electron neutrinos and in (converted) μ and τ neutrinos and the energy spectra of these low energy neutrinos. The experiments require relatively high event rates since the predicted small seasonal and day-night time dependencies can provide unique clues to the characteristics (masses and mixing) of the neutrinos.

Several innovative detectors, in advanced stages of development, have the potential to do this low energy physics. There are excellent prospects that such a

complete program of neutrino spectroscopy could be completed within one to two decades. These low energy solar neutrino detectors could also be used for sensitive tests of other non-standard-model properties of neutrinos, such as magnetic moments.

The original goal of solar neutrino research was to use solar neutrinos to test the standard theory of how the sun shines. Precise tests of this theory will be possible once the propagation characteristics of neutrinos are known. The full resolution of the solar neutrino problem will also prepare us to study neutrino properties in new astrophysical environments, such as supernovae and the Big Bang, in which still higher matter densities and more complicated theoretical scenarios are encountered.

II. Double Beta Decay

Fundamental particles have twins, called antiparticles that have the same masses and spins, but opposite charges. For example the electron's antiparticle is the positron, a particle identical to the electron apart from its opposite (positive) charge. Clearly the electron and positron are distinct particles: the charges allow us to distinguish one from another. But what if there were a particle with no electric charge, and no charges of any other kind? What would distinguish particle from antiparticle?

The question of what distinguishes the neutrino and antineutrino has profound implications for particle physics. The possibility that the neutrino might be identical to the antineutrino allows the neutrino to have a special kind of mass---called a Majorana mass---that violates one of the important conservation laws of the standard model.

This question of the particle-antiparticle nature of the neutrino is associated, in turn, with a very rare phenomenon in nuclear physics. Certain nuclei exist which appear to be stable, but in fact decay on a timescale roughly a trillion times longer than the age of our universe. This process, double beta decay, involves a spontaneous change in the nuclear charge by two units, accompanied by the emission of two electrons and two antineutrinos. Following 30 years of effort, double beta was finally detected in the laboratory about a decade ago: It is the rarest process in nature that scientists have succeeded in measuring. Physicists are currently engaged in searches for a still rarer form of this process, one in which the two electrons are emitted without the accompanying antineutrinos. The existence of such “neutrinoless” double beta decay directly tests whether the neutrino is a Majorana particle.

The observation of neutrinoless double beta decay would have far reaching consequences for physics. Neutrinoless double beta decay probes not only very light neutrino masses—current limits rule out Majorana masses above ~1 eV—but also very heavy ones, up to a trillion eV. Interference effects between the various neutrino families (electron, muon, tau) can be studied with double beta decay and are not easily tested elsewhere. The existence of Majorana neutrinos is the basis for our best theory explaining why the familiar neutrinos are so light, relating these small masses to physics occurring at energy scales a trillion times beyond those accessible in our most powerful accelerators. The conservation law tested in neutrinoless double beta decay is connected, in many theoretical models, with the cosmological mechanism that produced a universe rich in nucleons (rather than antinucleons).

Recent experimental progress in this field has been rapid. Thirty years of effort was required before the standard-model-allowed process, two-neutrino double beta decay, was directly observed in 1987. Today accurate lifetimes and decay spectra are known for about a dozen nuclei. The standard process is crucial to theory, providing important benchmarks for the nuclear physics matrix element calculations that are done to relate neutrinoless beta decay rates to the underlying neutrino mass.

Progress in neutrinoless double beta decay searches has been equally impressive. Extraordinary efforts to reduce backgrounds through ultrapure isotopically enriched materials, improved energy resolution, and shielding of cosmic rays and natural radioactivity has produced a “Moore's law'” for neutrinoless beta decay, a factor-of-two improvement in lifetime limits every two years over the past two decades. The bound from the nucleus ^{76}Ge, $\sim 2 \times 10^{25}$ years, corresponds to a Majorana mass limit of (0.4-1.0) eV, with the spread reflecting nuclear matrix element uncertainties.

A new generation of experiments is being proposed to probe Majorana masses in the range of 0.03-0.10 eV, a goal set in part by the squared mass difference, $\Delta m^2 \sim (0.05 \text{ eV})^2$, deduced from Super-Kamiokande's atmospheric neutrino deficit (described in a later section of this paper). These ultrasensitive experiments are confronting several new challenges. A new background—the tail of the two-neutrino process—can be avoided only in detectors with excellent energy resolution. Detector masses must be increased by two orders of magnitude: the counting rate is a fundamental limit at the current scale of ~10 kg detector masses. As the detector mass is increased, proportional progress must be made in further reducing backgrounds through some combination of active shielding, increased depth of the experiment, and purer materials.

The current generation of experiments includes the Heidelberg-Moscow and IGEX ^{76}Ge detectors, the

Caltech-Neuchatel effort on ^{136}Xe, and the ELEGANTS and NEMO-3 ^{100}Mo experiments. They have comparable goals (lifetime limits in excess of 10^{25} years) and comparable masses ~10 kg. The Heidelberg-Moscow experiment has acquired in excess of 35 kg-years of data and has established the stringent lifetime limit mentioned above (2×10^{25} years). All of these experiments are being conducted outside the U.S. because deep underground facilities are unavailable here, although several have U.S. collaborators.

The new experiments under consideration include enriched ^{76}Ge detectors, a cryogenic detector using ^{130}Te, ^{100}Mo foils sandwiched between plates of plastic scintillator, a laser tagged time-projection-chamber using ^{136}Xe, and ^{116}Cd and ^{100}Mo in BOREXINO's Counting Test Facility. Some of these proposals are quite advanced, while others are in the research and development stage. The detector masses are typically ~1000 kg. Several proposed experiments depend on the availability of Russian enrichment facilities to produce the requisite quantities of the needed isotopes.

These experiments represent a crucial opportunity to advance the field of neutrino physics. The scale of neutrino masses is now being revealed in atmospheric and solar neutrino experiments, and will hopefully be confirmed in reactor and accelerator oscillation experiments like K2K, MINOS, and KamLAND. A new standard model incorporating massive neutrinos must include information on the Majorana contributions to the neutrino mass. The next generation of massive double beta decay experiments will begin to probe neutrino masses relevant to atmospheric and solar neutrino experiments, and thus might provide constraints necessary for understanding new physics.

II. Dark Matter

The dark matter puzzle is a central problem of cosmology. Since the pioneering work of Zwicki in 1933, astronomers have suspected the existence of a dark component that dominates the universe's mass, clumps into large structures, but cannot be seen as it does not emit or absorb light. Over the last decade, the astronomy community has reached the consensus that dark matter is present at a variety of scales from spiral and elliptical galaxies to super clusters of galaxies. Moreover, it seems increasingly likely that this dark matter may be made of something different than ordinary baryonic matter. The mass density of dark matter may be ten times higher than that of the baryons inferred from the primordial abundance of light elements. The temperature fluctuations of the cosmic microwave background are two orders of magnitude below the values one would expect if the observed large-scale structure of our universe were attributed entirely to baryons. One possible explanation is that baryons are hidden in condensed objects such as Massive Compact Halo Objects (MACHOs). Microlensing observations imply that MACHOs are unlikely to be abundant enough to form the halo of our galaxy.

A natural explanation for dark matter is that it is made of non-baryonic particles produced in the early hot universe. Underground facilities are essential for testing two of the best motivated candidates: light massive neutrinos and Weakly Interactive Massive Particles (WIMPs). Both of these particles were in thermal equilibrium with the rest of the universe at early times.

• Neutrinos of mass much smaller than 2 MeV/c^2 fall in the generic category of particles, which decoupled when they were relativistic. Their current number density is roughly equal to that of the photons in the universe. The relic particle mass density is therefore proportional to the particle's mass (unless that mass is very small). The atmospheric neutrino oscillation results convincingly indicate the existence of at least one massive neutrino whose cosmological density is at least comparable to the mass density of stars. Although it is not possible to form galaxies with neutrinos alone, the general program of understanding the neutrino masses described in this report is essential to map the role that neutrinos play in cosmology.

• Another generic class of candidates are particles that thermally decoupled from the rest of the universe when they were non-relativistic. Their present density is inversely proportional to their annihilation rate. For these particles to be of the order of the critical density (e.g., one third of it), this annihilation rate has to be roughly the value expected from weak interactions, hence their name of Weakly Interactive Massive Particles. This may be a numerical coincidence or a precious hint that physics at the W and Z scale is important for the problem of dark matter. Indeed, in spite of its phenomenological success, the standard model of particle physics is known to be incomplete. New physics near the W and Z^0 scale could lead to particles whose relic density is close to the critical density. For example, in order to stabilize the mass of the vector intermediate bosons, one is led to postulate the existence of a new family of supersymmetric particles in the 100 GeV/c^2 mass range. The lightest supersymmetry particle is thus an outstanding dark matter candidate.

The WIMPs search is being carried out intensively with germanium detector arrays of unprecedented radiopurity and with very large NaI scintillation detectors. The field is at the forefront of the effort to develop novel cryogenic sensors providing excellent

background discrimination. Current first-generation experiments have achieved a sensitivity significant to begin probing supersymmetry. Several second-generation experiments under development in the US and Europe have the potential to explore large regions of the supersymmetric parameter space.

The dark matter physics community is currently discussing a third generation of WIMP experiments for the second half of the decade. Two possible directions are envisioned. If the second-generation experiments discover a signal, the emphasis will probably shift to the detection of the recoil directionality, which would link the signal to the Galaxy and provide information on the Milky Way halo. The candidate technologies, e.g., photon detection in isotopically pure materials, low-pressure time projection chambers, and extremely sensitive motion sensors detecting the scattering event, are particularly sophisticated and their development should be started as soon as possible. If the second-generation experiments fail to find a signal, it will be necessary to use photon-mediated or liquid xenon experiments with as much as 1~ton of detector material. The emphasis on the development would then be ultra-low radioactivity, very high rejection power, and large-scale production at low cost. This second route would become compelling if supersymmetry is discovered at the Tevatron or LHC.

A very deep site that is properly equipped (for instance with clean rooms and the possibility of handling cryogenic fluids) would be an important asset. Most of the sensitivity of the experiments currently under construction relies on the discrimination between nuclear recoils and electron recoils. The former might signal WIMP interactions while the latter are generated by radioactivities within the detector. High energy neutrons, produced by cosmic muons in the apparatus or the cavity walls, are potentially problematic as they also produce nuclear recoils, mimicking WIMPs. The rates are unfortunately poorly known. Although the second generation of experiments may be done at 2000 m.w.e. with little neutron shielding, the third generation will likely require deeper sites. Underground material refining facilities (e.g., for the detector supports) could also prove important in reducing ambient backgrounds.

Although the field of dark matter research is still young, there are strong suggestions that the underlying physics is profound. Maps of the cosmic microwave background and tests of the Hubble expansion using supernovae as standard candles suggest that the universe is flat, currently balanced by a combination of dark matter and dark energy. These cosmological results hint at deep connections between the dark matter associated with new particle physics and the laws that govern the large-scale evolution of our universe.

III. Nucleon Decay

A great many species of elementary particles have been discovered in the century since Thompson's discovery of the electron. With a very few exceptions, all known elementary particles spontaneously disintegrate into other particles. For instance, some forms of natural beta radioactivity arise when a neutron within an atomic nucleus decays into a proton, an electron and an antineutrino. The average time before a decay occurs—called the particle's lifetime—is characteristic of the species of decaying particle.

For modern physicists it is the particle that does NOT decay which requires an explanation. This explanation usually looks for a conserved quantity whose value must be the same for the parent particle and for all of the daughters in the event that a decay takes place. For instance, electric charge is conserved in the neutron decay mentioned above, because the charge (zero) of the initial neutron equals the sum of charges of its daughters: proton (*+1*) plus electron (*-1*) plus antineutrino (zero). Since energy conservation requires particles to decay into daughter particles with a smaller mass, the lightest particle carrying a conserved charge must be stable. The electron is the lightest electrically charged particle, and this is our understanding of why the electron does not decay.

So far as we know ordinary matter does not decay, and this implies the proton must be extraordinarily stable. If the ambient radioactivity found in ordinary matter were due to decaying protons (it isn't) then the proton lifetime would have to be more than 10^{16} years, or a million times longer than the age of the universe. This limit can be raised even further if known sources of radioactivity are removed, as was first demonstrated by Reines and collaborators in 1954, who established a limit of about 10^{22} years.

The remarkable stability of the proton is explained in modern particle theory (the Standard Model) by proposing that it is also the lightest particle to carry a conserved charge. Whereas electric charge conservation keeps the electron stable, for the proton the relevant conserved charge is called baryon number. Its conservation was first proposed by Stuckelberg in 1938 and by Wigner in 1949.

Until the 1970s there were no compelling theoretical arguments for violation of baryon number conservation. This situation changed with the success of efforts to unify the weak and electromagnetic forces and with the development of quantum chromodynamics as the theory of the strong interaction. Theoretical efforts to construct grand unification theories which would further unify these three forces led naturally to interactions which violated baryon number conservation, and so predicted

the proton should decay. Since these new baryon-number violating interactions were very weak, the proton lifetime was predicted to be extremely long. The simplest and most popular of these theories, based on the symmetry group SU(5), predicted a proton lifetime in the range of $10^{28\text{-}30}$ years and specified the dominant decay product to be a positron and a neutral pion ($p \rightarrow e^- + \pi^0$).

These predictions stimulated ambitious new proton decay searches with massive underground detectors—including the Frejus, IMB, Kamiokande, Kolar and NUSEX experiments---in the 1980s. In its initial report in 1983, the largest of these detectors, IMB, set a lower limit of 6.5×10^{31} years for the lifetime for the decay $p \rightarrow e^- + \pi^0$, effectively ruling out the minimal SU(5) grand-unified theory. With additional data collected over the remainder of the decade, the lower limit on the lifetime was increased to 8.5×10^{32} years.

Further improvement of these limits requires large, higher-sensitivity detectors: to test lifetimes of 10^{33} years would require about 10^{33} protons or neutrons, or a ten kiloton mass. This was the primary motivation for building the Super-Kamiokande experiment in Japan. The 50-kiloton Super-Kamiokande detector began taking data in 1996.

Although larger detectors could produce larger proton decay signals, they also produce more background events, where an ordinary reaction is mistaken for proton decay. Backgrounds for proton decay arise when cosmic rays interact in the upper atmosphere producing muons and neutrinos, which can penetrate and interact within the detector. The number of muons reaching the detector can be reduced by locating the detectors underground, but neutrinos cannot be avoided so simply because they can pass through the entire earth unscathed. Although the vast majority of these atmospheric neutrino interactions bear little resemblance to proton decay, a small fraction are indistinguishable based on the measured topology and kinematics of the events. Recently obtained data from a scaled-down version of Super-Kamiokande installed in the neutrino beamline at the KEK accelerator in Japan will help experimentalists to improve their estimates of the rates of such background events. More sophisticated simulations of neutrino production in the atmosphere, coupled with new measurements of the primary cosmic ray fluxes and the secondary particles produced will likewise refine our understanding of the atmospheric neutrino fluxes themselves in the near future.

While the data from Super-Kamiokande have yet to reveal evidence for proton decay, the motivation for still more sensitive searches is strong. Baryon number differs from electric charge in that there is no fundamental reason why it should be conserved. Recent theoretical papers have stressed the relevance of Super-Kamiokande's discovery of neutrino oscillations to the mechanism for proton stability. One effort to incorporate oscillations within a grand unified model predicts the proton lifetime to lie in the range of 10^{34} years, with decays into kaons and antineutrinos ($p \rightarrow \nu + K^+$) being predicted as the dominant decay mode. Such decays could be revealed by new experiments that improve on Super-Kamiokande's sensitivity by a factor of five or ten.

By producing important atmospheric and solar neutrino results in addition to new limits on baryon number violation, Super-Kamiokande illustrates the strong intellectual and practical connections between proton decay experiments and other kinds of underground science. Furthermore, the theoretical motivations are strong. There is evidence that our fundamental approach to unification is sound, and although models can predict a broad range of proton lifetimes, the range immediately beyond current experiments is exceedingly interesting. Proton decay remains one of the very few opportunities for directly testing grand unified theories with experimental data.

IV. Atmospheric Neutrinos

When primary cosmic-ray protons and nuclei enter the atmosphere, their interactions produce secondary, "atmospheric" cosmic rays including all the hadrons and their decay products. The spectrum of these secondaries peaks in the GeV range, but extends to high energy with approximately a power-law spectrum. Because they are affected only by the weak force, atmospheric neutrinos rarely interact in the earth. Thus a single underground detector can use the atmospheric neutrino beam simultaneously in a short-baseline and a long-baseline mode to search for neutrino oscillations over a range of path lengths from 10 to 10,000 kilometers, with sensitivity to mass-squared differences down to less than $\sim 10^{-4}$ eV^2.

Because they are weakly interacting, neutrinos were the last component of the secondary cosmic radiation to be studied. With the advent of very large, deep underground detectors, whose construction was originally motivated by the search for proton decay, there are now extensive measurements of the flux of atmospheric neutrinos. What is emerging from recent studies is a discovery which is likely to have an impact comparable to that of the original discoveries made with atmospheric cosmic rays half a century ago, including existence of the pion, the kaon and the muon. The 50-kiloton Super-Kamiokande experiment, with a 20-kiloton fiducial volume, has now accumulated sufficient statistics to see clearly that the flux of muon-neutrinos depends not only on the rate at which they are

produced in the atmosphere, but also on the path length they travel to the detector. There is a deficit of upward muon-neutrinos relative to downward neutrinos measured in the same detector, the response of the detector being up-down symmetric.

The most likely cause of this path length dependence is neutrino oscillations, in which neutrinos produced as muon-type, after passing a certain distance (which depends on energy), manifest themselves with a different "flavor," in this case as τ-neutrinos. This behavior suggests that the neutrinos possess a small but non-zero mass. If so, this would be the first evidence for physics beyond the standard model of particle physics. This possibility has stimulated intense activity to find the implications for particle theory, and to relate this manifestation of neutrino physics to the long-standing solar neutrino problem (or the "solar neutrino opportunity" as it is described elsewhere in this essay).

The first evidence that atmospheric neutrinos were not behaving as expected came from the observation by IMB that the fraction of neutrino interactions with stopping muons was lower than expected. Then Kamioka reported that the ratio of muon-like to electron-like neutrino interactions was lower than expected. The Frejus experiment, however, reported a ratio consistent with expectation. These detectors had fiducial volumes ranging from a fraction to a few kilotons. As statistics accumulated from the water detectors (IMB and Kamioka) and first results were reported from Soudan, evidence for the "atmospheric neutrino anomaly"' increased. Then, the Kamioka experiment published the first evidence for a path length dependence characteristic of neutrino oscillations. An important aspect of both ν_μ/ν_e and upward/downward is that, as ratios, both are insensitive to uncertainties in the calculations of what is expected in the absence of oscillations. The $\nu_\mu \rightarrow \nu_\tau$ oscillation interpretation that is emerging from the data is also consistent with deviations from the expected angular distributions of neutrino-induced upward muons measured in MACRO and Super-Kamiokande. This event sample probes a higher range of neutrino energies than the neutrino interactions inside the detector.

The identifying characteristic of neutrino oscillations, the rise and fall of neutrino intensity as a function of energy, cannot be observed at present with Super-Kamiokande. This is a consequence of the limited energy and angular resolution of the experiment coupled with the fact that, with the estimated value of the mass of the heavier neutrino, the first dip occurs for paths in which neutrinos are coming from near the horizon. The path length changes rapidly with zenith angle near the horizon. This consideration also limits the accuracy with which neutrino mass can be determined with the atmospheric neutrino beam.

Assuming a next-generation nucleon decay detector in a dedicated underground laboratory, it is natural to ask what would be the prospects for atmospheric neutrino physics. Assuming the detector would have an order-of-magnitude larger sensitive volume, several possibilities could be explored. These might include:

- Larger statistics for more precise determination of the mixing angle;
- Possible observation of ν_τ appearance;
- Better sensitivity to oscillations by containing higher energy events, which have naturally better angular resolution. The goal would be to resolve the first oscillation dip, which would allow a more precise determination of neutrino mass;
- More statistics on neutral current events;
- Study of ~GeV neutrino interactions in nuclei.

V. Long baseline neutrino oscillation experiments

The data on atmospheric neutrinos probably provides the strongest evidence today for the existence of neutrino oscillations and hence a non-zero neutrino mass. If indeed the effect seen by the Super-Kamiokande experiment (and supported by IMB, Kamioka, Soudan 2 and MACRO) is due to neutrino oscillations then the most important characteristics of the phenomenon are:

- Large mixing angle ($\sin^2 \theta > 0.88$ at 90% CL);
- $1.5 < \delta m^2 < 5 \times 10^{-3}$ eV^2 at 90% CL;
- Dominant mode of $\nu_\mu \rightarrow \nu_\tau$.

The characteristics of these parameters are such that the phenomenon can be investigated very well by the terrestrial long-baseline accelerator experiments. The dominant neutrino flavor produced by the accelerators is ν_μ, from π or K decays. The energies at which copious neutrino beams are available (few GeV), and feasible accelerator-detector distances (few hundred or few thousand km) provide L/E ratios well matched to the suggested δm^2. Finally, the large mixing angle for the dominant modes allows precise studies of the parameters.

At the present time, three different long-baseline accelerator oscillation programs are either scheduled or already running. The K2K experiment, in Japan, utilizes a neutrino beam from the KEK PS and Super-Kamiokande as the detector. The mean neutrino energy is about 1 GeV and the baseline is 250 km. The experiment started taking data in the middle of 1999 and has already seen events in the detector, which are about 2σ away from the no-oscillation hypothesis. The MINOS experiment, in the US, utilizes the beam from the Main Injector accelerator at Fermilab (120 GeV protons) and a magnetized iron scintillator spectrometer

in a former iron mine in northern Minnesota. The baseline is 730 km, and the energy is variable from a mean energy of 3 GeV to about 15 GeV. The experiment should commence data taking at the end of 2003, and, depending on the energy of the beam used, detect a few thousand to a few tens of thousands of events per year. The CERN neutrino program, Geneva, Switzerland, utilizes a neutrino beam from the CERN SPS directed towards Gran Sasso Laboratory in Italy, about 730 km away. The experimental program emphasizes detection of τ neutrinos and thus the mean beam energy is about 20 GeV. A hybrid emulsion detector, OPERA, has been approved and a liquid argon TPC, ICARUS, is a strong possibility for the second detector. The data taking is scheduled to start in May 2005.

