The US Underground Laboratory Initiative: DUSEL

Dan Akerib
Case Western Reserve University

EFI Symposium
University of Chicago
10 Dec 2004
Underground science

• Rich science history and bright future
• Pioneering work in the US, but no major central multi-purpose US laboratory
• Major Physics milestones
  ◆ Homestake neutrino expt
  ◆ IMB
  ◆ Kamiokande/SuperK
  ◆ SNO

from NRC-NFAC report
Physics Program

• Broad program of particle physics and astrophysics requiring large detectors and/or deep underground sites

• A survey:
  ◆ Dark matter
  ◆ Double beta decay
  ◆ Solar neutrinos --new knowledge and new detectors.. New path in the future
  ◆ Long-baseline neutrinos
  ◆ Proton decay
  ◆ Supernova observatory

◆ Broad benefits of common infrastructure, low background techniques, technical support, etc.

common large detector
• Neil Spooner’s talk
  - Suppression of cosmogenic neutron background for ton-scale requires great depth
• Some numbers
  - CDMS estimated neutron background ~ 0.05 evts in 20 kg-d @2000mwe
  - =1 evt/400 kg-d
  - Increase exposure (MT) by ~10,000
  - => 25 events @2000mwe
  - Target ~0.1 event to run at zero background
  - Uncertainties in neutron yield - aim for factor 500 suppression
Double beta decay

• Only way to learn of majorana nature of neutrino
  - Rate depends on absolute mass scale

• 2-neutrino process observed

• Claimed observation -- controversial -- needs to be checked

11 kg, ~10 years
Double beta decay

• Many new experiments gearing up to test this claim and go beyond it...
• Major US efforts
   Majorana expt- 500 kg Ge76 (86%)
   EXO - 1-ton LXe TPC
Solar neutrinos

• What have we learned?
  ◆ Davis pioneering experiment identifies solar neutrino deficit
  ◆ SNO confirms that solar $\nu_e$ oscillates into $\nu_\mu + \nu_\tau$
  ◆ KamLAND reactor experiment consistent

• What is the next challenge: a precision measurement of p-p $\nu$’s
  ◆ 90% of solar neutrinos - improve test of standard solar model
    • Energy source other than fusion?
  ◆ Independently confirm neutrino mixing parameters
    • Low-energy p-p $\nu$’s dominated by vacuum oscillations
    • Test unitarity of 3-generation