These experiments will try to elucidate the nature of the atmospheric neutrino effect. Specifically, some of the experimental goals are: a) confirmation of the existence of neutrino oscillations by verification of neutrino disappearance and a change in the energy spectrum between the near and far detectors; b) precise measurement of the oscillation parameters obtained mainly from the detailed study of the energy spectra for ν_μ interactions; c) verification that the $\nu_\mu \rightarrow \nu_\tau$ mode is the dominant oscillation mode, by either observing τ's directly or by seeing a change in the NC/CC ratio; d) observation (or improvement of limits) on subdominant oscillation modes, e.g., $\nu_\mu \rightarrow \nu$ or $\nu_\mu \rightarrow \nu_{sterile}$, and e) investigation of the possible presence of more exotic phenomena like neutrino decays (possibly in conjunction with oscillations) or presence of extra dimensions.

All three of the experiments mentioned above rely on underground laboratories for their principal (i.e., far) detector. We can ask to what extent an underground location is essential for long baseline accelerator experiments. The correct answer is probably that it is not as essential as for some of the other physics programs discussed above in other sections but it greatly facilitates a number of measurements and allows one to expand the scope of the experimental program. Some of the more important reasons for choosing an underground location are as follows:

The far detectors need to be massive and thus cover a large area leading to a significant number of cosmic rays passing through or interacting in a surface detector. The cosmic ray background constrains the trigger and forces some *a priori* decisions as to which categories of events will be detected. This background might also necessitate an extensive cosmic ray veto shield.

One way to reduce the problems discussed above is to use a very short beam-on time in the accelerator, so as to reduce the cosmic ray problem by selecting events only in a narrow time window. The problem with the short on-time solution is that it can create serious pileup problems in the near detector, where the event rate will be a million times or so greater. This may well constrain the accelerator intensities that one can use. For some machines, for example, neutrino factories based on muon storage rings, the very nature of the machine precludes very short beam-on times.

Use of a hybrid emulsion detector is seriously compromised in a ground-level detector. Such detectors require a very high percentage of good trigger events so as to minimize the required emulsion use, development, and scanning. Clean event selection, without a great deal of auxiliary tracking information, is much easier to accomplish if the cosmic ray flux is suppressed. In addition, because of the long memory of emulsions, the exposed emulsions will be much cleaner, that is, freer of background, if they are exposed in an underground detector.

For lower energies, and for studies of neutral current events or charged current events for non-ν_μ modes, interactions of neutrons from cosmic rays could simulate neutrino interactions of interest. This background would be suppressed for underground detectors.

In summary, underground laboratories provide significant advantages for long-baseline neutrino oscillation experiments. These advantages may become even more important for the next generation of experiments; these experiments will have higher statistical precision and thus the minimization of systematics will become even more important.

VI. Supernova Neutrinos

A core-collapse supernova is one of the most striking events occurring in the cosmos. The neutrinos that are emitted represent 99% of the $\sim 10^{53}$ ergs released by the collapse. Supernova neutrinos carry detailed information about the collapse mechanism and about new neutrino physics at very high matter densities and within strong magnetic fields. They may allow neutrino observers to distinguish the formation of a neutron star from the formation of a black hole, complementing information learned from gravitational wave detectors and from optical observations. The long time behavior of the neutrino luminosity probes the neutrino opacity deep within the protoneutron star, where high density nuclear matter may exist in exotic states.

In the current best model of core collapse supernovae, neutrinos play an essential role in the explosion mechanism itself, helping to revive the stalled hydrodynamic shock wave by heating the nucleon soup left in the shock's wake. Neutrinos also

play an important role in the synthesis of heavy elements in supernovae. Thus the detection of supernova neutrinos would provide a wealth of information on topics ranging from flavor mixing to the evolution of galactic metals.

The available data on supernova neutrinos are limited to the ~20 events from Supernova 1987A, recorded in the Kamiokande and IMB detectors. All of these events may have been produced by electron antineutrinos interacting with the protons within these water Cerenkov detectors. The neutrino events from SN1987A provided a qualitative confirmation of theoretical ideas about core collapse (for example, the neutrino cooling time and the total energy release), and demonstrated the potential for supernova neutrinos to constrain neutrino masses kinematically. Yet, because we lacked the requisite detectors at the time of SN1987A, much information was lost because of the small number of recorded events and the inability to separately detect electron neutrino, electron antineutrino, and heavy-flavor neutrino events.

The next Galactic supernova should generate thousands of events in underground neutrino observatories that either exist now or will be operating in the near future, such as Super-Kamiokande, SNO, LVD, and KamLAND.

The predicted mean energies of the different neutrino flavors are: 11 MeV (ν_e), 16 MeV ($\overline{\nu}_e$), and 25 MeV (ν_μ, $\overline{\nu}_\mu$, ν_τ, $\overline{\nu}_\tau$). This temperature hierarchy is determined by basic features of neutrino-matter interactions and is relatively insensitive to model assumptions. Distinctive oscillation signals, such as an inversion of the electron and heavy flavor neutrino temperatures, may be observable. Matter enhanced oscillations could occur for densities up to ten orders of magnitude larger than the densities probed by solar neutrinos. Neutrino mixing angles as small as 10^{-5} could lead to complete $\nu_e \rightarrow \nu_\tau$ conversion.

Observation of the $\overline{\nu}_e$ is relatively easy; they interact via the charged-current interaction, transferring essentially all their energy to a positron that can be detected in a water Cerenkov detector. However, the ν_μ, $\overline{\nu}_\mu$, ν_τ, $\overline{\nu}_\tau$ at supernova energies interact only through the neutral-current interactions; they transfer only part of their energy to the detector. Thus the energy distributions of ν_μ, $\overline{\nu}_\mu$, ν_τ, $\overline{\nu}_\tau$ must be sampled by observing them with multiple detectors having different detection thresholds. Suitable detectors include the oxygen nuclei in the water Cerenkov detectors, deuterium (in SNO), carbon in organic scintillators (excitation of the 15.11 MeV state), and lead and iron (proposed as targets in future detectors). If many events are observed in detectors with separate sensitivities to ν_e, ν_e and heavy flavor neutrinos, then this information may be used to test oscillation hypotheses and to learn about the dynamics of core collapse and neutron star cooling.

The time profiles of the neutrinos could be used to infer their masses from their time-of-flight differences, provided good statistics are achieved. The mass, or an upper limit to the mass, of the heaviest neutrino could be determined down to about 30 eV, a six-order-of-magnitude improvement over the present limits. Discrimination between the different types of events could be achieved from the differences in their signatures in water Cerenkov detectors or from the mean energies of the different flavor neutrinos in a detector that observes only neutral current events. If sharp temporal features exist in supernova neutrino spectra, lower mass bounds might be obtainable.

Much of the information carried by supernova neutrinos is important to other endeavors in physics and astrophysics. The supernova mechanism is one of the outstanding terascale computing challenges in numerical astrophysics: detailed temporal and spectral information on the neutrino flux would place stringent constraints on modeling efforts. If neutrinos can be used to diagnose aspects of the collapse, such as the possibility of delayed collapse into a black hole, constraints might be placed on the resulting gravitational wave form, aiding gravity wave experimentalists in their attempts to identify a signal. The intimate connection between neutrinos and supernova nucleosynthesis opens up an interesting intersection with optical astronomy: rapid strides are being made in determining r-process and other abundances in early, metal-poor stars.

Finally, as rare events, supernovae present special challenges to neutrino experimentalists. Estimates of the Galactic supernova rate range from one to ten per century. Thus one must think in terms of long-term observatories rather than short-term experiments. The long time between supernova events argues for supernova observatories that are either inexpensive and easy to maintain, or have multiple purposes.

VII. Nuclear Astrophysics

Experimental nuclear astrophysics is concerned with the study and measurement of nuclear processes that drive both the steady evolution and the explosion of stellar systems. In the Precision Era of nuclear physics, simulating stellar conditions in the laboratory is a crucial link for interpreting the wealth of observational elemental and isotopic abundances data from satellite-based observatories through complex computer simulation of stellar evolution and stellar explosion. Two major goals have crystallized over the last decade. The first centers on the understanding of nuclear

processes far off stability in the rapid rp- and r-processes, which characterize nucleosynthesis in novae, X-ray bursts, and supernovae. The second goal focuses on understanding hydrostatic nuclear burning through the different phases of stellar evolution, determining the lifespans of the stars and the onset conditions of stellar explosions. They also determine the elemental and isotopic abundances observed in stellar atmospheres and in the meteoritic inclusions that have condensed in stellar winds.

The laboratory measurement of nuclear processes in stellar explosions requires the development of a new generation of radioactive beam facilities both to produce the exotic, short-lived nuclear species and to observe reactions that occur on the split-second timescales of stellar explosions. Different techniques are needed for the study of reactions that characterize the long-lasting, quiescent periods of stellar evolution. A new generation of high intensity, low-energy accelerators for stable beams must be built to simulate within human timescales the processes that occur in nature over stellar lifetimes. To obtain empirical information regarding the effects of the stellar plasma on fusion rates, one must go to very low energies in the laboratory where the effects of atomic electrons become most important.

While more than thirty years of intense experimental study have allowed us to define the major features of nuclear burning during hydrostatic stellar evolution, so far only two fusion reactions have been studied at the actual stellar energy range. Many other rates crucial to stellar modeling have been deduced indirectly from extrapolations of higher energy laboratory data. These extrapolations can be off by orders of magnitude in cases where the underlying nuclear structure is poorly constrained. The resulting uncertainties complicate the modeling of important phases of stellar evolution, such as the CNO reactions within massive main sequence stars and the later stages of nuclear burning where reactions on heavier species dominate. Descriptions of the red giant and the asymptotic giant helium and carbon burning phases, which are the sites for the s-process responsible for the origin of more than half of the known elements, are also limited by nuclear physics uncertainties. The fusion of $^{4}He + ^{12}C$ is, for example, an important reaction occurring in the initial stage of a supernova in which the above-ground laboratories have difficulties making low energy measurements because of cosmic ray backgrounds. A more detailed knowledge of nuclear rates is necessary to interpret and understand the rapid convection processes that link the nucleosynthesis site deep inside the star with the stellar atmosphere.

While the motivation for improving our knowledge of stellar reaction rates is clear, experimental studies of reactions for the hydrogen-, helium-, and carbon-burning phases are often frustrated by the combination of extremely small cross sections (at the sub-pico-barn level) and high backgrounds induced by cosmic ray interactions at the accelerator sites. The cosmic ray-induced counting rate in ground-level detectors exceeds the signal by many orders of magnitude at energies corresponding to stellar temperatures.

A low-energy accelerator facility LUNA has been installed at the Italian Gran Sasso Underground National Laboratory to study nuclear reactions of importance for the pp-chain, which supplies almost all of the sun's energy. The enormous reduction of cosmic ray background by almost a mile of rock shielding led to the first successful measurement of the $^{3}He(^{3}He,2p)^{4}He$ reaction at energies characteristic of solar fusion (~16 keV). This measurement eliminated a highly speculative but long-standing uncertainty in the solar neutrino problem, the possibility of a low energy resonance in the ^{3}He-^{3}He system. A similar effort on two other reactions important to the pp-chain, $^{3}He(\alpha,\gamma)\$^{7}Be$ and $^{7}Be(p,\gamma)^{8}B$, could help sharpen standard solar model predictions of the ^{7}Be and ^{8}B solar neutrino fluxes.

Underground facilities provide generic opportunities for studying nuclear reactions at stellar energies because of the massive passive shielding of cosmic rays. However, while passive shielding is essential, at low energies beam-induced background requiring active shielding also arises. Here there are great opportunities for improving underground measurements of stellar reactions. In this regard the LUNA accelerator, which operates with high intensity dc-mode proton and alpha beams, offers only limited options. A high-intensity low-energy ($\leq$ 1 MeV/amu) heavy-ion accelerator in ac-mode could provide better conditions through inverse kinematics measurements. This includes higher effective efficiencies and event identification techniques through timing and particle identification with a recoil separator system, and a beam rejection power of better than 10^{-20} of the total system. Such a facility requires extensive R\&D studies on the accelerator aspects, gas-target techniques, and recoil separator improvements. The need for beam intensities of > 1 mA for achieving a rate of a few events per month will define extremely stringent requirements for the experimental equipment. The availability of suitable underground sites would motivate many in the nuclear reactions community to study what might be achievable.

VIII. Geoscience

Geoscience research is of critical importance for groundwater resource evaluation, energy resource extraction, environment remediation, and nuclear waste isolation. One of the most challenging aspects of subsurface evaluation is the heterogeneity of characteristics, fractures, faults, and interfaces, controlling localized (channeled) flow and transport paths, as well as rock deformation and failure. Traditional geoscience research activities are based primarily on coring and logging along boreholes from the ground surface and laboratory measurements of small rock and fluid samples collected from different stratigraphic layers. The geoscience community recognizes the limitations of stratigraphy-based models in capturing the heterogeneous nature of subsurface features, events, and processes and emphasizes the importance of using underground tunnels for direct access to deep geological formations for observation, characterization, and testing.

Many recent advances in geosciences are associated with nuclear waste repository studies in fractured tuff at Yucca Mountain, Nevada, and in salt bed at Carlsbad, New Mexico. Seepage evaluation along tunnels, geochemical and isotopic signals of old flow paths, fracture opening and rock deformation induced by stress releases, geophysical imaging of fluid movement and structure changes, and the heater tests for coupled process evaluation are among the highlights from tunnel studies. Numerical models have been used successfully to represent the flow and transport fields at different scales, with parameters calibrated against data collected in both boreholes and tunnel test beds.

An urgent need exists to continue the momentum for geoscience research that builds upon the experience of tunnel studies and expands the scope for experiments over time periods longer than the duration available in underground facilities before operations begin. The next generation of underground tests, the systematic evaluation of processes over different spatial scales, and the development of advanced techniques for long-term monitoring over great distances are logical activities for new underground laboratories currently under consideration. Such a laboratory would offer a unique opportunity for geoscience to join other physical sciences in developing a sharply focused understanding of subsurface physical characteristics and environmental conditions. As in other physical sciences, new understanding and new geoscience can evolve from analyses of large data sets collected over long time periods and over ranges of relevant scales. There is no substitute for an *in situ* program of measurement and observation.

Deep underground laboratories can be used to investigate subsurface multiphase flow and reactive chemical transport processes, characterize physical and chemical properties of weak and fractured rocks, and investigate model predictions through large-scale, long-term controlled experiments. Geoscience studies depend sensitively on site and formation characteristics.

Some of the important subjects to be investigated include the following geohydrological processes: seepage into and drainage out of tunnels, the heterogeneity of rock formations, and the multiphase transfers and coupled processes. Geochemistry studies are also important, especially mineral assemblages and alterations, pore water composition and tracer distribution, and age determination and isotopic measurements. Geomechanics can be investigated using strength and deformation measurements of fractured rocks, *in situ* stress measurements, and fracture behavior and propagation measurement, while geophysics can be studied using imaging, rock failure and damage monitoring, and long-baseline, low-frequency investigation of rock-masses.

An integrated geoscience test bed may require multilevel, multitunnel configurations over the spatial scales of 10 to 100 m in each spatial dimensions. The experiments may last over decades to test slow processes such as heat transfer. The largest Yucca Mountain heater test at a single drift is scheduled for four years of heating and four years of cooling. If the rock mass between two drifts is the key area of study, the tests may require decades of heating and cooling. For large-scale flow and transfer tests with reactive and conservative tracers, the plume quantification may require periodic drilling and sampling. ``Mine-back'' observations are required to validate the plume images based on borehole network monitoring. Unique equipment required for the geoscience test beds would include:

- Electrical power to run the heaters in megawatt range;
- Drilling equipment operated under above-boiling conditions in heated block or below-freezing conditions for geochemical sampling to preserve fluid;
- Mechanical excavation equipment for mine-back operation.

IX. Materials Development and Technology

The field of underground particle physics and astrophysics, and solar neutrino research in particular, has created a unique opportunity to extend and exploit our understanding of ultra-low background materials, counting techniques, and ultra-pure chemical methods. The 2 to 3 orders of magnitude improvement in the ability to detect natural and man-made phenomena over what is achievable using non-underground

technologies, suggests a bright future for new applications in materials analysis.

Since the first solar neutrino experiment established the recording at the few atom level of the rare gas ^{37}Ar produced by neutrinos from the sun, underground science has set new records in the detection of specific isotopes at very low levels. These low-event-rate measurements are based principally on three key areas of technology: material background reduction, ultra-low level counting techniques, and ultra-pure materials. The three areas are related, and a summary of the current status is provided here.

In the radiochemical solar neutrino detectors, newly developed ultra-low level gas proportional counters have achieved backgrounds in selected energy windows at the levels of a few events per year. These counters have since been used to detect not only ^{37}Ar and ^{71}Ge at the single atom level but also at similar levels, isotopes such as ^{133}Xe and ^{135}Xe that are produced in nuclear reactors. In the GALLEX project, it was demonstrated that a few atoms of ^{133}Xe could be collected and counted in less than a day from a volume of about 150 m^3. To extend this capability requires the use of material with ultra-low natural radiation background for shielding; for example, low radioactivity lead from Roman times, collected from sunken naval vessels off the Italian coast. Also the Xe atoms have to be chemically manipulated through synthesis and purification steps. The purification steps involve separation of Xe atoms from a few ^{222}Rn atoms. Also the counting gas is prepared from pre-nuclear-age xenon and tritium-free water used in the gas preparation is collected from sources under the Dead Sea in Israel.

With low radioactive shielding, combined with ultra-pure scintillators, (the Borexino Counting Test Facility (CTF) achieves 10^{-16} g/g removal of Th and U isotopes), one can achieve detection systems for Xe isotopes at the few atom level and corresponding orders of magnitude improvement in sensitivities. At such levels, the traditional terminology "μBq/m^3" is not representative and one refers to counting atoms per hundreds of cubic meters. In this illustration, the application to fission isotopes or nuclear activities is clear. The magnitude of the improvement in sensitivity opens new horizons---shorter collection times, smaller sample sizes, longer transport times, and much improved sensitivity to short-lived isotopes.

In addition to the proportional counter case illustrated above, ultra-low background research is achieving world record sensitivity in liquid scintillators at the few event level. For example, ^{14}C has been detected for the first time from crude oil in the CTF and ^{85}Kr has been detected from atmospheric samples as small as one liter. Low-level cryogenic x-ray detectors are used at the Gallium Neutrino Observatory for the detection of chemically separated ^{71}Ge; the new very low background germanium detectors of the Max Planck Institute fur Kernphysik achieves sensitivity at the level of a few background events per month per gamma ray line. Such new capabilities provide for considerable extensions in the ability to perform analyses of trace elements.

The development for underground experiments of the low-level detector techniques, the ultra-pure chemical manipulation of small amounts of materials, and the collection of low background materials, some quite exotic, is an important research area. The PIsCES (Precision Isotope Counting Experimental Setups) program was formulated by the Space Science Division of the Naval Research Laboratory, in collaboration with U.S. and European partners, to provide a mechanism to extend these techniques and explore the analysis of exceedingly small amounts of materials. Combined with neutron activation of stable isotopes and accelerator mass spectroscopy the sensitivities to trace analysis in small material sample sizes is further expanded.

Although the Gran Sasso Underground National Laboratory provides a small facility that can accommodate some of their low counting rate capability for materials applications and detector development, a facility is needed in the U.S. to house dedicated detectors with a larger research scope. The larger detectors at the Gran Sasso Underground National Laboratory have a high priority for use with ongoing solar neutrino projects and are rarely available otherwise. For this reason the PIsCES collaboration has sought the creation of a U.S. underground facility.

XI. Monitoring Nuclear Tests

All nuclear explosions produce large quantities of fission products and their daughters. Important among these radioisotopes are ^{133}Xe and ^{135}Xe. The monitoring of radioactive noble gases is, indeed, one of the techniques enumerated in the Comprehensive Test Ban Treaty (CTBT) for verifying compliance with the accord. The amount of radioactive xenon reaching the surface after an underground detonation and subsequently mixing with the atmosphere is a function of the permeability of the rock, the depth of burial, and the fission yield of the device, often complicating radiochemical monitoring efforts.

In principle the detection of ^{133}Xe (half-life 5.3 days) alone would suffice to confirm that a nuclear explosion has occurred. In fact, however, small but fluctuating amounts of ^{133}Xe are present in the air as a result of emissions from normally operating nuclear reactors. As a result, it may be necessary to detect the ratio of ^{135}Xe

(half life 9.2 hours) to ^{133}Xe in order to confirm that a nuclear detonation, as opposed to reactor emissions, has been observed.

The short half lives of both isotopes, combined with severe dilution of the radioactive gases in the atmosphere and the comparatively long time that may be required to get an air sample, place a premium on the ability to detect both in small quantities. Also, attempts to evade the CTBT, which bans all nuclear test explosions of whatever yield, may employ small tests, where the yield of the nuclear event is tons rather than kilotons. As a result, a very-low-background counting facility such as has been proposed by the PIsCES collaboration for testing at the Gran Sasso Underground National Laboratory is a necessity. PIsCES combined with appropriate sampling techniques would likely lower the yield threshold for the detection of nuclear explosions by radiochemical means by 1 to 3 orders of magnitude below today's best capabilities. Such thresholds are probably well below the level at which any testing state could hope to gain information useful for improving its nuclear stockpile.

Sensitive radiochemical detection of nuclear explosions is particularly important when other possible cheating scenarios are taken into account. The most commonly cited method of evasive testing is to detonate the test device in a very large underground cavity. In theory, at least, the shock wave and seismic signal from the explosion can be reduced by a factor approaching 100. This would make a 1-kiloton explosion seem to seismographers to be only a 10-ton detonation, and hence far harder to detect by seismic means alone. However, a 1-kiloton fission explosion produces the same amount of radioactive xenon, regardless of whether it has been seismically decoupled or was fully tamped in hard rock. Indeed, cavity decoupling acts to release additional radioactive gases in two ways. A fully coupled blast causes a collapse "chimney" to form, sealing in much of the radioactive debris; a decoupled test does not result in such a self-sealing effect. In addition, the large surface area of the decoupling cavity provides more channels through which radioactive gases can reach the surface.

The possibility that another country could improve its nuclear weapons by evasive testing when the U.S. was effectively prevented from any type of testing by the openness of our society played a role in the October, 1999 rejection of the CTBT in the Senate. An underground laboratory with sensitive equipment would address this concern. The facility could contribute significantly to U.S. knowledge of the testing programs of other nations. An underground laboratory in the U.S. to which samples could be brought quickly, and under U.S. control, would be an important addition to efforts to deter nuclear proliferation around the world.

XII. Microbiology

Due to the expense and contamination associated with coring from the surface, few microbial samples have been collected from depths greater than 0.5 kilometers. These few samples nevertheless have demonstrated that microbial communities do extend down to 2.8 kilometers below the surface. The extreme conditions there, including extremes of temperature, pressure, salinity, pH, and ambient radiation, and the low availability of energy sources and liquid H_2O, approach the limits for life and novel "extremo-philes" have been isolated. The paucity of high quality samples, however, has greatly hindered efforts to determine the size, structure, and metabolic activities of the deep subsurface microbial communities and the biogeochemical processes that support them. Recent investigations in the ultradeep gold mines of South Africa indicate that deep underground excavations provide unique ``windows'' into the subsurface continental biosphere.

The depths and pressures of Homestake Mine approaches those at ocean ridges and the temperatures of the mined formations lie within the zone for microbial thermophilicity (45°—65° C).

The microbial communities encountered in these mines are composed of a mixture of contaminating (allochthonous) and indigenous (autochthonous) microorganisms. To distinguish autochthonous from allochthonous microorganisms requires sample collection and processing techniques that quantify and minimize the allochthonous microbial contaminants in the mine water and rock core samples. This permits evaluation of the relationship between the indigenous microbial communities and large-scale hydrogeochemical facies of water as well as small-scale geochemical heterogeneity of rock and pore water.

With long term access to an underground facility with instrumented boreholes and a small field laboratory, scientists can address many fundamental questions regarding the relationship between subsurface microbial community dynamics and biogeochemical and hydrological processes:

• Does primary production of organic substrates by autotrophic microorganisms dominate in certain subsurface terrestrial environments over heterotrophic utilization of organic substrates originally produced by surface-based photosynthesis? This question has been hotly contested in the recent literature and directly impacts the search for life on planets within our solar system.

• What are the abiotic mechanisms and rates for H_2 and CH_4 production in the subsurface and are they sufficient to support chemolithotrophic microbial communities? Radiolytic reactions have been proposed as a source of H_2 and abiotic redox reactions involving water, inorganic C, and mineral-bound Fe(II) have been proposed as sources of H_2, CH_4 and light hydrocarbons.
• Are *in situ* microbial activities so low as to only support average doubling times on the order of centuries? This has been proposed on the basis of geochemical modeling, which yielded rates that were 10^3-10^6 lower than laboratory measurements. *In situ* measurements at high temperature and pressure analogous to those performed at deep-sea vents have not been undertaken. If this hypothesis is correct, have subsurface microorganisms evolved special agents to guard against the deleterious environmental effects, such as ambient radiation?
• A fracture flow hydrogeological regime dominates most terrestrial deep subsurface settings. Are the deep subsurface microbial communities present in fluid-filled fractures distinct from those embedded in the rock strata? Are they responsible for the precipitation of fracture-filling minerals? Because coring such environments from the surface utilizes high pressure drilling fluids, which invariably contaminate the fracture surfaces and adjacent rock matrix, these questions have not been appropriately addressed. Expensive packer systems are also required to isolate discrete fracture zones for fluid sampling to avoid mixing and contamination. Microbial colonization of the deep subsurface occurs primarily by microbial transport through fractures, particularly when topographically- or hydrothermally-driven meteoric water flow and fracture-generated permeability is enhanced by tectonics. With an underground facility, however, low fluid pressure coring and inexpensive packers can be employed enabling us to delineate the differences between fracture and rock matrix microbial communities.

These questions will never be resolved with the collection of one core from a single site or a single set of rock or water samples. Rather, the distribution, diversity and activity of microbial communities in a subsurface environment must be examined in terms of a hydrogeologically and geochemically well-characterized location by a sustained effort over several years. Such a research program would provide greater insights into how microorganisms can function and survive in extreme deep terrestrial environments, how their activity produces distinctive geochemical or molecular signatures, and how we may better culture and study such organisms in the laboratory. New technologies designed to detect life on other planets or quantify microbial activity at high temperature and pressure require ready access to well-characterized subsurface sites for field testing.

Appendix B

National Underground Laboratory Committee Report

John Bahcall[1], Barry Barish[2], Frank Calaprice[3], Janet Conrad[4], Peter J. Doe[5], Thomas Gaisser[6], Wick Haxton[7], Kevin T. Lesko[8], Marvin L. Marshak[9], Kem Robinson[8], Bernard Sadoulet[10], Henry Sobel[11], Michael Wiescher[12], Stan Wojcicki[13], John Wilkerson[5]

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Committee Recommendations

The Committee unanimously recommends the establishment of a deep premier national underground scientific laboratory to enable US leadership and synergism in a broad array of scientific fields in the coming decades.

The committee endorses a single primary site as the most effective method of realizing the anticipated scientific program.

The Committee believes that there are two excellent sites for a premier deep underground science laboratory: Homestake and San Jacinto. The committee admires the commitment of the proponents of the proposals to outreach and communication of basic science to the American public. Based on the information we have received, and on the independent assessment by the committee, we judged that Homestake and San Jacinto are very similar in their technical suitability for underground experiments. Although the committee is not charged with making a formal site selection, time is of the essence, and the agencies need to be aware of the time-sensitive nature of the site selection. We strongly encourage interagency cooperation to help realize this exciting opportunity for science.

At the time of this meeting the committee favors the Homestake site for the following reasons:

- faster time scale to produce important scientific results,
- less initial capital outlay to produce world-class science,
- greater positive impact on the local population,
- lower inherent uncertainties.

The San Jacinto site is also judged to have great potential for several reasons:

- horizontal access allows simple and cost effective access and operation,
- lower operating costs,
- the close proximity of strong scientific research universities.

The Homestake pre-proposal at present is not complete. First the indemnification problem must be solved. Second, a representative, national group of underground scientists must be involved in the preparation of a formal proposal that describes a detailed science program and a complete cost estimate for the laboratory. Given the imminent closure of the Homestake mine, these two issues must be solved in a timely fashion, or the advantages which lead us to favor the Homestake site will be significantly reduced.

Like Homestake, San Jacinto could become the premier site in the world, but further work is needed. Concerns include cost, construction permitting, and site optimization. A more broadly representative group of proposers would be desirable, as well as a comparison of the San Jacinto site to nearby alternatives. We encourage the San Jacinto site advocates to continue working on the preparation of a proposal. If the issues with the Homestake mine are not resolved adequately in a timely fashion, the San Jacinto site is an excellent opportunity.

The Committee has received and considered a pre-proposal from advocates for the Carlsbad Underground National Laboratory. The Technical Assessment Sub-Committee visited the Carlsbad site and the existing Soudan

Underground Laboratory. The Committee believes that both these sites have played important roles in the development of underground physics.

The considerable resources of the Carlsbad site and the relative ease of excavation in salt have and will likely continue to facilitate a number of prototype experiments. The support in New Mexico for fundamental physics at Carlsbad is impressive and provides an excellent example of how a future national laboratory should inform and educate the American people.

The Soudan Laboratory has well hosted the Soudan 2 detector for more than a decade and has recently expanded to house the far detector for the important MINOS Fermilab-to-Soudan neutrino oscillation experiment and the CDMS-II dark matter detector. The physics program at Soudan is an excellent model for how to work collaboratively to inform and educate both the general public and K-12 school children about science.

Despite these considerable assets, the Committee strongly believes that limited depth, and thus excessive cosmogenic background, preclude these facilities from being general purpose underground science facilities for the United States. The Committee further believes that while these sites have a future role in a comprehensive program, the advantages of collaboration and synergy favor focusing the majority of future detectors at a single deep site.

The Need for a National Underground Science Laboratory

Underground science includes studies at the frontiers of particle physics, nuclear physics, astronomy, geology, and biology, as well as applied areas such as materials science and nuclear proliferation. In the past decade, fundamental progress has been made in underground experiments in such diverse and exciting fields as nucleon decay, atmospheric neutrino oscillations, the solar neutrino measurements, searches for dark matter, the measurement of nuclear fusion cross sections at stellar temperatures, and the discovery of novel microorganisms that live deep in the earth. In order to participate in these discoveries, U.S. scientists have had to either take their equipment to other countries or, in a few cases, to make use of non-optimal facilities in the U.S.

The questions addressed by underground experiments are among the most fundamental and exciting problems in modern science. Underground experiments will continue to be at the forefront of fundamental science in the coming decade. Many of the science projects are described in some detail in the accompanying document “Underground Science.”

The next generation of underground experiments is more challenging technically than previous studies and will therefore require both significant resources and good planning and management to succeed. Creating a National Underground Science Laboratory (NUSL) will establish the conditions that will enable the science, which must be done with large, sophisticated equipment, to succeed in a cost effective way. A well run NUSL will have a coherent research program whose priorities are constantly reviewed in order to produce the best science results.

There are advantages in centralizing most of the experiments in one underground laboratory:

- Sharing of common infrastructure including access, machine shops, administrative support, computing, and telecommunications;
- Provision for a common safety support that must oversee equipment and procedures for dangerous components such as flammable andcryogenic materials;
- Synergistic interactions among scientists doing different experiments in an environment where they can easily exchange ideas;
- Establishment of common facilities that can be used by different groups interested in, for example, low radioactivity materials or low level counting measurements;
- Creation of a support organization that can make possible the testing and implementation of new ideas within an established coherent scientific program.
- Providing a critical mass for outreach to the local population, especially K-14, and to the public at large.
- Provide a research center that would be a base for international collaborations to maintain scientific and technical staff for developing and carrying out large scale projects.
- Provide a nurturing and exciting scientific environment in which students and young scientists would develop.
- Provides a center for international scientific meetings,

The committee believes that the arguments in favor of a National Underground Science Laboratory are compelling and urgent.

In order to be world-class, the NUSL must be deep. A depth of approximately 6000-7000 meters of water equivalent (m.w.e) is desirable for manyclasses of experiments and is required for certain experiments such as the next generation of solar neutrino and double beta-decay experiments.Above this level, interference from the cosmic ray related backgrounds constitute the limiting factor for high sensitivity experiments. The nextgeneration solar neutrino detectors, dark matter searches, and double beta-decay studies require as low a cosmic ray produced muon

flux as possible. The simplest and most reliable way to achieve lower cosmic-ray induced backgrounds is to do experiments at greater depths.

The Committee has received many Letters of Interest by scientists throughout the world who would like to perform pioneering experiments in different subjects using such a deep underground laboratory. Currently, he deepest available general underground scientific laboratory is located at a depth of 3800 m.w.e. in the Gran Sasso National Laboratory in Italy.

We believe that the United States will be in a position to lead the world in pioneering scientific investigations by establishing a National Underground Science Laboratory with a depth extending to 7000 m.w.e.

Appendix C:

Report on the Technical Evaluation of Underground Laboratory Sites[1]

F. P. Calaprice[4], P. Doe[5], K. T. Lesko[2], M. L. Marshak[3], Charles Nelson[1], D. Lee Peterson[1], K. E. Robinson[2], J. Wang[2] and J. F. Wilkerson[5]

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Summary

The Technical Assessment Sub-Committee has investigated four proposed national underground science laboratory sites in the United States and visited existing laboratories in Italy and Japan. In addition, the Sub-Committee has met twice with the full Committee and interacted extensively through site visits, telephone and email with advocates for the various sites. The Sub-Committee has also solicited independent engineering and geological advice and has identified and visited on its own several potential horizontal access sites in the California-Nevada border region. In aggregate, the Sub-Committee has committed more than one person-year to its studies.

The site visits and discussions led the Sub-Committee to identify 28 individual factors, grouped into 11 categories that are relevant to site selection. The relative importance of these factors varies. The Sub-Committee reports information about all of these factors both for the proposed sites and for the laboratories in Italy and Japan. The Sub-Committee believes that in many respects the Italian National Laboratory of Gran Sasso (LNGS) sets a "baseline" that a new American laboratory must exceed. This criterion has led the Sub-Committee to an assessment that is summarized here and discussed in the report.

All four sites investigated in detail are acceptable for underground research. The depth factor alone justifies narrowing the site search to Homestake and San Jacinto sites for a primary national facility. These two sites may well be equivalent within the uncertainties of our criteria and assessments, but the availability of the Homestake site is more time-dependent. Selecting between these sites likely requires consideration of other factors, such as the success probability of various development scenarios and tolerance for risk. With respect to Carlsbad Underground

[1] Professor Calaprice is a participant in the Borexino Collaboration in the National Laboratory of Gran Sasso and has 10 years experience in underground science. Dr. Doe, Dr. Lesko and Professor Wilkerson are physicists, participating in the Sudbury Neutrino Observatory (SNO) Collaboration, working in the Creighton Mine in Sudbury, Canada. Professor Marshak, chair of the Technical Sub-Committee, is a participant in the Soudan 2 and MINOS Collaborations, working in the Soudan Mine in northeastern Minnesota. He was the founding director of that laboratory and has 21 years experience in underground science. Dr. Nelson and Dr. Petersen are professional engineers, specializing in underground civil construction projects for transportation, utilities, workspace, storage and other purposes. They have designed both the Soudan 2 and the MINOS halls at the Soudan Laboratory. Dr. Robinson is a physicist at the Lawrence Berkeley National Laboratory and has extensive experience in the planning and construction of large science projects. Dr. Wang is an experienced geophysicist at the Lawrence Berkeley National Laboratory.

National Laboratory and Soudan Laboratory, the Sub-Committee believes that underground science that exploits the special advantages of each of these sites should and will likely continue. The Sub-Committee also suggests continued study at an appropriate level of the California-Nevada border sites, to facilitate a deep alternative if both the Homestake and San Jacinto sites prove infeasible.

The Sub-Committee believes the case for a multi-purpose underground science laboratory is compelling. The technical considerations assessed by the Sub-Committee indicate that the project is feasible. Within one to five years, the United States can have a world-leading facility to advance a wide range of important science that requires very sensitive detectors and a very low background environment. The Sub-Committee believes this initiative should proceed on the fastest possible time scale.

This report is organized in the following manner. The first section introduces the charge, structure, methodology and approach of the Technical Sub-Committee. Section 2 discusses summary characteristics and attributes of each of the principal sites or laboratories visited by the Sub-Committee. Section 3 explains the evaluation criteria used in assessing the sites and the comparative characteristics of the sites and laboratories to these characteristics. The Sub-Committee analysis and summary are presented in Section 4. Appendix A is a glossary of mining and excavation terms whose understanding aids in the discussion of the technical aspects of the various sites. Appendix B is the criteria document that was communicated to the various site advocates in order to ensure that all sites would be studied and evaluated in the same manner. Appendix C is a summary table of specific items and cost information presented by the four major candidate sites. Appendix D presents the findings and preliminary evaluation of possible alternative candidate sites in the California-Nevada border area.

1. Introduction

The Technical Evaluation Sub-Committee was charged with developing a set of criteria to evaluate sites for a possible national underground physics laboratory in the United States, evaluating a set of sites against those criteria and making an initial assessment regarding site selection. The Sub-Committee gratefully acknowledges financial support for its efforts from the National Science Foundation through the Institute for Nuclear Theory at the University of Washington and from the U.S. Department of Energy through the School of Physics and Astronomy at the University of Minnesota. The Sub-Committee also wishes to express its thanks for the gracious hospitality it has received from site proponents and interested citizens during its site visits, and the cordial reception accorded to Committee members during site visits to existing underground physics laboratories outside the United States.

A brief summary of the Sub-Committee's work is as follows: The Sub-Committee retained the firm of CNA Engineers of Minneapolis to provide expertise and advice to the Committee during its study. CNA Engineers has 17 years of experience in engineering design and construction supervision at Soudan Underground Physics Laboratory and has worked on numerous underground transportation, workspace and sanitation projects in different parts of the world. Sub-Committee members participated in a meeting with the full committee in Alexandria, Virginia, on December 14. On January 9-11, Sub-Committee members visited the Homestake

Mine in Lead SD, followed by a visit to the Soudan Mine, MN on January 12. Sub-Committee members next visited the National Laboratory of Gran Sasso in Abruzzo, Italy, on January 29-30. They next visited the Kamioka Laboratory in Mozumi, Japan on February 12-13, followed by a visit to the WIPP site near Carlsbad NM on February 16. Several members of the Sub-Committee visited possible site for a horizontal access laboratory along the California-Nevada border on February 21-23. Sub-Committee members toured the San Jacinto site near Palm Springs CA on February 28 and March 1. The Sub-Committee then met in Berkeley CA on March 2 and reported to the full Committee on March 3-4. During this entire process, the members of the Sub-Committee exchanged numerous emails and telephone calls with each other, members of the full Committee, site proponents and other interested persons.

To assist site proponents in the preparation of pre-proposals and to help guide its own thinking, the Sub-Committee prepared a document entitled *Criteria for Technical Evaluation of an Underground Laboratory Site*, which is included as Appendix B. The "Criteria" document includes work breakdown structure (WBS) for both the capital and operations activities of a national underground laboratory. For specificity, the "Criteria" document describes four example detectors. Detector A is a modest-sized, ultra-low-background detector of the type that might be used for a $\beta\beta$ decay or a cold dark matter experiment. The salient feature of Detector B is a large inventory (perhaps 1 kiloton) of flammable liquid scintillator, similar to a super-Borexino or a super-KamLAND. Detector C has an even larger inventory of a liquid cryogen, for example, 5 kilotons of argon. Finally, Detector D is an ultra-K detector, containing perhaps 0.5 megatons of water. While these four example detectors do not include all possibilities, they are good indicators of the types of stress that will be placed on a national underground laboratory. Thus, they provide a good metric for site evaluation.

The Sub-Committee believes that in many ways the National Laboratory of Gran Sasso (LNGS) provides a *baseline* for evaluating national underground laboratory proposals and sites in the United States. While the LNGS seems to be currently full and has a planned program of experimentation well into the future, the Sub-Committee believes that LNGS could and quite likely would make space for a new compelling and well-planned experiment. Thus, the Sub-Committee believes that merely duplicating the capabilities of LNGS in the United States is not sufficient. The new United States National Underground Scientific Laboratory (USNUSL) should enable a new generation of detectors with significant increases in sensitivity over what is currently available. This goal of significant increase in sensitivity underlies the discussion in this report.

The Sub-Committee believes that historically physics detectors have attained increased sensitivity in two ways—increasing signal and decreasing background. One or more of the following specific strategies are likely necessary to achieve the goal of higher sensitivity:

1. Increase target or detector mass
2. Use more sensitive and likely more exotic materials, for example, increasingly use materials which are more costly, unstable, toxic, flammable, explosive or cryogenic
3. Reduce both direct and induced cosmogenic background with increased depth underground

4. Reduce radioactivity background by locating in less radioactive rock, by improved local shielding and/or by better control of radon
5. Increase signal and/or reduce background by achieving lower levels of naturally occurring radioactive impurities
6. Increase signal and/or reduce background by using more and/or better electronics, software algorithms and computer processing

The first five of these strategies directly relate to the properties of the proposed USNUSL and its infrastructure. Strategies involving electronics and computer processing or software can presumably be implemented at any laboratory site. The Sub-Committee criteria for evaluating possible laboratory sites are thus related to the first five of these strategies to achieve a new level of sensitivity in a wide range of low background detectors.

The Sub-Committee's methodology during its visits was to engage the site proponent's in vigorous discussion about how to prepare the best possible case for each site. First, the Sub-Committee received information from the advocates, in some cases in advance and in others during the site visit. The Sub-Committee then inspected the physical site. Next the Sub-Committee discussed the information received, the on-site observations and the information received from its consultants with the site advocates. In some cases, these discussions were quite extensive and resulted in major re-thinking of their ideas by the site advocates. The Sub-Committee then received additional and, in some cases, new information from the site advocates. Finally, the Sub-Committee turned to an evaluative mode and attempted to assess all the information it had received from the site advocates, from its own observation and from its consultants with regard to each site.

We note a caveat that should be used in considering our report. Our entire process was very short. We very much appreciate the responses we received from site advocates under extreme time pressure, but we realize, that of necessity, the scope of these responses was limited. We restricted advocates to 10-page pre-proposals, again because of the time constraints. Our process is perhaps best regarded as a preliminary technical review. While we are confident of the thrusts of our analyses, we believe the scientific communities should subject actual proposals for a national underground science laboratory to extensive peer review.

2. Sites

The Sub-Committee has investigated two existing foreign laboratories—National Laboratory of Gran Sasso (LNGS) and Kamioka, four proposed sites—the Homestake Mine, San Jacinto, the Soudan Underground Physics Laboratory and the Waste Isolation Pilot Plant (WIPP). Near the end of the Sub-Committee's consideration process, the proponents of a laboratory at WIPP renamed their proposal Carlsbad Underground National Laboratory (CUNL) and that name will be used to describe the WIPP site in the remainder of this report.

The Sub-Committee also sought to locate possible sites without current proponents, so-called *green-field* sites. A laboratory built at an arbitrary location would require two new vertical shafts or a single new vertical shaft divided into two independent shafts by a fire-rated barrier. The construction cost of either arrangement to a depth of 2,500 m is likely greater than $200 million not including the cost of laboratories, surface facilities or detectors. The Sub-Committee believes that it would be difficult to justify such an expense. A more feasible alternative is to find other

sites similar to Mt. San Jacinto, where the ground elevation changes so rapidly that a depth of 2,500 m could be achieved with a horizontal access adit or tunnel of length 5,000 m to 10,000 m. The construction cost for access in these sites is perhaps 50% of the cost of sinking two shafts. In addition, the resultant horizontal access has lower operating costs, lower costs for excavation of laboratories and lower costs for detector installation than a vertical shaft laboratory. The Sub-Committee identified many sites, but selected four such sites in the vicinity of the California-Nevada border for on-site investigations. These sites are presented here as a composite in a very preliminary context as the California-Nevada sites.

2.1 National Laboratory of Gran Sasso (LNGS): The LNGS is located just outside Assergi between L'Aquila and Teramo in the Abruzzo region of Italy, approximately 150 km east of Rome. The LNGS was built as a supplement to a 11 km double tunnel on the A24 *autostrada* that traverses the Italian peninsula west-to-east from Rome to the Adriatic coast. The underground laboratory with a depth of 3,800 mwe consists of three primary halls of approximate dimension 20 m by 100 m by 20 m high. The access to the LNGS is by vehicle from the westbound *autostrada* tunnel. The experimental halls are connected by a series of underground drifts, some of which are large enough to permit access by a standard highway semi-trailer to each of the experimental halls. The LNGS has a campus consisting of several buildings housing offices, laboratories, supply rooms, machine shops, dormitory rooms and a cafeteria about 1 km outside the western tunnel portal. Access from this campus to the underground laboratory requires driving onto the *autostrada*, through the entire length of the eastbound tunnel, accessing a special ramp and then driving approximately halfway through the westbound tunnel. The return to the outside campus is shorter, requiring only a drive halfway through the westbound tunnel and then the 1 km to the campus.

The LNGS has about 15 years of excellent operating experience. The replacement of detectors by new detectors is now an ongoing process. An expansion of the LNGS was authorized in 1990, but has been delayed by environmental and other concerns. The LNGS is well subscribed by both old and new detectors, but could likely accommodate a totally new detector within the next five years, if the detector were funded and had a compelling physics rationale. LNGS is a truly international laboratory.

2.2 Kamioka Observatory Laboratory (Super-K and KamLAND): The Kamioka Laboratory is located near Mozumi, about 75 km south of Toyama, a port on the Sea of Japan. Mozumi is approximately 300 km west of Tokyo. The Kamioka laboratory was built in a mine complex at a shielding depth of 2700 mwe. It was initially accessed via a 7 km mine rail adit beginning on the mountainside above Mozumi. The primary access now is through a 3 km vehicular adit capable of passing a standard highway semi-trailer. The adit portal is located about 10 km by road from Mozumi. The underground facilities consist primarily of two main laboratories both upright cylinders with domed roofs. The smaller laboratory with a liquid volume of approximately 10,000 m^3 once housed the Kamioka detector. The KamLAND liquid scintillator detector is now being installed in this hall. The second hall, with a liquid volume of approximately 50,000 m^3 houses the Super-Kamiokande detector. The complex includes a few drifts that are used for access and some stub drifts that are used for control rooms, storage and vehicle parking.

The Kamioka Laboratory has an office building and a dormitory/cafeteria building, both located in Mozumi. The round-trip from Mozumi to the laboratory requires about 30 minutes. Because Mozumi is very small, population less than 1,000, many visiting physicists live about 3/4-hour drive from Mozumi, towards the coast, where the population is larger and services more numerous.

2.3 Carlsbad Underground National Laboratory: The proposed CUNL would have an underground laboratory located at the Waste Isolation Pilot Plant, a government-owned, DOE facility. WIPP is located about 50 km east of Carlsbad, Eddy County, NM in the Permian Basin, a large deposit of halite and anhydride layers with underlying rich deposits of petroleum and natural gas. The office-laboratory-stock room complex for CUNL would likely be located in Carlsbad, possibly on land owned by the State of New Mexico and used by New Mexico State University for an environmental monitoring center.

The CUNL laboratory site is an extraordinary complex of surface and underground facilities, including state-of-the-art hoisting, ventilation and materials handling systems. The underground site is completely dry; no pumping is required. The current underground complex is located in an extensive salt formation at a depth of 1,600-1,800 mwe. The CUNL proponents have developed a plan to locate a laboratory complex near the bottom of the halite, a depth of 3,000-3,200 mwe. The site advocates and their technical consultants report that depths below 3,200 mwe cannot be achieved at CUNL because of the risk associated with digging into the hydrocarbon deposits known to exist below the halite and anhydride beds.

2.4 Homestake Underground National Laboratory: The Homestake Gold Mine is located in Lead, Lawrence County, SD. This mine has been worked for approximately 125 years and has more than 800 km of drifts at various levels with the deepest workings at 2,600 m. The mine has two active shafts (Yates shaft and Ross shaft) with multi-compartment hoists that reach a level 1,600 m below the ground. From there, access to the lower levels is via an internal winze (shaft) or via a ramp system that accommodates rubber-tired vehicles. The Homestake mine has a large number of surface buildings, many of which are quite old and probably not of high utility for an underground laboratory. The heads of both shafts are located within a 5-minute drive of the center of Lead. The nearest commercial airport at Rapid City is about an hour drive to the east.

The Homestake mine has a number of existing underground rooms that are for used for various support functions at a variety of depths down to 2,100 m. These rooms are typically 20 m by 50 m by 10 m in height. The rooms are generally stabilized with conventional techniques such as rockbolting or shotcreting, but appear stable over time intervals of more than 10 years. Homestake could house laboratories at several different depths with a maximum possible depth of about 7,200 mwe. Because of temperature and lithostatic pressure considerations, the bulk of the low background laboratories would likely be located at 6,500 mwe. Because of the configuration of the mine systems, a likely location of less deep laboratories would be at about 4,500 mwe. Converting the mine to a national underground laboratory would require renovation of the mine's mechanical and access systems, closing off a large part of the mine that will not be used, and construction of new caverns to house detectors. These detector laboratories would be located in non-ore-bearing rock. The Homestake Mining Company also requires an

indemnification against liabilities as a result of science activities. This important issue appears to require federal legislation.

2.5 Mount San Jacinto: Mt. San Jacinto is located in Riverside County CA with its base rising at the western edge of the City of Palm Springs CA. An aerial tramway operated by a public authority traverses up most of the mountain's western slope. The portal for a proposed horizontal access adit (tunnel) to the Mt. San Jacinto underground laboratory would begin about 1 km to the west of the Tramway Valley Station, about 100 m south and connected to the Tramway access road. The area around the portal is currently an overflow parking lot for the Tramway, that has also been used to store refuse from the recent Tramway renovation. The land required for the laboratory is mostly state-owned, either by the Tramway authority or as part of a state park. The site of an external campus for the San Jacinto laboratory is not yet defined, although the advocates suggest a wide availability of sites in Palm Springs, a roughly 30 minute round trip from the underground laboratory. These sites include private land and public land assigned to higher education.

The initial cost of the proposed San Jacinto Laboratory is significantly affected by the length of the access adit, which in turn depends on the required laboratory depth. The Sub-Committee believes the most desirable option achieves a depth of 6,500 mwe with a slightly upward-sloping adit of approximately 7,700 m in length. Approximately 10% more depth could be achieved with a somewhat shorter, downward-sloping adit, albeit with an additional operating cost because of the need to pump water.

2.6 Soudan Underground Laboratory: The Soudan Underground Laboratory is located at a depth of 2,200 mwe in St. Louis County in northeastern Minnesota. The Soudan Laboratory is located in a hematite mine converted to a state park in the 1960's. Physics experiments at Soudan started in 1981. Since that time, two large experimental halls have been excavated, each approximately 15 m wide by 12 m high. The Soudan 2 hall is about 70 m in length; the MINOS hall is approximately 100 m in length. Currently, the Soudan Laboratory has only a single usable shaft with a cage dimension of approximately 1 m wide by 2 m deep with the possibility of carrying lengths up to 12 m and weights up to 6 tons. The Soudan Laboratory is the target for a Fermilab neutrino beam that is currently under construction.

Because of its shallow depth, the advocates of the Soudan Laboratory believe that it is best suited for detectors that utilize it special capabilities of current availability, staff experienced in installing and operating physics detectors and a neutrino beam. Soudan is not suited for ultra-low background detectors because of its limited depth. It is not suited for the detectors with flammables or cryogens because of its single shaft. Building the large *ultra-K* water Cerenkov detector at Soudan would require a new primary shaft with the existing shaft used as a secondary escape. Available land exists for this option and the cost of the new shaft would be a small fraction of the total project cost for "ultra-K."

2.7 California-Nevada Border Horizontal Access Sites: The sites investigated in the California-Nevada border region include Charleston Peak, between Las Vegas and Pahrump in Nevada, Telescope Peak between Panamint Valley and Death Valley in California, Mount Tom and Mount Morgan, west of Bishop CA and Boundary Peak in the White Mountains almost

directly on the California-Nevada border. It appears possible to achieve depths of 6,000 mwe or more with horizontal or slightly inclined adit lengths of 6,000 to 10,000 m. The Mt. Tom/Mt. Morgan site has an existing, unused mine that allows a detailed investigation of the geology without additional drilling. More information about these sites is presented in Appendix D.

3. Evaluation Factors

The Sub-Committee used its collective experience in performing nuclear and elementary particle physics experiments, including underground experiments, as well as its observations during site visits to existing laboratories to develop a set of evaluation factors that can be used to assess the potential of various sites. Clearly, some of the factors are much more important than others. The weights assigned to the various factors by different people will vary based on individual experiences, tolerance for risk and general approach. The Sub-Committee also believes that assessments on each factor can be combined in different ways—that is, additively or multiplicatively. Indeed, some factors should likely be combined one way and other factors should be combined another way. Regardless of these concerns, the Sub-Committee used assessments with respect to these factors to reach the conclusions that are reported in Section 4. The methodology issues lead to reliability estimates on the conclusions that are also discussed in that section.

The recommended evaluation criteria include the following 28 factors collected into 11 groups:

Group 1:	Construction Costs—access, underground halls, outfitting mechanical/electrical systems, installing detectors
Group 2:	Facility Operating Costs
Group 3:	Risk—environmental/permitting, rock/salt structural integrity, seismic, mechanical systems
Group 4:	Management—scientific, site operations, ownership/sharing
Group 5:	Depth
Group 6:	Neutrino Beam
Group 7:	Time to Detector Installation
Group 8:	Outreach Possibilities
Group 9:	Local Awareness and Support
Group 10:	Laboratory Context—cost of living, climate, travel to laboratory area, commuting to laboratory, local universities, ease of access, local industrial infrastructure, scientific environment
Group 11:	Suitability for Detectors—ultra-low background, flammables and cryogens, "ultra-K" large water Cerenkov detector

3.1 Underground Costs: Both capital and operating costs are clearly important criteria in site selection and design of an underground science laboratory. During the site evaluation process, the Sub-Committee developed some general understandings of cost trade-offs for underground laboratories, which are reported here. Appendix C is a comparative table of the four principal candidate sites of their shielding depth and estimated costs.

(a) Capital or construction cost: The up-front cost of building a laboratory depends on a number of factors including (1) existing physical plant, if any, (2) whether the laboratory is built in rock or salt, (3) the quality of the ground, (4) the size of equipment that can be used, (5) the amount of materials handling required and (6) the cost, skill and availability of labor.

An *existing physical plant* is advantageous for a number of reasons, even if the laboratory is primarily built new. Existing access permits direct inspection of the ground quality without extensive test boring programs. An existing access has generally established a history of permitting for the site, as well a public perception that heavy construction on a site is expected. Existing access can be renovated, generally at less cost than new construction. Even if not renovated, an existing access can provide a secondary egress for safety or a ventilation access, reducing or eliminating the need for these features in new construction. Finally, since up-boring of a shaft is generally cheaper than down-boring, an existing access can reduce the cost of new shaft development.

There are some cost disadvantages associated with existing access. These include possibly antiquated mechanical systems that might require substantial maintenance or updating and buildings that need to be removed; other closure issues associated with shrinking the size of the existing underground physical plant to a needed and efficient size, including the cost of sealing off unused areas and pumping from a larger than necessary physical plant; legacy environmental issues and a need for workforce re-education and re-training to adapt from mining to civil construction.

Unit volume excavation costs in *salt* are approximately 3 to 5 times less than construction costs in *rock*. Salt is generally excavated using continuous grinders that are able to loosen enormous quantities of salt per person-hour worked. The density of salt is about 20% less than the density of rock, resulting in lower materials handling costs. In some locations, excavated salt can be sold, while excavated rock is generally at best given away, reducing disposal costs. Salt deposits are dry, so water handling is not required. Salt also exhibits plastic flow and pure salt does not generally have faults.

Ground quality affects construction costs in a number of different ways. The best ground is homogenous, high compressive strength rock or pure halite or anhydride beds without clay or rock inclusions. Areas with ore generally have heterogeneous rock and are less desirable. Areas that have been mined or have fractures or faults or inclusions have inhomogeneous stress fields and are more difficult both for design and construction. The poorer the ground, the more ground support is required. This ground support in the form of bolts, mesh and/or shotcrete increases both project cost and time.

Project cost is also affected by the *size of equipment* that can be used for excavation and transportation of muck and the *amount of materials handling* that is required. Labor typically represents about 40% of total project cost. Larger equipment can increase worker productivity and reduce labor cost. Each transfer of excavated rock or muck from one conveyance to another also increases cost.

Since labor is a significant cost, the *cost, availability and productivity of labor* are all important factors. Under the Davis-Bacon Act, labor costs are determined by the U.S. Department of Labor for each type of worker in each geographic area. A shortage of labor can increase costs through delay. Although, in principle, such delay costs to the contractor, in reality, contractors who are losing money seek to recover some of these losses from owners in a variety of ways. Well-trained and motivated workers and efficient management can also reduce project

costs. The relatively high mobility of workers in the United States may limit the effect of these factors.

The cost of excavating *shafts* is approximately two to three times the cost of excavating *adits, drifts or tunnels* of similar cross-section and length. This cost primarily results from the materials handling problem. When rock or other material is loosen by blasting or continuous mining in a tunnel project, the loose material or muck can be easily scooped up with a front-end loader and placed on a conveyer or in a skip or dump truck for disposal. This method applies to downgrade tunnels, providing the slope of the excavation is not too large. When material in a down-bored shaft project, it is difficult to pick up and move. One exception is when the bottom of a new shaft is accessible via another shaft. Then, the muck can be pushed down a bored hole and retrieved using heavy equipment at the bottom. Another more efficient alternative is to drive a shaft upward—a so-called raise. This approach also facilitates automated mucking.

The cost of tunnels and shafts can be as much as doubled by *water infiltration* along the entire length. Water infiltration occurs in fractured ground conditions. Progress by either tunnel boring machine (TBM) or drill-and-blast methods is slower in fractured ground due to rock support issues. Furthermore, tunnels and shafts with water infiltration generally require watertight linings that also slow the progress of the work. In many cases, water infiltration and the resultant linings are only an issue for a fraction of the tunnel or shaft length—perhaps 10%—and the costs are reduced proportionately.

The excavation costs for *laboratory caverns* can vary by as much as a factor of two with lower costs for horizontal access. Generally, horizontal access permits use of larger equipment, which results in higher labor productivity, as discussed earlier. Secondly, horizontal access generally reduces materials handling because muck can be directly loaded into over-the-highway dump trucks and taken from the excavation site to a disposal area with no further handling. A vertical access facility often requires moving muck with underground transport, shifting it to a vertical skip and then moving the muck to long distance transport on the surface.

(b) Operating cost: Over a 20-year project lifetime, the laboratory operating costs are likely to exceed the capital costs. In general, the operating costs depend on the number, size and complexity of mechanical and other systems. These systems typically include: hoisting (in vertical access laboratories), ventilation, pumping (in vertical or downward-sloping horizontal access laboratories), cooling (depending on electrical load and rock temperature), electrical and security. These costs for a laboratory alone—not including the detectors' operating costs—are likely to amount to 5-10% of the capital cost per year. Because vertical access laboratories have more systems than horizontal access laboratories, the operating costs for a vertical access laboratory could be two to three times higher than for horizontal access. Local wage scales will certainly affect operating costs.

3.2 Construction Cost Factors

3.2.1. Construction Cost for Access: This factor includes site acquisition costs and costs for renovation and construction of shafts, adits, roadways, hoisting mechanisms or any other infrastructure required for both laboratory construction and ongoing physics access to the actual laboratory sites. Essentially, this item includes all capital costs other than costs specifically included in Factors 3.2.2 and 3.2.3 described below.

Gran Sasso: Horizontal vehicular tunnel access mostly built as highway project
Kamioka: original access via 7 km mine rail adit built for mining; current main access through single-lane vehicle adit
CUNL: Existing access for small or shallow detectors. New shaft required for access to the maximum 3,200 mwe level
Homestake: Proposed plan would renovate and extend one shaft in Phase 2 of the project
San Jacinto: New horizontal tunnel is required
Soudan: Existing access for small detectors. New shaft would be required for "ultra-K" detector

3.2.2. Construction Cost for Laboratories: The Sub-Committee's Technical Criteria document described three laboratories as part of the conceptual plan for the USNUSL. This factor includes the cost of preparing cavities for these laboratories including excavation, rock/salt disposal, and rock bolting, shotcreting and other procedures required to prepare clean, stable but empty caverns for detectors.

Gran Sasso: 3 laboratories, each approximately 20 m by 100 m by 20 m high built by drill-and-blast techniques with muck removal through highway tunnel; hard limestone rock; horizontal access
Kamioka: Super-K cavity holds approximately 50,000 m^3 of water of water and Kamiokande cavity (now housing KamLAND) approximately 5 times smaller; hard rock; horizontal access
CUNL: Salt; vertical access
Homestake: Hard rock; vertical access
San Jacinto: Hard rock; horizontal access
Soudan: Hard rock; vertical access

3.2.3. Construction Cost for Lab Mechanical Systems (Outfitting): In a typical underground laboratory, the cost for outfitting may nearly equal the cost for construction. Outfitting includes electrical power distribution, HVAC systems, life safety systems, general-purpose rigging and detector support systems, networking and communications systems and any other systems required to convert empty space into an efficient physics laboratory. Outfitting costs will vary from one site to another depending on costs of materials, prevailing wage rates and site properties such as ambient rock temperature that affects HVAC systems and method of egress that affects life safety systems. Davis-Bacon Wage Index (DBWI) computed as (1 electrician + 0.5 boilermaker + 1 equipment operator + 1 concrete finisher) normalized to Soudan as 1.00. The high level of integration in the American economy may reduce the effects of local wage variations.

Gran Sasso: Horizontal access
Kamioka: Horizontal access
CUNL: Vertical access, DBWI=0.80
Homestake: Vertical access, DBWI=0.63
San Jacinto: Horizontal access, DBWI=1.21
Soudan: Vertical access, DBWI=1.00

3.2.4 Construction Cost for Detector Installation: The cost of installation varies from detector to detector but it is at least 10 percent of a total detector cost and, in some cases, may be more than 20 percent of the total cost. Installation may also be a significant factor in the time required from approval of an experiment to the first physics publication. In some cases, installation costs are understated, because post-docs or graduate students perform a significant amount of installation work. Some sites may have lower installation costs or shorter installation times than other detectors because of ability to bring equipment to the laboratory in larger or heavier units or because of lower installation labor costs.

Gran Sasso: Horizontal access for large equipment and sub-contractors; large halls with bridge cranes provide adequate room for staging and good materials handling capability
Kamioka: Horizontal access for moderate-sized equipment and sub-contractors; limited staging area
CUNL: Large, modern hoist currently exists to 2000 foot level
Homestake: Access for detector installation is presently limited but improves after hoist and shaft upgrading in Phase 2
San Jacinto: Horizontal access for large equipment and sub-contractors
Soudan: Installation efficiency for "ultra-K" detector improves after construction of new shaft

3.3 Operating Cost

The operating cost of a site is the expenditure required for site for maintenance and depreciation of the site infrastructure not including the specific costs of operation of any detectors. Operating costs for sites will vary depending on prevailing wage rates and the extent and complexity of the mechanical systems required by the site. Sharing the site with another entity that contributes to operating costs for common access or other mechanical systems may reduce laboratory operating costs.

Gran Sasso: Maintenance of access mostly by *autostrada* agency; horizontal access requires fewer mechanical systems
Kamioka: Access shared with mining company; horizontal access requires fewer mechanical systems
CUNL: Vertical access and ventilation systems shared with waste repository; pumping and cooling not required
Homestake: Vertical access; science is sole user of all systems including access, pumping, ventilation and cooling
San Jacinto: Horizontal access; science is sole user of ventilation and cooling systems

Soudan: Vertical access; share access and pumping with state park; mostly natural ventilation

3.4 Risk Factors

3.4.1 Permitting and Environmental Risk: There is considerable experience both in United States and abroad of delay and cost escalation in major projects, including scientific projects, due to permitting and/or environmental considerations. There is no doubt that USNUSL must operate in a safe and environmentally conscious manner. This factor suggests more the time and expense required at various sites to determine what is safe and environmentally sound. It also includes an estimation of the time and cost that might be required to ascertain whether a particular detector containing exotic materials could be installed at USNUSL.

Gran Sasso: Laboratory expansion has been delayed for years over environmental concerns
Kamioka: Historic mining area; shared location between science and active mining
CUNL: Extensive permitting history and experience; shared mission site with primary focus on transuranic waste disposal
Homestake: Liability release legislation required; historic mining area; single purpose site after conversion
San Jacinto: Large nearby population; single purpose site
Soudan: Historic mining area; University of Minnesota issues own building permits

3.4.2 Rock/Salt Risk: This risk factor includes multiple considerations relative to the risk of capital and operating cost overruns due to unexpected rock or salt conditions. The sites vary considerably in the degree of knowledge of actual rock conditions at the proposed USNUSL site. The deep sites have high lithostatic pressures and laboratory construction could encounter considerable difficulty, even in sites with relatively well-known rock conditions. The risk in salt is different and is related mostly to possible unexpected costs due to detector or support structure misalignment as a result of salt creep or a possible need to re-mine cavities

Gran Sasso: Hard limestone rock; *autostrada* tunnel permits access to rock in order to choose optimal laboratory site, but major aquifers present
Kamioka: Hard rock; extensive mining development permits access to rock in order to choose optimal laboratory site
CUNL: Extensive salt layer with clay layer intrusions
Homestake: Multiple rock types; extensive mining development permits access to rock in order to choose optimal laboratory site
San Jacinto: Igneous rock batholith; not feasible to core much of access tunnel prior to construction
Soudan: Multiple rock types; schistose

3.4.3 Seismic Risk: Although engineering can control seismic risk, there is an additional cost required to build USNUSL and install detectors in a seismically active region. In addition, there is a risk of a more intense than expected earthquake or an engineering or installation mistake that leads to failure in an earthquake of expected magnitude.

Gran Sasso: Active seismic area; the highway tunnels traverse two vertical faults and follow under a third horizontal fault.
Kamioka: An active seismic region with mining-related local seismic activity
CUNL: No seismic activity in recent geologic history
Homestake: No seismic activity in recent geologic history:
San Jacinto: San Jacinto and San Andreas faults within 25 km. Both faults are major and currently active.
Soudan: No seismic activity in recent geologic history

3.4.4 Mechanical Systems Risk: Sites with more extensive HVAC, hoisting or other machinery have an operating cost risk due to the possibility of failure of significant mechanical systems. Such failure could entail significant emergency operating expenditures and/or significant lost time in access to the USNUSL. While the importance of this factor is likely correlated with the magnitude of the operating cost, the Sub-Committee deems this risk factor of sufficient importance to include it separately.

Gran Sasso: Horizontal access; only major mechanical system is ventilation
Kamioka: Horizontal access; major mechanical systems are ventilation and radon de-gasification
CUNL: Hoisting and ventilation systems; risk shared with waste repository facility
Homestake: Hoisting, ventilation, pumping and cooling systems
San Jacinto: Ventilation and cooling systems
Soudan: Hoisting and pumping systems; risk shared with state park

3.5 Management

3.5.1 Scientific Management: While the ultimate decisions about scientific management will be made in discussion with the funding agencies, this issue was discussed during several of the site visits. The usual national laboratory model, both in the United States and abroad, centers on an established scientist as the Scientific Director. A Board of Directors appoints the Scientific Director, after extensive consultation in the scientific community and with the funding agencies. The Board members are themselves appointed by important national institutions. A Program Advisory Committee, consisting of a broad range of scientific experts, advises the Scientific Director. The quality of the laboratory program is reviewed by a Visiting Committee, which includes expert scientists, who are mostly not involved in the day-to-day activities of the Laboratory. Those scientists who are directly involved in the Laboratory form a Users' Committee to represent their ideas and concerns.

Gran Sasso: Management by INFN
Kamioka: Management by Institute for Cosmic Ray Research (ICRR)
CUNL: LANL (University of California), Department of Energy, New Mexico State University, University of New Mexico plus others
Homestake: University or other consortium including the South Dakota School of Mines & Technology
San Jacinto: University of California, particularly UC Irvine, plus others
Soudan: University of Minnesota plus others

3.5.2 Site Operations Management: Management of site operations may require somewhat different skills from scientific management. While in the usual national laboratory model, site operations form a distinct division that ultimately reports to the Scientific Director, other models are possible. In particular, some sites have existing operational structures with extensive knowledge and experience in operating the site. These human resources are important and care must be taken to retain and enhance them. In general, civil construction and laboratory operation are different enough from mining operations and ore extraction that re-training and re-deployment of existing staff may be advisable.

Gran Sasso: Site operations management by INFN
Kamioka: Mining operations and site work performed by Mitsui Corporation
CUNL: Site operations management by Westinghouse TRU Solutions, the existing management and operations contractor to the DOE
Homestake: Site operations by existing staff following re-orientation and re-training
San Jacinto: Assemble new staff under University of California management
Soudan: Augment existing physics operational staff

3.5.3 Ownership and Site Sharing: The sites considered differ in whether use of the site is exclusive to USNUSL or use of the site is shared with another entity. Sharing has an advantage in reducing operating costs, but it has a disadvantage in potential access or other conflicts. Sharing is particularly disadvantageous if the use other than scientific research has priority. This factor also considers whether the management entity for USNUSL has sufficient ownership and/or easements to provide for future expansion or modification of the site capabilities.

Gran Sasso: Access shared with *autostrada*, but otherwise dedicated site
Kamioka: Mining activities in the past are now sharply curtailed
CUNL: Ownership by DOE; shared use with waste repository
Homestake: Ownership by State of South Dakota; exclusive science use
San Jacinto: Ownership by State of California; exclusive science use
Soudan: Ownership by State of Minnesota; shared use with state park

3.6 Depth

Detectors are placed underground primarily to lower backgrounds due to the direct and indirect effects of cosmic rays. Direct effects include the passage of muon and muon-generated particles through the detector. Indirect effects include radioactivity generated by spallation and nuclear de-excitation following the passage of a muon or muon-generated particle. Although the sensitivity of particular detectors to depth varies, for most detectors deeper is better down to depths at which neutrino-generated muons dominate the muon flux. Depths of more than 7,000 mwe are probably not important but 7,000 mwe is clearly better than 5,000 mwe. For the same vertical depth, a site with relatively flat overburden has integrated flux equivalent depth about 10 percent greater than that of a mountain. It is possible that some detectors would prefer shallower depths, either to use remnant muon flux for testing or calibration or because of somewhat lower costs associated with construction and operation at shallower depths. For this reason, a site that offers a variety of depths, including one or more deep locations, is likely preferably to a site with a single, fixed depth.

Gran Sasso: 3,800 mwe; mountain; single depth
Kamioka: 2,700 mwe; mountain; single depth
CUNL: 1,600-2,000 mwe now; 3,200 mwe later with new shaft; flat overburden; halite and anhydride overburden has lower density but higher atomic number than rock
Homestake: 6,700 mwe most likely depth; flat overburden; most feasible depths include 700 mwe, 1,500 mwe; 2,100 mwe; 3,100 mwe; 3,400 mwe; 4,500 mwe; 7,200 mwe
San Jacinto: 6,500 mwe; mountain; range of depths can be selected by laboratory location
Soudan: 2,200 mwe; flat overburden; depth measured using muon flux

3.7 Neutrino Beam

The study of neutrinos is an important feature of underground, low-background physics. Current thinking is that the "ideal" baseline for a neutrino oscillation experiment is approximately 2,500 km.

Gran Sasso: 750 km to CERN
Kamioka: 300 km to KEK
CUNL: 1,750 km to FNAL; 2,900 km to BNL
Homestake: 1,290 km to FNAL; 2,530 km to BNL
San Jacinto: 2,610 km to FNAL
Soudan: Beam from FNAL currently under construction — 740 km to FNAL; 1,720 km to BNL

3.8 Time to Install First Detectors

Although the time scale for accelerator and non-accelerator nuclear and particle physics experiments has become increasingly long, there is value to achieving the first physics results as early as possible after authorization to establish a USNUSL. This criterion clearly favors existing over new sites, but the Sub-Committee believes that its importance justifies its inclusion.

Gran Sasso: Currently operating
Kamioka: Currently operating
CUNL: Small detectors now; medium detectors in 6 months; large detectors at new, deeper level in 3 years
Homestake: Small detectors now, larger detectors in 1-3 years (new larger chambers in 1-2 years, new hoist in 2-3 years).
San Jacinto: 5 years
Soudan: Small detectors now, *ultra-K* in 5 years

3.9 Outreach

The American scientific community has a clear responsibility to America's citizens to inform them about the goals and progress of scientific research. The science likely to take place at USNUSL is exciting fundamental science that can be well communicated to both the general public and to diverse student and other groups. This factor represents an estimation of both the outreach potential of a particular site based on the size of the local permanent and vacationing population and the perceived quality of any outreach plans described by the site advocates.

Gran Sasso: Good public visibility regionally and nationally; frequent tours by school and other groups
Kamioka: Good public visibility regionally and nationally; tours by school and other groups
CUNL: 500,000 tourists per year visit Carlsbad Caverns; NMSU outreach center program in Carlsbad
Homestake: 3 million tourists per year in Black Hills
San Jacinto: 300,000 residents in Coachella Valley; 15 million people live within 3-hour drive
Soudan: Ongoing experience with outreach programs; history of coordination with state park; 40,000 tourists per year

3.10 Local Support and Awareness: The siting of the USNUSL is clearly, in part, a political process. Awareness and support by local citizens, governments and institutions is clearly an important aspect of the siting process. Local governments and/or institutions can provide some funding, especially in the early stages of the laboratory development. In addition, the USNUSL will need to meet local regulations and codes with respect to construction, transportation of materials and other operational aspects. The site visits have also suggested to the Sub-Committee that local political support as reflected through State Congressional delegations will likely have a real effect on the progress of USNUSL.

Gran Sasso: Strong support by some municipalities and groups and resistance by others.
Kamioka: Good community awareness and support within local limited population

CUNL: Strong local and political support; growing public awareness
Homestake: Strong local and political support; extensive public awareness
San Jacinto: Strong local support; limited public and political awareness
Soudan: Strong local support; extensive public awareness

3.11 Site Environmental Factors

3.11.1 Cost of Living: This factor affects USNUSL through the cost to maintain graduate students, post-docs and visitors at the USNUSL site. Although this cost does not accrue directly to USNUSL, it likely affects the ability and willingness of collaborating institutions to maintain people on site for detector installation and operation. The cost for each site listed below includes a two-week stay at a moderately priced hotel (for example, Day's Inn), airfare from Chicago and meals).

CUNL: $1,547
Homestake: $1,533
San Jacinto: $2,754
Soudan: $1,365

3.11.2 Climate: People like to live and work in nice climates. This factor addresses purely the meteorological climate.

CUNL: 30° to 90° F; semi-arid
Homestake: 20° to 70° F; semi-arid
San Jacinto: 60° to 100° F; desert
Soudan: -20° to 75° F; boreal forest

3.11.3 Travel to Sites: Scientists will visit the USNUSL from various parts of the United States and the world. This factor addresses access to the laboratory, mostly by commercial air service. It includes flight time, number of connections, frequency of service, main line vs. commuter service, cost of travel and driving time required from the nearest airport to the site.

Gran Sasso: About 2 hour drive (depending on traffic) from Rome Leonardo da Vinci Airport
Kamioka: About 1 hour drive from Toyama Airport. Flights to Toyama leave only from Tokyo Haneda Airport, while flights from U.S. to Tokyo arrive at Narita Airport. Airport change in Tokyo requires at least 2 hours
CUNL: Carlsbad Airport is 1/2 drive from laboratory, but has only commuter service; Midland (2 hour drive) and El Paso (3 hour drive) have jet service
Homestake: Rapid City Airport is 1 hour drive and has jet service to Minneapolis and commuter service to Denver and Salt Lake City
San Jacinto: Palm Springs Airport is 15 minute drive and has jet and commuter service
Soudan: Hibbing Airport is 1 hour drive and has commuter service; Duluth Airport is 1.5 hour drive and has jet service to Minneapolis and Chicago

3.11.4 Commute Time: Although ease of travel to the USNUSL is important, the time for a typical worker or physicist to reach her or his workplace is also important. People need and

choose to live where housing and services such as stores, health care, schools and other goods and services are available. In some sense, this factor is a measure of the driving time between USNUSL and the nearest supermarket.

Gran Sasso: Assergi to the Laboratory is a 30 minute round trip
Kamioka: Mozumi to the Laboratory is a 30 minutes round trip. Most long-term visitors live nearer Toyama, resulting in a 1 to 2 hour round trip.
CUNL: 1 hour round trip
Homestake: 15 minute round trip
San Jacinto: 30 minute round trip
Soudan: 15 minute round trip

3.11.5 Local Universities: USNUSL ideally will have a rich intellectual and academic life and provide an environment that nourishes physics innovation, both experimental and theoretical. Proximity to one or more strong research universities is clearly an asset.

Gran Sasso: Nearest universities involved in laboratory are in Rome
Kamioka: Strong involvement from universities in Tokyo and Sendai
CUNL: University of Texas El Paso is 3 hours away; New Mexico State University in Las Cruces is 4 hours away; University of New Mexico in Albuquerque is 5 hours away
Homestake: South Dakota School of Mines and Technology is 1 hour away
San Jacinto: University of California Riverside is 30-minute drive; UC San Diego, UC Irvine, UCLA, Caltech, USC and many Cal State campuses are within 2-3 hours (depending on traffic)
Soudan: University of Minnesota-Duluth is 90-minute drive; UM-Twin Cities is 4-hour drive

3.11.6 Ease of Personnel Access: The Sub-Committee believes that perceived ease of personnel access to the laboratory is important both as a substantive factor and as a quality-of-life factor. Ideally, the laboratory is available 24 hours per day, seven days per week. At best, access to the laboratory also requires no advance notice, requires no waiting, takes a minimal amount of time and allows personnel to bring small amounts of equipment with them. For safety and security reasons, access should be controlled and monitored, but the control/monitoring system should be as reliable and automatic as possible and impose as little as possible burden on authorized staff while keeping out unauthorized people and maintaining a real-time log of the identity and location of personnel underground.

Gran Sasso: Possible to drive in via *autostrada* tunnel and park at laboratory, although most people use shuttle bus
Kamioka: Possible to drive-in via horizontal access and park at laboratory
CUNL: Vertical access; some limitations on waste hoist access; 45-day index notification period required before first visit by non-U.S. national
Homestake: Vertical access, automated after renovation
San Jacinto: Horizontal access; underground parking
Soudan: Vertical access, automated with new hoist

3.11.7 Local Industrial Infrastructure: The National Underground Science Laboratory requires both goods and services that are similar to those used in heavy industrial and natural resource recovery operations. Spare parts may be needed on short notice for equipment such as front-end loaders, drills, forklifts and other materials handling devices. Contract services may be needed for specialty welding, machinery repair and mechanical and electrical system maintenance. This factor addresses the extent to which such goods and services may be available in the vicinity of the laboratory site.

Gran Sasso: Rome is about a 2-hour drive
Kamioka: Mining area; Toyama is a seaport with good industrial infrastructure
CUNL: Historic and current mining and hydrocarbon extraction area; 30 minute drive to Carlsbad, 2-3 hours drive to Midland and El Paso
Homestake: Historic mining area with tourism as current main activity; 1 hour drive to Rapid City
San Jacinto: Primary local industries are tourism and agriculture; 15 minutes to Palm Springs, 30 minutes to Riverside, 2-3 hour drive to Los Angeles
Soudan: Historic and current mining area; 60-90 minute drive to Mesabi Range mining cities and Duluth

3.11.8 Scientific Environment: graduate students will do much of the work of installing and operating detectors at the NUSL and post-doctoral research associates living at the Laboratory for extended periods. This factor relates to the scientific environment for these people. It assesses to what extent graduate students, while at the Laboratory can, pursue their general scientific and academic development, not just their skill at a particular project.

Gran Sasso: Universities in Rome and L'Aquila
Kamioka: University in Toyama, but not active in Laboratory. Data analysis and computing center in Mozumi
CUNL: Several campuses 3-5 hour drive
Homestake: South Dakota School of Mines and Technology is 1-hour drive
San Jacinto: Access to UC Riverside, UC Irvine, Cal State San Bernardino and universities in Los Angeles
Soudan: University of Minnesota Duluth is 90-minute drive

3.12 Suitability Factors for "Typical" Detectors Described in the "Criteria" Document

3.12.1: Suitability for Detector A (Ultra-Low Background)

Gran Sasso: Moderate Depth
Kamioka: Moderate Depth
CUNL: Shallow to moderate depth
Homestake: Very deep
San Jacinto: Very deep
Soudan: Shallow depth

3.12.2 Suitability for Detector B (Large Inventory of Flammables) and Detector C (Large Inventory of Cryogens)

Gran Sasso: Horizontal access permits direct deliveries of materials without transfer
Kamioka: Horizontal access permits some direct deliveries of materials without transfer
CUNL: Vertical access; approved-Environmental Assessment for these materials
Homestake: Vertical access
San Jacinto: Horizontal access permits direct deliveries of materials without transfer
Soudan: Not relevant unless new shaft is built for "Ultra-K" detector

3.12.3 Suitability for Detector D (Ultra-K Water Detector)

Gran Sasso: Horizontal access facilitates large excavation; hard rock environment
Kamioka: Horizontal access facilitates large excavation; hard rock environment
CUNL: Vertical access; salt environment; currently no water at site
Homestake: Vertical access; hard rock environment; shaft renovation will facilitate excavation of large quantities of rock
San Jacinto: Horizontal access facilitates large excavation; hard rock environment
Soudan: Vertical access; hard rock environment; new shaft required to facilitate large excavation

4.0 Analysis and Assessment of Observations

The Sub-Committee presents the following analysis and assessment of its observation for the purpose of informing the full Committee in its discussions.

4.1 The Sub-Committee has carefully examined all known information about each of the four sites studied in detail—Carlsbad UNL, Homestake, San Jacinto and Soudan—in order to determine the possible existence of a "show-stopper" at any site. A "show-stopper" is a factor that cannot be addressed by good engineering design or other good practices and which has such negative consequences that it would be impossible to do important and competitive science experiments at that site. The Sub-Committee finds no such "show-stopper" factors. In other words, the Sub-Committee believes that all four sites are feasible as scientific laboratories.

4.2 The Sub-Committee believes that a national underground laboratory in the United States should facilitate a new generation of detectors with higher sensitivities than what can currently be achieved. One important factor in achieving higher sensitivity is reduction of background due to radiation. The Sub-Committee believes that backgrounds due to natural radioactivity at any site can be readily reduced by a good choice of materials and by appropriate shielding against ambient radioactivity. The Sub-Committee further believes that radioactivity due to radon at any site can be controlled using straightforward techniques such as additional ventilation, water degasification and impermeable polyurethane coatings (Mine Guard or Urylon). Direct and indirect cosmogenic radioactivity, however, can only be reduced by extreme depth. For that reason, the Sub-Committee believes, based on recent experience with the SNO detector, that extreme depth (>6,000 mwe) is now required to achieve otherwise reachable sensitivities in double beta decay and solar neutrino detectors. In addition, the Sub-Committee believes that many detectors, including an "ultra-K" detector, would benefit from depths at least as deep as Gran Sasso, that is, 3,800 mwe. For these reasons, the Sub-Committee suggests that strong consideration should be given to establishing a primary site for the National Underground Laboratory at a location that can feasibly provide access to depths >4,000 mwe. Access to multiple depths, both shallow and deep, is also likely a positive factor. Other sites have been used for previous detectors and will likely continue to be used for some detectors for a variety of reasons. Of the particular sites considered by the Sub-Committee, only the Homestake and San Jacinto sites meet this condition regarding depth.

4.3 The Sub-Committee has attempted to assess the degree of certainty to which one might determine that one site is "better" than another. With the exception of the depth factor described above, the Sub-Committee believes that an ordinal ranking of sites with a high level of certainty is difficult to achieve. The Sub-Committee has found among its members a high level of congruence in the ordinal ranking of sites with respect to each factor. However, there is a wider range of opinion with respect to the relative importance of each factor. Some of the largest variations of this type are associated with risk factors and reflect wide ranges of individual tolerance for risk. This variance is particularly clear in the assessment of what weight should be given to major, project-stopping risks, even if the probability of an adverse event is small. There is also a range of opinion on whether factor rankings should be combined additively or multiplicatively, that is, whether a single important factor should have a large effect on the overall ranking. The Sub-Committee suggests that a choice among sites may require factors other

than those described here, such as the success probability of various development scenarios for the various sites.

4.4 *Carlsbad Underground National Laboratory (CUNL):* The CUNL site benefits from a substantial past and ongoing investment by the United States resulting in an excellent human resource and physical infrastructure. The salt ambient at CUNL is also easy and cheap to dig and offers dry environments with low radioactivity due to uranium, thorium and radon. The site advocates believe that "salt creep" can be addressed by good engineering design and by techniques such as "pre-mining" or "re-mining." For these reasons, CUNL has hosted and will likely continue to host a variety of important detectors. Indeed, for quick turnaround for detector development and prototyping in a low background environment, CUNL is currently the best site in the United States in many respects. As indicated above, the Sub-Committee believes that the depth factor alone suggests that CUNL should not be the primary site for a national underground laboratory. However, the Sub-Committee encourages the DOE and Westinghouse TRU Solutions to continue its present efforts to support important underground science, including crucial detector research and development and prototyping studies.

4.5 *Homestake Underground National Laboratory:* The Sub-Committee believes that Homestake offers an excellent site for an underground national laboratory. The existing human resource and physical infrastructure are outstanding. The commitment of the State and people of South Dakota to this project is impressive. The Sub-Committee cautions, however, that the value of the Homestake site is time-dependent. The Homestake Mining Corporation has publicly indicated that it plans to close the mine and terminate employment for many of its staff no later than the end of 2001. Although a severance package will tend to keep staff members on site until they are laid off, site advocates have noted that significant staff erosion can be expected to begin when schools close in June 2001 and to continue over the next six months. At some point, if plans for an underground laboratory appear uncertain, the Homestake Mining Corporation, as part of its normal closing process, might take actions that would diminish the value of the physical assets at Homestake as a basis for a national underground Laboratory. The Sub-Committee believes that if the full Committee should designate Homestake as the primary site, the Committee should also strongly encourage site advocates to pursue a time-sensitive plan that would minimize the possibility of deterioration of either the human or physical resources of this site. The Sub-Committee also notes that solving the indemnification issue may not be an easy or quick process.

4.6 *Mount San Jacinto:* The Sub-Committee believes that San Jacinto offers an excellent site for a national underground laboratory. The proposed horizontal access at San Jacinto provides long-term advantages in cost of laboratory excavation, installation of detectors and ongoing operating costs. The Sub-Committee was impressed by the strength of local support among civic leaders who were informed about the project. The Sub-Committee notes, however, that San Jacinto is qualitatively different from the other sites not just in its horizontal access, but also in the number of people who live nearby and in the absence of a recent mining tradition at the site. Although the large local population and even larger population within 150 km provides significant outreach potential, as well as urban amenities that make the site attractive, it also increases the efforts required to educate potential neighbors about the project. Native American traditions with respect to Mt. San Jacinto and the natural beauty of the region further complicate this task. Both the National Environmental Protection Act (NEPA, which applies at all sites) and the California

Environmental Quality Act (CEQA) apply to the Mt. San Jacinto site. These acts provide an adjudication process, that is, there is a way to determine whether and under what conditions, an underground science laboratory could be built at Mt. San Jacinto. The Sub-Committee believes that such a process, if well managed, might lead reasonably quickly to findings of no impact and requirements of relatively small mitigation. This belief rests on the project design, which places the entire laboratory underground, except for a well-camouflaged portal and roadway, requiring an aggregate of about one acre of land. All other surface structures are placed in already urbanized areas of Palm Springs and are irrelevant to the environmental issue. The Sub-Committee suggests, because of the quality of the San Jacinto site, efforts should continue to increase public awareness about the project and to begin the NEPA and CEQA processes, even if the full Committee places first priority on another site.

4.7 *Soudan Underground Laboratory*: The Soudan Laboratory particularly impressed the Sub-Committee in several respects. Soudan currently exists, has a highly-skilled, science-oriented support staff and has a track record of doing science for more than a decade. The Soudan Laboratory demonstrates the feasibility of renovating a mine into a world-class physics laboratory. Although smaller than Gran Sasso and shallower than a number of sites, Soudan continues to host important and competitive physics detectors. Indeed, the MINOS Far Detector and CDMS II make significant physics productivity at Soudan likely for at least another decade. These accomplishments are even more impressive because of the small size of the single shaft at Soudan. The Sub-Committee is also impressed by the outreach efforts at Soudan, particularly the construction of a visitor gallery for the MINOS Far Detector Laboratory and the plans to begin regular visitor tours of the Laboratory in cooperation with the State Park, beginning in Summer 2001. A further advantage of the Soudan site is its location as the target area for the Fermilab Main Injector neutrino beam. Despite these advantages, the Sub-Committee believes that the limited depth at Soudan suggests location elsewhere of the primary site for the national underground laboratory. The Soudan site will likely continue to provide a venue for significant detectors, especially those that do not require great depth and would benefit from the neutrino beam. In particular, the "ultra-K" detector, if constructed at Soudan, would both require and justify the cost of a constructing a new shaft to provide dedicated physics access, while retaining a connection to the State Park shaft for visitor access and a safety egress.

4.8 *Other Sites:* The Sub-Committee has identified additional potential sites in the vicinity of the California-Nevada border, that appear to offer possibilities for horizontal access and some of the other advantages of Mt. San Jacinto. A cursory investigation suggests that these sites may have fewer environmental concerns than the San Jacinto site, either because of small nearby populations and/or because of a local tradition of mining, either for ore or in connection with the Nevada Test Site. The Sub-Committee suggests, again regardless of the recommendation by the full Committee, that investigation of these sites should continue, at least to the point of determining whether there may be clear "show-stoppers" connected with any of them. A further discussion of these sites is included in the Appendix D.

4.9 *Summary:* The Sub-Committee's analysis is reported to the full Committee in summary as follows: All four sites investigated in detail are acceptable. The depth factor alone justifies narrowing the site search to Homestake and San Jacinto. These two sites may well be equivalent within uncertainties, but the quality of the Homestake site is more time-dependent. Selecting

between these sites likely requires consideration of other factors, such as the success probability of various development scenarios and tolerance for risk. With respect to Carlsbad UNL and Soudan, the Sub-Committee believes that underground science that exploits the special advantages of each of these sites will likely continue. The Sub-Committee also suggests continued study at an appropriate level of the California-Nevada border sites, to facilitate a deep alternative if both the Homestake and San Jacinto prove infeasible.

Finally, the Sub-Committee wishes to step outside the boundaries of its charge and make the following statement. “The case for a multi-purpose underground science laboratory is compelling. The technical considerations assessed by the Sub-Committee indicate that the project is feasible. Within one to five years, the United States can have a world-leading facility with unsurpassed depth to advance a wide range of important science that requires very sensitive detectors and very low background. The Sub-Committee believes this initiative should proceed on the fastest possible time scale.”

Appendix C.1: Glossary of Mining Terms

Addit: A horizontal or nearly horizontal tunnel with a single opening or portal. Addits end inside the earth. They are generally built for mining in regions with significant elevation variations.

Back: The ceiling of a tunnel or stope or the rock/salt immediately below this ceiling. When excavating a stope, the rock or salt nearest the back is generally excavated first. Ground support is then installed into the back before removal of the remaining rock or salt, which is known as the bench.

Bench: The rock or salt that remains after the back is excavated. The cost per unit volume for removing the bench is almost always less than the cost per unit volume for removing the back.

Bolt: A bolt is a high-tensile-strength steel rod that is inserted into a hole drilled into rock and then locked into place with either grout or a mechanical anchor. Bolting increases the tensile and sheer strength of rock.

Drift: A tunnel with no portals, that is, a tunnel that begins and ends underground.

Drill and Blast: The common excavation technique in which holes are drilled into rock and filled with high explosive, which is then detonated to excavate and pulverize the rock. The volume of blasted rock is typically 140% of the original rock volume.

Ground Support: Bolting, meshing or shotcreting, all of which are used to increase the tensile and sheer strength of the rock, to inhibit rock defoliation or to catch small pieces of rock that may defoliate.

Muck: Pulverized rock loosened by a mining operation that needs to be removed to leave a tunnel or a stope. “Muck” can also be used as a verb to describe the process of removing this rock.

Over-mining: The technique of compensating for salt creep by making cavities larger than the desired dimensions. This strategy implies reasonable initial knowledge about the desired lifetime of the cavity.

Portal: An opening to the outside environment at the end of an addit, tunnel or shaft.

Pre-mining: The technique of compensating for salt creep by mining a cavity, allowing the salt to creep for some time interval (generally months) and then trimming the cavity to the desired dimensions.

Raise: A short winze. Personnel raises are generally equipped with ladders rather than hoists. Rock raises are used for dropping rock to a lower level. The term raise is used because raises are usually bored upwards.

Re-mining: The technique of compensating for salt creep by periodically milling cavities to their original dimensions.

Salt Creep: The tendency for halites and anhydrides to exhibit plastic flow under lithostatic pressure. The amount of creep depends on the size of openings and the extent to which salt flow may be constricted by rock or facilitated by clay slip planes. Salt creep may be addressed by over-mining, pre-mining or re-mining. Rock support is generally ineffective at preventing salt creep.

Shaft: A vertical access that begins at ground level and ends within the earth. Shafts often have multiple compartments that are used for various purposes including personnel hoisting, rock or hoisting and piping and other utility access. Shafts are used for mining in regions where ground elevations are relatively uniform.

Shotcrete: Concrete that is sprayed onto rock using high pressure pumping systems.

Stope: A cavity, sometimes large, from which ore is extracted. In mining terms, underground laboratories are stopes. Stoping is the process of opening up a stope.

TBM: Tunnel boring machine. TBMs are used to bore long, horizontal or nearly-horizontal tunnels. Since the capital cost of a TBM is typically $10 million, they are not cost-effective for short tunnels.

Tunnel: Specifically, a tunnel is a cavity with a long horizontal or nearly-horizontal dimension and short dimensions at right angles to this long dimension that has an opening or portal at each end. More generally, a tunnel is the generalization of addit, drift and tunnel.

Winze: A shaft with no portal, that is, a shaft which begins and ends underground.

Appendix C.2: Criteria for Technical Evaluation of an Underground Laboratory Site

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1. Introduction

The selection of an underground laboratory requires the evaluation of a broad range of technical criteria. No site is likely perfect for even a single underground physics experiment. Site selection for a multi-purpose laboratory is even more difficult because the "best" site for one detector may not be the optimal choice for another, very different detector. The Technical Sub-Committee places a high priority on site properties that will facilitate significant, likely order of magnitude, sensitivity improvements in a wide range of low background experiments. Such improvements will probably result from one or more of the following: (a) increase in sensitive mass, (b) decrease in impurities, (c) more sensitive instrumentation and/or electronics and (d) more difficult to handle or more costly materials. The properties of a laboratory that will facilitate significant progress include: (a) fast, convenient access for personnel and instrumentation of varying size and weight, (b) large, clean, air-conditioned, well-illuminated experimental and support rooms with sufficient room for staging, assembly, monitoring and maintenance of large, complex detectors, (c) a range of rock depths at one or more sites, some of which are equal to or greater than those available elsewhere in the world and (d) a management plan and outreach strategy that will efficiently facilitate both the highest quality science and comprehensive public education and understanding.

The Gran Sasso Laboratory (LNGS) in Abruzzo, Italy provides both proposers and evaluators with a good reference point. LNGS provides an aggregate volume of 180,000 m at a depth of approximately 4,000 mwe. About half of the volume is contained in three large experimental halls, each with a cross-section of approximately 15 m by 15 m and a length of approximately 100 m. The remaining volume is provided in a variety of access and experimental tunnels, connecting and circumscribing the three large halls. LNGS provides good access for large and heavy instrumentation through horizontal vehicular tunnels capable of passing the largest highway trucks and trailers. LNGS is also clean, dry, at a comfortable temperature and humidity and supplied with abundant electrical power and communications. A new laboratory should represent a significant improvement over LNGS in as many attributes as possible with few, if any, compromises with respect to LNGS capabilities. To further assist proposers, we discuss here four possible prototype experiments, but these should be considered as simply illustrative of likely experimental requirements. The last of these examples is a megaton-scale liquid Cerenkov or scintillator detector optimized for both proton decay and neutrino physics. The compressed time scale of this study and the complexity of an "ultra-K" detector mostly limit consideration of

this last detector to a "go or no-go" dichotomy. We expect to report only very preliminary estimates of feasibility and cost for this enormous detector at the various sites.

The strategy for this evaluation is to the extent possible to compare diverse sites on an equivalent basis. The obvious common denominators are physics capabilities and cost, both capital and operating. The trade-off between capital and operating costs for a particular site should assume that it will be possible to secure an initial capital outlay for building and/or renovating the site. Proposers should also assume that the initial investment will be sufficient to enable the laboratory to operate in an efficient manner and have a reasonable time to build a depreciation/replacement reserve for significant equipment maintenance. There are some factors, particularly those in the general category of "quality-of-life" that are not easily addressed in this approach. For those factors, we expect to report information for each site without extensive evaluation.

The Technical Assessment Sub-Committee believes that the four sites it is currently considering as well as any sites that may be proposed can be generally divided into one of two categories: deep and shallow. "Deep" is defined as access to depths substantially greater than those available at LNGS while "shallow" sites are limited to LNGS depths or less. The Sub-Committee further believes that physics considerations may well dictate that an optimal underground physics laboratory strategy for the United States should include access to a "deep" site. If so, two alternatives are obvious: (1) locate the laboratory at one site that has a range of depths available, including some that are "deep" or (2) locate the laboratory at one "deep" and one "shallow" site. Of the prototype detectors described here, the "ultra-K" detector would benefit the least from large depth. In addition, the lithostatic pressure at large depth might complicate construction of the large spans required for its enormous volume. The Sub-committee strongly recommends to proposers that they include plans and costs to reach the greatest depth that might be reasonably attainable at their sites, as well as describing plans and costs for locating the laboratories and other facilities at the greatest depth now available at their site, without substantial shaft, addit or drift development. For simplicity, we suggest that proposers assume Detectors A, B and C as described below are all at the same depth, although other, perhaps more optimal arrangements are of course possible.

The Sub-Committee also believes that a national underground physics facility must be designed and constructed to the standards of a long-term, human-occupied civil engineering project and not those of an operating mine. As much as possible, the entire facility, including shafts, addits, drifts and laboratories, should be dry, have a temperature of approximately 18° C and a relative humidity of less than 60 percent. Design and construction standards should include appropriate rock/salt excavation methodology and support measures; fire suppression, gas detection and other safety systems; and two independent accesses. Proposers should also consider designs that might build in refuge facilities at a relatively small cost, such as outfitting an isolated control room or pump room with fire stops and an independent air supply.

An important parameter in achieving a world-class facility is low background from radioactivity. Some experiments may require local shielding and/or increased ventilation in order to reduce background levels. The Sub-Committee is interested in data concerning radioactive

backgrounds from uranium, thorium and potassium at each proposed site. Data concerning radon levels, both without and with forced ventilation and neutron fluxes would also be useful.

2. Detectors

This evaluation assumes installation in the laboratory of Detectors A, B and C described below. The evaluation of the feasibility of the megaton-sized Detector D is done separately. To facilitate detector assembly and installation and to provide for future laboratory flexibility, proposers should assume that Detectors A, B and C will be each installed in "general-purpose" laboratory hall with rectangular-solid volumes and domed ceilings to distribute lithostatic pressure. Thus, the laboratory design should include three rooms, each of width 20 m by length of 100 m by height of 20 m. The design for Detector D should be in the "mailbox" geometry with width and height of 50 m each and length of 200 m. Detector D must be located for safety reasons below the grade level of its access drifts. Access drifts between laboratories should be as short as possible and should be of cross-section of at least 8 m by 8 m to facilitate use of space in one laboratory as a staging area for a detector in another laboratory. While a real laboratory design will likely include additional smaller rooms for mechanical equipment, control rooms, etc., these additional rooms need not be included in the design at this time.

Detector A: Detector A is a device of modest size (less than 1,000 kg of active material) that is sensitive to ionization and/or thermal excitation (phonons). A single laboratory might house several detectors of this type. Typical physics goals for Detector A might be a cold, dark matter search (successor to CDMS 2) or a $\beta\beta$ decay experiment. Detector A may be operated at cryogenic or room temperatures but its sensitive material is solid and stable in the event of a loss of cooling or electrical power. Detector A requires the lowest possible radioactive and electromagnetic backgrounds. The total power requirement of Detector A is 100 kW and the laboratory should have sufficient power to operate three such detectors simultaneously.

Detector B: Detector B is most likely a solar neutrino experiment with 1 kiloton of liquid scintillator. Detector B requires a well-developed capability for the storage, installation and operation of a large inventory of volatile and flammable material. A particular goal of Detector B is the lowest possible trigger energy threshold, so Detector B is highly sensitive to radioactivity at energies <1 MeV. Although Detector B uses high-gain photodetectors, a design goal for Detector B is single photoelectron sensitivity. For that reason, Detector B also requires a high level of attention to electromagnetic interference from pumps and other motors and to ground loops. The finished size of Detector B, including its immediate ancillary equipment, is 60 m by 18 m by 18 m high. The electrical power requirements of Detector B are 500 kW.

Detector C: Detector C is a high-resolution tracking neutrino and proton decay detector containing 5 kilotons of liquid argon or xenon. The salient design feature of Detector C is risk management for a large inventory of a suffocating liquid cryogen in a confined underground location. Because of its tracking properties, Detector C is not particularly sensitive to low energy radioactivity, although a lower background trigger rate is always better than a higher one. The sensitive volume of Detector C is about 3,000 m^3. The electrical power requirements of Detector C are 500 kW.

Detector D: Detector D is a large water Cerenkov detector with a fiducial mass an order of magnitude larger than the Superkamiokande detector. Depending on its depth and the radioactivity of the surrounding rock, Detector D will likely require some outer volume of water as an active shield. For this evaluation, the active volume of Detector D will be 500,000 m^3 in the "rural mailbox" geometry. An additional area 50 m by 18 m by 18 m in height will be required for a purification systems and an instrumentation/physicist work area.

III. Standard Site

For the purposes of comparison, the Technical Subcommittee defines a standard site as having following properties:

(1) Free and clear volumes of the sizes specified with a wall surface appropriately stabilized to minimize wall movement, exfoliation, water leakage and dust.

(2) Two independent means of either horizontal or vertical access, designed to minimize access time and maximize access flexibility for personnel and instrumentation. The Sub-Committee sets as a goal the ability to deliver underground a standard international shipping container of cross-section 9 feet by 9 feet (with extra space for wheels), nominal length 20 feet and maximum total weight of 30 short tons, while keeping the container in a horizontal position. The Sub-Committee understands that some sites may not be able to meet all of these requirements without a level of expenditure that seems inappropriate. In such case, the proposers should indicate the current access restrictions and the cost and schedule to attain a reasonable level of improved access. The proposers should make clear the access restrictions that would remain with these improvements.

(3) A ventilation system capable of maintaining an ambient temperature of approximately 18° C with a relative humidity of less than 60 percent and sufficient fresh air flow to both (a) meet standards for personnel-occupied working spaces and (b) to limit radon concentrations to less than 10 percent excess of the level measurable outside the laboratory site. The Sub-Committee is interested in strategies and costs for controlling dust and water in the various laboratory sites. The ability of a site to provide additional air to support the use of diesel equipment for excavations is of interest to the Sub-Committee, but is not required.

(4) Three-phase, 440 V electrical power at the specified level. Sites in which the electrical power is particularly "dirty" or interruptible need to include costs for power conditioning and back-up power supplies.

(5) A radiation background level equivalent to that achievable in salt at 5,000 mwe depth. Sites with uranium-thorium backgrounds and sites shallower than 5,000 mwe may also be acceptable, but the cost of shielding required to achieve these levels shall be included in the site cost.

(6) A fire suppression system capable of dealing with ordinary laboratory hazards. The additional cost of fire suppression systems required for flammable detectors and the cost of safety systems for detectors with large inventories of suffocating gases should be considered as a detector cost rather than a site cost.

(7) T1 or better Internet access and a multi-fiber optic cable connection to the outside for Internet, telephone, timing signals, etc.

(8) A cooling system capable of dissipating 1 MW if the rock ambient temperature is less than 20° C and 1 MW plus the rock heat load if the rock ambient temperature is more than 20° C.

IV. Evaluation Parameters

The technical evaluation will estimate the following parameters for each of the Detectors A, B and C for each of the proposed sites. The estimates for Detector D will be limited to feasibility and rough cost estimates as described earlier.

Cost and Time to Prepare Site: Beginning with the current condition of the site, what is the cost and time to prepare the site to meet the required specifications of each experiment. This cost and time does not include the actual building, installation and operation of the experiment, but it does include any require remediation of the site, including installation of a passive or active radiation or electromagnetic shield to reduce background radiation to the standard level.

Annual Operations Cost: This is the annual cost of operating the site itself, not including the cost of operating any specific experiments. These costs include rent or mortgage amortization, if any, personnel costs, maintenance costs, including allowance for depreciation and equipment replacement, electricity and other expendables.

Capital and operating cost estimates should follow the work breakdown structure described below.

Risk: A large number of risk factors are associated with the operation of an underground laboratory. The risks to be evaluated for each site include at least the following: (a) injury to personnel or damage to equipment by accident, fire, explosion, collapse or other hazard; (b) risk of delay and/or increased cost in development of the laboratory or the installation of the detectors due to ownership, interference of other activities, political, environmental or other factors; (c) risk of loss of use of the site; (d) risk of compromise to physics results; (e) risk of adverse liability judgments or workers compensation claims.

V. Work Breakdown Structure

Consultants for the Sub-Committee have prepared the following capital and operating work breakdown structures (WBS). The level of detail presented here is intended only as a guide to proposers. **The Sub-Committee does not expect to receive a cost for each site for each entry in the WBS.** The Sub-Committee requests aggregate capital and operating cost estimates, along with itemized sub-costs that are roughly congruent to the Level 0 entries in the WBS. The lower levels of the WBS are an indication of which costs should be included in which Level 0 entries. If some Level 1 or lower entries have particularly large associated costs (>$5 million capital or $0.5 million operating), then these costs should be separately identified. Proposers should also indicate which costs will be funded in cash, in kind or with existing facilities by proposers or others outside of the NSF and DOE.

Underground Physics Facility Capital Work Breakdown Structure

1. Land Acquisition, Easements & Usage Fees
    - 1.1. 1.1. Surface Land Costs
    - 1.2. 1.2. Underground Rights Costs
    - 1.3. 1.3. Road Easements
    - 1.4. 1.4. Utility Easements
    - 1.5. 1.5. Public/Private Road Fees
2. 2. Surface
    - 2.1. 2.1. Access roads
    - 2.2. 2.2. Parking
    - 2.3. 2.3. Site Work
        - 2.3.1. 2.3.1. Clearing & Grubbing
        - 2.3.2. 2.3.2. Earthwork
        - 2.3.3. 2.3.3. Foundations
    - 2.4. 2.4. Surface Infrastructure
        - 2.4.1. 2.4.1. Electrical
        - 2.4.2. 2.4.2. Cooling
        - 2.4.3. 2.4.3. Water
        - 2.4.4. 2.4.4. Sewer
        - 2.4.5. 2.4.5. Communications
        - 2.4.6. 2.4.6. Compressed Gases
    - 2.5. 2.5. Buildings
        - 2.5.1. 2.5.1. Building 1-Visitor's Center & Administration
            - 2.5.1.1. 2.5.1.1. Meeting Rooms
            - 2.5.1.2. 2.5.1.2. Computer Support (including LAN and external connections)
            - 2.5.1.3. 2.5.1.3. Canteen
            - 2.5.1.4. 2.5.1.4. Operations staff area
            - 2.5.1.5. 2.5.1.5. Intellectual Programs
            - 2.5.1.6. 2.5.1.6. Visitor Work Area
        - 2.5.2. 2.5.2. Building 2-Housing
            - 2.5.2.1. 2.5.2.1. Sleeping rooms
            - 2.5.2.2. 2.5.2.2. Common rooms
            - 2.5.2.3. 2.5.2.3. Recreation facilities
        - 2.5.3. 2.5.3. Building 3-Warehouse & Assembly
            - 2.5.3.1. 2.5.3.1. Loading & unloading facilities
            - 2.5.3.2. 2.5.3.2. Storage
            - 2.5.3.3. 2.5.3.3. Clean room(s)
            - 2.5.3.4. 2.5.3.4. Crane areas
            - 2.5.3.5. 2.5.3.5. Machine shop
            - 2.5.3.6. 2.5.3.6. Shuttle Garage
        - 2.5.4. 2.5.4. Building 4-Laboratories
            - 2.5.4.1. 2.5.4.1. Chemistry
            - 2.5.4.2. 2.5.4.2. Physics & electronics
            - 2.5.4.3. 2.5.4.3. Clean room(s)
    - 2.6. 2.6. Surface Physics
        - 2.6.1. 2.6.1. Access
        - 2.6.2. 2.6.2. Site Preparation
        - 2.6.3. 2.6.3. Infrastructure
        - 2.6.4. 2.6.4. Communications
    - 2.7. 2.7. Rock Disposal Areas
        - 2.7.1. 2.7.1. Haulage Roads
        - 2.7.2. 2.7.2. Disposal Site Preparation
        - 2.7.3. 2.7.3. Environmental Requirements
        - 2.7.4. 2.7.4. Disposal Site Reclamation
3. 3. Underground Access

3.1. 3.1. Shaft(s), Hoist(s) & Headframe(s)
3.1.1. 3.1.1. Access Shaft
3.1.1.1. 3.1.1.1. Hoist & headframe
3.1.1.2. 3.1.1.2. Primary support & lining
3.1.1.3. 3.1.1.3. Waterproofing & drainage
3.1.1.4. 3.1.1.4. Steel & concrete structures
3.1.1.5. 3.1.1.5. Electrical service
3.1.1.6. 3.1.1.6. HVAC
3.1.1.7. 3.1.1.7. Communications
3.1.2. 3.1.2. Secondary Shaft
3.1.2.1. 3.1.2.1. Hoist & headframe
3.1.2.2. 3.1.2.2. Primary support & lining
3.1.2.3. 3.1.2.3. Waterproofing & drainage
3.1.2.4. 3.1.2.4. Steel & concrete structures
3.1.2.5. 3.1.2.5. Electrical service
3.1.2.6. 3.1.2.6. HVAC
3.1.2.7. 3.1.2.7. Communications
3.2. 3.2. Portal(s)
3.2.1. 3.2.1. Access tunnel portal
3.2.1.1. 3.2.1.1. Earthwork
3.2.1.2. 3.2.1.2. Soil & rock retainage
3.2.1.3. 3.2.1.3. Portal structure
3.2.1.4. 3.2.1.4. Waterproofing & drainage
3.2.1.5. 3.2.1.5. Access control
3.2.2. 3.2.2. Egress tunnel portal
3.2.2.1. 3.2.2.1. Earthwork
3.2.2.2. 3.2.2.2. Soil & rock retainage
3.2.2.3. 3.2.2.3. Portal structure
3.2.2.4. 3.2.2.4. Waterproofing & drainage
3.2.2.5. 3.2.2.5. Access control
3.3. 3.3. Tunnel(s)
3.3.1. 3.3.1. Access Tunnel
3.3.1.1. 3.3.1.1. Primary support & lining
3.3.1.2. 3.3.1.2. Waterproofing, drainage & humidity control
3.3.1.3. 3.3.1.3. Surface finishes
3.3.1.4. 3.3.1.4. Floor slabs
3.3.1.5. 3.3.1.5. Steel & concrete structures
3.3.1.6. 3.3.1.6. Electrical service & alarms
3.3.1.7. 3.3.1.7. Lighting
3.3.1.8. 3.3.1.8. HVAC & fume control
3.3.1.9. 3.3.1.9. Fire protection
3.3.1.10. 3.3.1.10. Communications
3.3.2. 3.3.2. Egress Tunnel
3.3.2.1. 3.3.2.1. Primary support & lining
3.3.2.2. 3.3.2.2. Waterproofing, drainage & humidity control
3.3.2.3. 3.3.2.3. Surface finishes
3.3.2.4. 3.3.2.4. Floor slabs
3.3.2.5. 3.3.2.5. Steel & concrete structures
3.3.2.6. 3.3.2.6. Electrical service & alarms
3.3.2.7. 3.3.2.7. Lighting
3.3.2.8. 3.3.2.8. HVAC & fume control
3.3.2.9. 3.3.2.9. Fire protection
3.3.2.10. 3.3.2.10. Communications
4. 4. Underground Facilities
4.1. 4.1. Caverns
4.1.1. 4.1.1. Common Area Cavern

4.1.1.1. 4.1.1.1. Primary support & lining
4.1.1.2. 4.1.1.2. Waterproofing, drainage & humidity control
4.1.1.3. 4.1.1.3. Surface finishes
4.1.1.4. 4.1.1.4. Floor slabs
4.1.1.5. 4.1.1.5. Steel & concrete structures
4.1.1.6. 4.1.1.6. Electrical service & alarms
4.1.1.7. 4.1.1.7. Lighting
4.1.1.8. 4.1.1.8. HVAC & fume control
4.1.1.9. 4.1.1.9. Fire protection
4.1.1.10. 4.1.1.10. Communications

4.1.2. 4.1.2. Utility Cavern
4.1.2.1. 4.1.2.1. Primary support & lining
4.1.2.2. 4.1.2.2. Waterproofing, drainage & humidity control
4.1.2.3. 4.1.2.3. Surface finishes
4.1.2.4. 4.1.2.4. Floor slabs
4.1.2.5. 4.1.2.5. Steel & concrete structures
4.1.2.6. 4.1.2.6. Electrical service & alarms
4.1.2.7. 4.1.2.7. Lighting
4.1.2.8. 4.1.2.8. HVAC & fume control
4.1.2.9. 4.1.2.9. Fire protection
4.1.2.10. 4.1.2.10. Communications

4.1.3. 4.1.3. Experimental Cavern A
4.1.3.1. 4.1.3.1. Primary support & lining
4.1.3.2. 4.1.3.2. Waterproofing, drainage & humidity control
4.1.3.3. 4.1.3.3. Surface finishes
4.1.3.4. 4.1.3.4. Floor slabs
4.1.3.5. 4.1.3.5. Steel & concrete structures
4.1.3.6. 4.1.3.6. Electrical service & alarms
4.1.3.7. 4.1.3.7. Lighting
4.1.3.8. 4.1.3.8. HVAC & fume control
4.1.3.9. 4.1.3.9. Fire protection
4.1.3.10. 4.1.3.10. Communications

4.1.4. 4.1.4. Experimental Cavern B
4.1.4.1. 4.1.4.1. Primary support & lining
4.1.4.2. 4.1.4.2. Waterproofing, drainage & humidity control
4.1.4.3. 4.1.4.3. Surface finishes
4.1.4.4. 4.1.4.4. Floor slabs
4.1.4.5. 4.1.4.5. Steel & concrete structures
4.1.4.6. 4.1.4.6. Electrical service & alarms
4.1.4.7. 4.1.4.7. Lighting
4.1.4.8. 4.1.4.8. HVAC & fume control
4.1.4.9. 4.1.4.9. Fire protection
4.1.4.10. 4.1.4.10. Communications

4.1.5. 4.1.5. Experimental Cavern C
4.1.5.1. 4.1.5.1. Primary support & lining
4.1.5.2. 4.1.5.2. Waterproofing, drainage & humidity control
4.1.5.3. 4.1.5.3. Surface finishes
4.1.5.4. 4.1.5.4. Floor slabs
4.1.5.5. 4.1.5.5. Steel & concrete structures
4.1.5.6. 4.1.5.6. Electrical service & alarms
4.1.5.7. 4.1.5.7. Lighting
4.1.5.8. 4.1.5.8. HVAC & fume control
4.1.5.9. 4.1.5.9. Fire protection
4.1.5.10. 4.1.5.10. Communications

4.1.6. 4.1.6. Experimental Cavern D (only aggregates estimates are desired)
4.1.6.1. 4.1.6.1. Primary support & lining

4.1.6.2. 4.1.6.2. Waterproofing, drainage & humidity control
4.1.6.3. 4.1.6.3. Surface finishes
4.1.6.4. 4.1.6.4. Floor slabs
4.1.6.5. 4.1.6.5. Steel & concrete structures
4.1.6.6. 4.1.6.6. Electrical service & alarms
4.1.6.7. 4.1.6.7. Lighting
4.1.6.8. 4.1.6.8. HVAC & fume control
4.1.6.9. 4.1.6.9. Fire protection
4.1.6.10. 4.1.6.10. Communications

4.1.7. 4.1.7. Refuge Cavern
4.1.7.1. 4.1.7.1. Primary support & lining
4.1.7.2. 4.1.7.2. Waterproofing, drainage & humidity control
4.1.7.3. 4.1.7.3. Surface finishes
4.1.7.4. 4.1.7.4. Floor slabs
4.1.7.5. 4.1.7.5. Steel & concrete structures
4.1.7.6. 4.1.7.6. Electrical service & alarms
4.1.7.7. 4.1.7.7. Lighting
4.1.7.8. 4.1.7.8. HVAC & fume control
4.1.7.9. 4.1.7.9. Fire protection
4.1.7.10. 4.1.7.10. Communications

4.2. 4.2. Tunnels

4.2.1. 4.2.1. "Main Street" Tunnel
4.2.1.1. 4.2.1.1. Primary support & lining
4.2.1.2. 4.2.1.2. Waterproofing, drainage & humidity control
4.2.1.3. 4.2.1.3. Surface finishes
4.2.1.4. 4.2.1.4. Floor slabs
4.2.1.5. 4.2.1.5. Steel & concrete structures
4.2.1.6. 4.2.1.6. Electrical service & alarms
4.2.1.7. 4.2.1.7. Lighting
4.2.1.8. 4.2.1.8. HVAC & fume control
4.2.1.9. 4.2.1.9. Fire protection
4.2.1.10. 4.2.1.10. Communications

4.2.2. 4.2.2. Connecting Tunnels
4.2.2.1. 4.2.2.1. Primary support & lining
4.2.2.2. 4.2.2.2. Waterproofing, drainage & humidity control
4.2.2.3. 4.2.2.3. Surface finishes
4.2.2.4. 4.2.2.4. Floor slabs
4.2.2.5. 4.2.2.5. Steel & concrete structures
4.2.2.6. 4.2.2.6. Electrical service & alarms
4.2.2.7. 4.2.2.7. Lighting
4.2.2.8. 4.2.2.8. HVAC & fume control
4.2.2.9. 4.2.2.9. Fire protection
4.2.2.10. 4.2.2.10. Communications

4.3. 4.3. Underground Infrastructure

4.3.1. 4.3.1. Electrical
4.3.2. 4.3.2. Cooling
4.3.3. 4.3.3. Water
4.3.4. 4.3.4. Sewer
4.3.5. 4.3.5. Communications
4.3.6. 4.3.6. Compressed Gases

5. 5. Permits, Fees and Professional Services

5.1. 5.1. Environmental Impact Studies

5.2. 5.2. Professional Services

5.2.1. 5.2.1. Conceptual Design
5.2.2. 5.2.2. Design Development
5.2.3. 5.2.3. Construction Documents

5.2.4. 5.2.4. Construction Services
5.3. 5.3. Building & Occupancy Permits
6. 6. Cost of Money
6.1. 6.1. Short-term Loans
7. "Quality of Life" Issues
7.1 Living Essentials
7.1.1 Housing
0.1.1.1 Apartment
0.1.1.2 Hotels/Motels
7.1.2 Transportation
7.1.2.1 Air Connections
7.1.2.2 Rail Connections
7.1.2.3 Highway Connections
7.1.2.4 Motorpool or Vehicle Rental
7.1.3 Food & Shopping
7.1.3.1 Restaurants
7.1.3.2 Stores
7.1.4 Entertainment
7.1.4.1 Nearest Town
7.1.4.2 Theater/life
7.2.5 Transportation from Housing to Site

7.2.6 Intellectual Environment
7.2.6.1 Visitor's Program
7.2.6.2 Theory program
7.2.6.3 Seminar Program
7.2.6.4 University Host Functions
7.2.6.5 Library

Underground Physics Facility Operating Work Breakdown Structure

1. Fees
   - 1.1 Rental Fees
     - 1.1.1 Surface Land Costs
     - 1.1.2 Underground Rights Costs
     - 1.1.3 Buildings
   - 1.2 Easements
   - 1.3 Usage Fees
     - 1.3.1 Roads

2. Utility Costs
   - 2.1 Electrical
     - 2.1.1 Lighting
     - 2.1.2 Ventilation
     - 2.1.3 Hoisting
     - 2.1.4 Pumping
     - 2.1.5 Experiments
   - 2.2 Water
   - 2.3 Sewer
   - 2.4 Communications
   - 2.5 Waste Services

3. Maintenance
   - 3.1 Access roads
   - 3.2 Surface Buildings
   - 3.3 Portal
   - 3.4 Shafts, Hoists, Cages
   - 3.5 Access Tunnels
   - 3.6 Common Areas
   - 3.7 Connecting Tunnels
   - 3.8 Caverns
   - 3.9 Systems
     - 3.9.1 Electrical
     - 3.9.2 Mechanical
     - 3.9.3 Water
     - 3.9.4 Sewer
     - 3.9.5 Communications

4. Equipment & Transportation
   - 4.1 Shuttles
   - 4.2 Surface Equipment
   - 4.3 Underground Equipment
   - 4.4 Supply Shops
   - 4.5 Common Laboratories

5. Staff
   - 5.1 Administration
   - 5.2 Operations
   - 5.3 Maintenance
   - 5.4 Technical Staff

- 5.5 Food Service
- 5.6 Public Relations

6. Outside Costs & Subcontracts
   - 6.1 Transportation
   - 6.2 Food Service
   - 6.3 Fire
   - 6.4 Maintenance
   - 6.5 Insurance
     - 6.5.1 Liability
     - 6.5.2 Environmental
     - 6.5.3 Closure Bond

Appendix C.3: Comparison of Select Characteristics and Costs of Four Principal Candidate Sites

	CUNL	Homestake	San Jacinto	Soudan
mwe[a]	1600[h] 1840[i] 3172[j] (3524)[k]	6156[j] (6700)[k] 6656[j] (7100)[k]	A: 5000[l] B: 6000[l] C: 6510[l] D: 7000[l]	2200[m]
Depth (m)	655 1300	2255 2438	See note u	710
Depth (ft)	2150 4265	7400 8000	See note u	2300
Density	2.44	2.73	2.73	3.1
Figure of Merit[b]	[n]$11/ton [o]$23/m^3 [p]$25/$m^2$	$140/$m^3$ [q]$50/ton	[r]$73/$m^3$	
LII Factor[c]	1.1	1.05-1.1	1	1.2
Halls	$5.9M[o] 3 halls of 15m x 10m x 100m	$40M[s] for 3 halls of 18m x 18m x 100m	$33M[t] 3 halls of 20m x 20m x 100m	
Cavern D[d]	See note u	See note u	$81.8M[v]	$70M[w]
Cost of Operations	($0M) $2- 10M/year[x] ($0M) $40M- $200M over 20 year lifetime	$3.8M/year[y] $76M over 20 year lifetime	$2.3M/year[y] $46M over 20 year lifetime	$1M/year[w] $20M over 20year lifetime
Cost of Access[e]	[z]$43.6M +($14.2)	$43M[aa]	$51M[bb] $65M[bb] $82M[bb]	$21M[w]
Declared Contingency	25%		25%	
Surface Building Costs[f]	25kft^2 = $6M +$10M	3 bldg = $53M 32k$ft^2$; 175k$ft^2$; 41k$ft^2$	$18k$ft^2$ warehouse + 12k ft^2 lab + $30k$ft^2$ Admin = $6.6M	
Total[g]	$63.7M ($104M)	$83M ($159M)	$115M ($161M)[cc]	

Appendix C.3 (continued)

Notes:

a) Meter water equivalent.
b) The figure of merit is the nominal cost per unit of excavated material.
c) Labor Installation Inefficiency Factor: An estimated multiplier on installation labor hours as a result of accessibility. The total labor costs are nominally <40% of the total cost of a detector.
d) Cavern of size required for "ultra-K" type detector (see Appendix B).
e) Cost of providing access, tunnel excavation, etc. to experimental chamber area.
f) From material presented by site advocates.
g) Total is Access + Chambers. Numbers in parenthesis represent costs including operations (surface buildings excluded).
h) Hime, et al.
i) Derived by nominal density with 1000 ft depth of rock, 1150 ft depth of salt, and muon angular distribution.
j) Derived by nominal density and depth.
k) Takes into account flat surface and muon angular distribution.
l) Minimum shield hemisphere radius intersecting mountain surface.
m) Experimentally measured.
n) Provided by WIPP engineer.
o) Taken directly from WIPP presentation materials.
p) Additional cost per square area of support (rock bolts, mesh, etc.) that must be provided on back or cavern.
q) Supplied by Homestake Mining Co. engineer.
r) Derived weighted average from numbers provided by San Jacinto advocates with $\$98/m^3$ for top heading excavation and $\$65/m^3$ with 0.25(top heading) + 0.75(bench).
s) Phase I from Homestake white paper. The cost for the miners necessary for the construction of detector chambers at the 7400ft level.
t) Presented to Technical Subcommittee by San Jacinto advocates.
u) Information not provided by site advocates.
v) Engineering estimate from CNA Engineers for dry, stable cavern with floor slab.
w) From Soudan representative: new shaft to 710m at $30k/m.
x) From CUNL presentation materials. Site advocates indicated that bare bones operating level would be zero, while the $2M - $10M/year is derived from a level of support staff for a scientific laboratory.
y) Stated by site advocates 3 March 2001 at Underground Committee Meeting.
z) From CUNL presentation materials. Costs shown are new shaft and miscellaneous access equipment in parenthesis.
aa) Phase II of Homestake development: Yates shaft extension and hoist upgrades.
bb) Tunneling costs presented by site advocates.
cc) Only option C with 6510 mwe shown.

Appendix C.4: Preliminary Evaluation of Additional Green Field Sites in Nevada and California

Joseph S. Y. Wang Kevin T. Lesko
Earth Sciences Division Nuclear Sciences Division
Lawrence Berkeley National Laboratory

Additional green field sites (i.e. undeveloped sites without extensive existing tunnels and deep mines) in Nevada and California are evaluated with attributes articulated by the Technical Sub-Committee of the National Underground Laboratory Committee. The sites include 1) Charleston Peak between Las Vegas and Pahrump in Nevada, 2) Telescope Peak between Panamint Valley and Death Valley, California, 3) Mount Tom and Mount Morgan west of Bishop, California and 4) Boundary Peak of the White Mountains on the Nevada state line. This evaluation is a supplement to site development plans for the Homestake Gold mine, South Dakota and Soudan Iron Mine, Minnesota, both with vertical access; Carlsbad Waste Isolation Pilot Plant, New Mexico, with new shafts to greater depths; and Mt. San Jacinto, California, with new nearly horizontal tunneling.

A large number of potential sites for a national underground science laboratory exist in the California-Nevada region. The sites presented here were chosen to probe a range of options for a deep underground laboratory. This preliminary evaluation is premature to represent the sites for final proposals or in site selection. Naturally, these sites many not share some of the attributes of the San Jacinto site near Palm Springs, California – three of them are in more remote locations, for example. For the purpose of reexamining the options within the California-Nevada region we have attempted to locate sites that:

• Present the opportunity for partnering with local and state governmental agencies in the construction of a mutually beneficial tunnel. This option follows the Gran Sasso model (the National Underground Laboratory of Italy) of sharing a highway tunnel with a scientific laboratory. To this end the **Charleston Peak** location was investigated.

• Present very deep options, in excess of 3,000m (9,843 ft) of overburden (elevation difference between peak and portal of a horizontal tunnel). **Telescope Peak** near Death Valley represents this option for extreme depth using horizontal access.

• Present the opportunity for assuming ownership of patented and unpatented claims and the use of existing mining and other permits for the expansion of an existing mining claim into a national underground laboratory. The soon-to-close **Pine Creek Mine**, while bordered by national forest land and wilderness regions in the California Sierras, presents a potential deep site with several of the permitting issues facing other proposed sites either already solved or only requiring modification of existing permits and not requiring entirely new permits.

• Present an approximate analog to the Mt. San Jacinto proposal, but in a state in which the mining industry represents a larger share of the economy. The **Boundary Peak** site provides similar overburden opportunities, similar geological features, and comparable tunneling lengths, however located in Nevada.

The following table summarizes the four sites evaluated in this report. It is stressed that a preliminary investigation of these sites is presented here, with as much information and supporting documentation as we could obtain within limited resources and time constraint.

Additional Potential Sites for Locating a National Underground Science Laboratory

Peak, Underground Lab Location Nearly Horizontal Tunnel Portal *Inclined Tunnel Portal*	Depth (m)	Elevation (m)	Tunnel Length (km)	Upward Grade	Orientation (deg. angle)
Las Vegas, Nevada					
Charleston Peak	**1828**	**3633**			
Peak Spring Canyon, Pahrump		1707	9.7	1%	38
Kyle Canyon, Highway 137		*2073*	*8.5*	*3%*	*-6*
Charleston Peak	**2406**	**3633**			
Manse, Pahrump		1036	19.0	1%	26
Kyle Canyon, Highway 137		*2073*	*8.5*	*10%*	*-6*
Death Valley, California					
Telescope Peak	**2923**	**3367**			
Panamint Flat Dry Lake		323	12.1	1%	24
Hanaupah Canyon, South Fork		*1219*	*6.0*	*13%*	*15*
Pine Creek Valley, California					
Mount Tom	**2454**	**4161**			
Inyo National Forest, South of Royana		1646	6.1	1%	-137
Pine Creek Mill		*2469*	*4.9*	*16%*	*149*
Mount Morgan	**2521**	**4190**			
Inyo National Forest, Ranger Station		1573	9.7	1%	-155
Pine Creek Mill		*2469*	*5.6*	*14%*	*-63*
Boundary Peak, Nevada					
Boundary Peak	**1815**	**4005**			
Von Schmidt Line		2134	5.7	1%	-45
Morris Creek		*2170*	*5.2*	*0%*	*138*

Site Attribute and Evaluation Approach

Depth (overburden thickness) of the proposed laboratory is the most important attribute of a site to be considered for the next generation of neutrino, nuclear science, and high energy physics experiments in the National Underground Science Laboratory. In addition to depth (required to shield cosmic rays), the sites need to be investigated for access mode (horizontal tunnel, inclined ramp, or vertical shaft), extent of new tunneling/excavation, radiation background (from radiochemcial elements in the formation), construction feasibility and stability of large caverns, drainage, ventilation, seismic hazards, and other technical and operational considerations. The proximity to population centers and academic institutions, with the associated impact on science education for the next generation of students, is also a factor in evaluating the sites. This evaluation focuses on depths of underground chambers and lengths of access tunnels.

In this study, we choose 1,800 m (5,906 ft) as the minimum depth, measured from the peak to the test level accessible by a nearly horizontal (with 1% grade) tunnel. If a second tunnel is required, we can either excavate two parallel tunnels or excavate another shorter tunnel, using an inclined ramp. With monotonic decline from the underground laboratory to one portal, natural drainage can be maintained and the underground experiment chambers can be operated without costly pumping requirements. The portals at different elevations and different temperatures can also promote natural ventilation and reduce operational costs of forced ventilation. Because most mountain ranges are located in national forests, in wilderness areas, or in state or national park lands, the impact of a national underground facility was intentionally minimized and no shaft as an escape route through hoist and lift is considered. All portal sites evaluated here can be reached by four-wheel drive vehicles from routes identified on topographic maps by the National Forest Service and the United States Geological Service.

Charleston Peak, Las Vegas

The eastern foothill of the Charleston Peak (elevation 3,633 m or 11,918 ft) in the Spring Mountains can be reached by Highway 137, 40 km (24 miles) from the outskirts of Las Vegas. Las Vegas is the fastest growing metropolitan area of the United States, with a population of ~1.4 million. The city of Pahrump is on the other side of Charleston Peak. Clark County (where Charleston Peak and Las Vegas are located) and the neighboring Nye County (where Pahrump and the Nevada Test Site are located) have extensive tunneling resources, expertise, and experienced work force for construction projects.

A nearly horizontal tunnel can start from the Peak Spring Canyon east of Pahrump, reach a cover of 1,828 m (6,000 ft) in 9.7 km (6.1 miles), and exit to connect to Highway 137 in 8.5 km (5.2 miles). Both portals are in the Humboldt-Toiyabe National Forests, and the peak is below the wilderness area. Additional overburden can be obtained at this location by shifting the portal down slope. It is possible to add approximately 600 m (1,969 ft) of cover if we double the tunnel length and move the starting portal ~10 km (6 miles) closer to Pahrump (on Bureau of Land Management land).

Charleston Peak in the Spring Mountains has regional inactive faults separating limestone blocks from other hard rocks. The presence of faults requires careful site characterization and mining

operation to anticipate rock failure in crossing the faults. The seismic hazard is relatively low at this site in comparison with other green field sites. The new tunnel can be constructed as part of an extension of Highway 137 to connect Las Vegas with Pahrump. This concept of associating test site with highway is similar to the case at Gran Sasso, Italy where three large halls were constructed for physics experiments. The underground lab is easily accessible through the highway tunnel.

Telescope Peak, Death Valley

Telescope Peak (elevation 3,367 m or 11,048 ft) can provide the rock cover of 2,923 m (9,591 ft) through 12.1 km (7.5 miles) horizontal access from the Panamint Valley. The portal is located at the northern end of Panamint Flat Dry Lake (elevation of 323 m or 1,060 ft). Ballarat (a gold mining ghost town) is 16 km (10 miles) south of the potential portal site. This portal is in private land outside the Bureau of Land Management Wilderness area. The peak is below the Death Valley National Monument land.

The second portal can be a steep inclined ramp, with exit 6 km (3.7 miles) east at the South Fork of Hanaupah Canyon. With the steep slope, water will not drain into the Death Valley National Monument, with the lowest point in the United States, 71 m (282 ft) below sea level. If the water quality is good, the drainage may be portable for Panamint Valley with resort and other business interests. The closest (~97 km or 60 miles) airport to Panamint Valley is in Inyokern with services to Los Angeles. The airport is near the China Lake Naval Air Weapons Station and the town of Ridgecrest.

Mount Tom and Mount Morgan, Pine Creek Valley

Mount Tom (elevation 4,161 m or 13,652 ft) and Mount Morgan (elevation 4,190 m or 13,748 ft) are in the high Sierras west of Bishop, California. Both peaks can be accessed with nearly horizontal tunneling to achieve over 2,438 m (8,000 ft) of rock cover. Mount Tom can be accessed 6.1 km (3.8 miles) from a location in the Inyo National Forest. Mount Morgan is higher in elevation and requires longer tunneling (9.7 km or 6 miles) from a National Forest Ranger Station at the foothill of Wheeler Ridge. Pine Creek Valley is bounded on the north by Mount Morgan and Wheeler Ridge, and on the south by Mount Tom. Both mountains are composed primarily of granitic and metamorphic rocks.

Pine Creek Mine within Pine Creek Valley is referred to as the "Mine in the Sky", since it uses horizontal accesses to reach tungsten ores above the tunnels. The Easy Go tunnel at an elevation of 2469 m (8,100 ft) is 3.2 km (2 miles) long, heading north toward the ore bodies between Mount Morgan (granitic) and Wheeler Ridge (metamorphic). The shorter Brownstone tunnel (with length of 0.8 km or 2,500 ft) is oriented to the south. The first parts of these Pine Creek Mine tunnels, located at the Pine Creek Mill site, are potential portal locations for inclined escape tunnels. Part of the existing tunnels may be used for escape tunnels. If the ramps from Pine Creek Mill are too steep, we may use other locations along the valley at lower elevations (and closer to the peak of Mount Tom) on national forest lands as exit points (for examples, the tailing ponds and the Scheelite site with gravel pits).

Observations from two existing tunnels from the Pine Creek Mill reveal many interesting features. The tunnels are wet at different locations, including the terminal end of the Easy Go tunnel, with ~1,219 m (4,000 ft) of overburden. The grade of ~0.5% is sufficient to drain large amount of seepage (millions of gallons per day, highest during spring runoffs along Morgan Creek). A long-standing arrangement to receive the ground water outflow exists with the local water control board. We observed that long sections of tunnel (hundreds of meters in length) do not require any rock or ground support, whatsoever. Natural ventilation is sufficient to maintain good air quality. Wide rooms (~25 m or 80 ft span), constructed decades ago, remain stable in stopes between the granite and marble structures. Radon gas control was needed during mining operations.

The mine has not been active for over ten years, with a diesel locomotive and the track still operational as of February 2001. The Pine Creek Mine is privately owned and is undergoing transfer of ownership for apparent salvage operations. The owner of the Pine Creek Mine was very open to discussions for scientific uses of the mine infrastructure. New tunnels may be treated as extensions of historical tunneling operations. The Pine Creek Mine has had decadal interactions with National Forest Services, Inyo County, and California Water Control Board. All of this information and mining experience are valuable for future tunneling development at these and similar sites and for dealing with permitting-granting agencies within forest, wilderness and publicly owned land in the West.

Boundary Peak, Nevada

Boundary Peak, the highest point in Nevada (elevation 4,005 m or 13,140 ft), is located at the northern tip of the White Mountains, ~64 km (40 miles) north of Bishop along Highway 6. The peak is accessible from three sides to achieve a cover of ~1,800 m (6,000 ft). The nearly northwest to southeast oriented approaches, one along the von Schmidt line (the historic state line between Nevada and California) and the other from Morris Creek, are 5.7 km (3.5 miles) and 5.2 km (3.3 miles), respectively. Sections of the tunnels are below valleys of the same orientation. It is also possible to excavate below more smooth landform and have the tunnel oriented in the north to south orientation, staring from the Queen Canyon mining district (with five or more existing or historical mining operations) to reach the Boundary Peak. The rock in Boundary Peak and White Mountains is mainly sedimentary.

Boundary Peak in Nevada provides similar covers and comparable tunneling lengths as Mt. San Jacinto in California. Mt. San Jacinto provides covers of 1,786 – 2,325 m (5,859 – 7,628 ft) with 4.7 – 7.6 km (2.9 – 4.7 miles) of nearly horizontal tunnels. Both sites are accessed with tunnels below valley floors. For tunneling into high-relief cliff face with rugged landform, the excavation needs to be carefully planned with detailed geologic mapping, water flow and geo-chemical/isotopic analyses, and geo-technical evaluations before and during mining operations. Unexpected delays in encountering hidden faults need to be avoided in any tunneling projects.

Other Potential Sites

The Sierras have many majestic high peaks, including Mount Whitney, the highest point in the continental United States (elevation 4,418 m or 14,494 ft). Many peaks have high relief

accessible from the valley floors to reach over 2,438 m (8,000 ft) rock covers. White Mountains can also provide over 2,438 m (8,000 ft) cover. The White Mountains Research Station of the University of California is located on the summit. The White Mountains, like Wheeler Ridge, has a relatively flat ridge over large areas. In Nevada, we also recognize that Mount Grant (west of an Army Depot in the town of Hawthorne), and Wheeler Peak (east of Ely in the Great Basin National Park) are potential sites with positive attributes.

Summary

High-relief mountains are abundant in Nevada and California. An underground laboratory located at Charleston Peak near Las Vegas and at Boundary Peak on the Nevada-California state line could provide over 1,800 m (5,906 ft) of rock cover above test chambers. An additional cover on the order of 610 m (2,000 ft) could be added to Charleston Peak site if the portal is moved closer to Pahrump along a potential extension of Highway 137. Mount Tom and Mount Morgan could provide over 2,438 m (8,000 ft) of cover if the access tunnels were driven from flat land outside the Pine Creek Valley, with Pine Creek Mine tunnels as potential portals/extensions for escape tunnels. Mount Tom and Boundary Peak provide similar overburdens with comparable tunnel lengths as the Mt. San Jacinto site. Telescope Peak at Death Valley provides the greatest cover of 2,923 m (9,591 ft), among the sites evaluated. Systematic analyses of geologic, geotechnical, geohydrological and geochemical characteristics are needed to assess the technical, social-economical, and outreach-educational attributes in site selection for the next generation of science experiments.

Acknowledgement

We gratefully acknowledge assistance and information provided by Jon Price and Joe Tingley of the Nevada Bureau of Mines and Geology, Jaak Daemen and Pierre Mousset-Jones of the Department of Mining Engineering, John Anderson of the Seismology Laboratory, and Jane Long of the Mackay School of Mines, University of Nevada at Reno. Preliminary discussions held with Nevada Bureau of Mines and Department of Mining Engineering of the University of Nevada at Reno reinforced the view that there exist many recent examples of tunneling projects with similar scale within Nevada, with a well understood permitting and approval process, and with a very likely strong support from the state for development of an underground science laboratory. We gratefully appreciate the information and hospitality extended by Jonathan Henry and Pete Belec of the Avocet Tungsten Inc. and Tom Crosby of Secor Inc. in the visit to the Pine Creek Mine. Valuable discussions with John Apps and Harold Wollenberg of the Lawrence Berkeley National Laboratory are greatly appreciated.

Appendix D:
Letters of Interest Sent to National Underground Laboratory Committee

Summary

Summary of Letters of Interest Submitted to the National Underground Science Laboratory Committee

March 2001

Interest in Multiple Areas

1. Multiple Interest - Siegrist, Schroeder, LBNL, 1-Mar-01, solar neutrino, double beta decay, dark matter, long baseline, low background, and nuclear astrophysics

2. Multiple Interest - Bowles et al LANL, 28-Feb-01, LENS (solar neutrino), long baseline, low background, supernova, and nucleon decay

3. Multiple Interest - Peter Smith, Rutherford Lab 12-Feb-01, OMNIS (supernova), large scintillator–solar ν detector, and liquid Xe dark matter

4. Supplement to above Smith letter, Peter Smith, Rutherford Lab, 20-Feb-01

5. Multiple Interest - McKeown and Vogel Cal Tech, 12-Feb-01, solar neutrino, double beta decay, dark matter

6. Multiple Interest - Avignone South Carolina, 19-Feb-01, solar neutrino, double beta decay, dark matter, supernova

Solar Neutrinos

7. CLEAN (Low energy solar neutrino cryogenic) – Doyle, Harvard, 7-Feb-01

8. HERON (superfluid He LE neutrino) – Lanou, Brown, 7-Feb-01

9. High Pressure TPC for solar neutrinos – Bonicini, Wayne State, 5-Feb-01

10.Hybrid radiochemical low energy solar neutrino - Lande et al, Penn

11. Solar Neutrinos – Gavrin, INR, Russia, 19-Feb-01

34. A GaAs Solar Neutrino Detector – T. Bowles, *et al*., LANL, 16 February 2001

35. LENS – S. Raghavan and M. Cribier *et al*.

Also see: 1, 2, 3, 5, 6, and 13.

Double Beta Decay

12. EXO (^{136}Xe ββ) – Gratta, Stanford, 5-Feb-01

13. MOON (^{100}Mo ββ & solar ν) - Ejiri & Robertson, Osaka, Univ Wash, 3-Mar-01

Also see: 1, 2, 5, 6, and 16.

36. Majorana – H. Miley, Pacific Northwest Laboratories, 29 March 2001

Dark Matter

14. CryoArray -- CDMSIII, WIMP detection - Gaitskell & Akerib, University College London & Case Western Reserve, 16-Feb-01

15. Dark Matter - Collar, CNRS, France, 20-Feb-01

16. Dark Matter, neutrino detection – Willis, Columbia, (see Aprile below)

17. DRIFT (WIMP TPC detector) - Martoff & Snowden-Ifft Temple University

18. Liquid Xe for Dark Matter - Aprile & Hailey, Columbia, 18-Feb-01

19. WIMPS with neutrons – Ward, Dept. of Energy, 20-Feb-01

Also see: 1, 2, 3, 5, and 6

Nucleon Decay

20.UNO (nucleon decay) – Jung & Sobel, Stony Brook & UCI for UNO proto-collaboration, 20-Feb-01

21.Nucleon Decay - Mann and Lande, Univ. of Penn, 5-Feb-01

Also see: 2 and 3.

Atmospheric Neutrinos

See: Nucleon Decay, Long Baseline, and Solar Neutrino Experiments.

Long Baseline Neutrino Oscillation Experiments

22.Long Baseline – Neutrino Factory - Schellman for 23 signers, 15 Institutions, 18-Feb-01
23.Neutrino Factory Detector at WIPP – Cline, UCLA,
Also see: 1, 2, and 3.

Supernova Neutrinos

24. OMNIS (supernova) at WIPP - Boyd and Murphy, Ohio State
25. OMNIS - Fenyves & Burgett, Univ. of Texas-Dallas, 16-Feb-01

Also see: 1, 2, 3, 6, Nucleon Decay, and Solar Neutrino Experiments.

Nuclear Astrophysics

26. Nuclear Astrophysics Accelerator Measurements – Gai, Univ. Conn, 16-Feb-01
27. Nuclear Astrophysics Accelerator Measurements – Greife, Colorado School of Mines, 7-Feb-01
Also see: 1

Geoscience

28. Geophysics – Benson, LBNL, 19-Feb-01
Also see 33

Materials Development and Technology

29. Low background studies - Coursey, Karam, Lindstrom, Nico, NIST, 21-Feb-01
30. Cyro-detectors for neutrino scattering and gravity - Trimble (for Weber), UCI, 8-Feb-01
Also see: 1, 2, 31, and 32.

Monitoring Nuclear Tests

31.PIsCES (ultra-low background detectors and materials analysis) – Hartmann for collaboration, NRL,
32.PIsCES (ultra-low background detectors and materials analysis) – Gursky, NRL, 8-Feb-01

Microbiology

33. Biology and Geoscience, Onstott for collaboration, Princeton, 16-Feb-01

The *verbatim* text of the Letters of Interest are available on the website:
www.physics.umn.edu/~marshak/AppendixD.pdf

Appendix E: Engineering

The Homestake Gold Mine has been operated for ~125 years and is the "brand name" property of the Homestake Mining Corporation of Walnut Creek CA (www.homestake.com). The geology at Homestake has been extensively studied for many years. Homestake staff, contractors and consultants have drilled and extracted cores from large numbers of bore holes for many years. Exposed geological features have been mapped in more than 800 km of drifts at more than 20 levels in the mine. The geology of the Homestake Mine has provided material for large numbers of academic papers, theses and dissertations because of the prominence of the mine and its location nearby several major universities with strong mining engineering and geosciences programs. *The Homestake Gold Mine, An Early ProterozoicIron-Formation-Hosted Gold Deposit, Lawrence County, South Dakota,"* U.S. Geological Survey Bulletin 1857 (1991), by S.W. Caddey, et al. lists approximately 75 references to academic papers regarding the Homestake Mine.

The South Dakota School of Mines and Technology (SDSM&T) has retained qualified and licensed engineering and architectural consultants to evaluate the Homestake site and to develop the planning and cost estimates that underly this proposal.

- Dr. John D. Osnes, Geomechanics Manager for Respec, Inc., an integrated consulting and services company with offices in Rapid City, Pierre, Albuqueque, Carlsbad, St. Paul, Phoenix and Houston, has reviewed previous rocks mechanics studies at Homestake by the University of Utah, SDSM&T and the U.S. Bureau of Mines. Dr. Osnes concludes that "*in situ* conditions are generally adequate for their construction," with the word "their" a reference to experimental rooms of cross-section 18 m by 18 m by 100 m in length. Dr. Osnes estimates that a three month onsite investigation would be required to determine specific location, orientation and ground support for a series of Gran Sasso-type laboratories.
- Dunham Associates, mechanical, electrical and structural consulting engineers with offices in Minneapolis, Las Vegas and Rapid City (www.dunhamassociates.com), have reviewed the mechanical, electrical, communications and safety systems at Homestake. The costs listed in this proposal are based on their conceptual design and resulting cost estimates for the conversion of these systems from mining to support for an underground science laboratory.
- Dynatec Corporation of Richmond Hill (Toronto) Ontario, one of North America's leading mining contractors (www.tonto.com) has developed a conceptual design and costs for underground excavations, shaft extension and renovation of the Homestake hoisting equipment. Dynatec is a design-build firm and presumably would be interested in performing the work at Homestake for the prices provided to SDSM&T and included in this proposal.
- The architectural firm TSP Three, Inc. of Rapid City (www.teamtsp.com/tsp3/home.html) has developed conceptual architectural drawings and cost estimates for the Upper Campus buildings and roadway and parking improvements.

SDSM&T faculty and staff have reviewed the cost estimates of the outside consultants and checked those estimates against the operating cost experience of the Homestake Corporation, as reported both by management and by labor at the Homestake site.

Finally, all of the conceptual designs and cost estimates have been reviewed one final time by Dr. Lee Petersen and Dr. Charles Nelson of CNA Engineers, Inc. of Minneapolis. CNA Engineers specialize in underground construction for habitable spaces. Their previous projects include both the Soudan 2 Underground Laboratory and the MINOS Far Detector Underground Laboratory, both located at Soudan MN, and likely the most appropriate prototypes in the United States for the type of national underground laboratory proposed for construction at Homestake.

All of the engineering consultants have provided extensive documentation that will provide the basis for the first Technical Design Report (TDR) for the Homestake project. The Homestake TDR will inform the various "Temple" reviews that will proceed, once the project is approved.

Appendix F: EPSCoR Linkages to NUSL

South Dakota has participated in the NSF-EPSCoR program since 1989. Data compiled by the NSF in 1989 declared South Dakota as the most eligible state for inclusion in the EPSCoR program. During the subsequent ten-year period, South Dakota has progressed from 19th to 14th on this EPSCoR eligibility scale and only one other EPSCoR state has improved its ranking to a greater degree. Reasons for this improvement include: a) a 85% increase in the number of NSF awards to SD investigators between 1989 and 2000, b) a 320% increase in total grants and contract funding to South Dakota universities during 1989 to 2000, c) South Dakota was declared to be one of only eight states with a statistically significant annual R&D growth rate over 3% (NSF Data Brief, July 10, 2000), and d) SBIR awards totaling more than $9 million have been made to 23 "start-up" companies in South Dakota since 1995. In addition, South Dakota has recently embarked on a collaborative effort to expand its EPSCoR activities by seeking funding from EPSCoR programs at NIH, DoD, DoE, NASA, and EPA.

One of the major outcomes from the EPSCoR program has been the successful linkage of South Dakota researchers with colleagues in other EPSCoR states. The development of the NUSL presents an opportunity to expand significantly on this base of EPSCoR linkages. News of the potential NUSL in South Dakota has quickly spread among EPSCoR states during the past several months and the informal reactions from numerous individuals from these states have been both enthusiastic and supportive. Hence, we plan to build on this enthusiasm by hiring a qualified individual who will be tasked specifically with engaging relevant researchers from all EPSCoR-eligible states in the overall research and educational opportunities inherent to the NUSL. These opportunities will be especially welcomed by the research and educational communities in the EPSCoR states that are in close proximity of South Dakota; i.e., North Dakota, Nebraska, Wyoming, Montana, and Idaho. Currently, there is no major research-oriented center in this core group of EPSCoR states and the proposed NUSL will help fill this gap.

Appendix G: Letter to the National Science Foundation Regarding a National Underground Science Laboratory from the Nuclear Science Advisory Committee

June 5, 2001

Dr. Robert Eisenstein
Assistant Director, Mathematical and Physical Sciences
Room 1005 N
National Science Foundation
4201 Wilson Boulevard
Arlington
Virginia 22230

Dear Dr. Eisenstein,

This letter is written to express unanimous support by the members of the Nuclear Science Advisory Committee (NSAC) for the creation by the National Science Foundation of a National Underground Science Laboratory at the Homestake Mine site in South Dakota.

As you are well aware, NSAC is presently engaged in developing the next Long Range Plan for Nuclear Science in the United States. A consensus reached during a recent meeting of the Long Range Plan working group in Santa Fe, was that an important element of our vision for the future of Nuclear Science in the United States is leadership in the area of underground science within the next decade. Further, there is presently an outstanding opportunity for the United States to assume world leadership at the frontier of underground science through the acquisition and development by the National
Science Foundation of the Homestake mine in South Dakota to create a deep underground (7000 meter of water equivalent (m.w.e)) laboratory. Such a laboratory could house a generation of important NSF and DOE experiments on fundamental physics. We understand that there is also considerable interest in underground science within the biology, earth sciences, and material sciences communities.

In the last decade, fundamental progress has been made in underground experiments in such diverse areas as nucleon decay, atmospheric neutrino oscillations, solar neutrino oscillations, and searches for dark matter. These studies have not only increased our understanding of the fundamental properties of the universe, but have pointed to new
and even more challenging frontiers of compelling scientific interest. To explore these frontiers, the next generation of experiments (e.g. solar neutrino, double beta decay, etc.) will require a deep underground laboratory to reduce cosmic ray-related backgrounds, which constitute the limiting factor for high sensitivity experiments. A National Underground Science Laboratory at a depth of 7000 m.w.e., at the Homestake Mine site would constitute a world class facility, with a dedicated infrastructure to insure U.S. leadership in underground studies well into the next century.

This opportunity is unique, as the mining company presently operating at the Homestake site could construct the caverns necessary for an underground laboratory in a very cost-effective manner, once commercial operations cease. The science of the underground laboratory and its place in the broader nuclear science program will be discussed when we submit our report. We are writing to you now, however, because the decision to seriously investigate this possibility is time-critical. Without a serious expression of interest and possible commitment towards the future development of this site for this purpose, it will be intentionally flooded to avoid the potential liability associated with abandoning an open mine.

In view of the compelling nature of the science to be done in a deep underground laboratory, and the potential benefit to the United States of world leadership in this area, we strongly recommend that the National Science Foundation undertake

an immediate study to assess the feasibility of the Homestake site for a National Underground Science Laboratory, and that it invite a detailed proposal and technical design report for serious consideration. NSAC is unanimous that the initiative to create a National Underground Science Laboratory is very important to further fundamental progress in the physical sciences, to train the next generation of scientists in the United States, and to maintain U.S. leadership in the world scientific community.

Sincerely,

James Symons, Chair
Nuclear Science Advisory Committee

c. James F. Decker, DOE
J. Dehmer, NSF
P. Rosen, DOE
B. Keister, NSF
D. Kovar, DOE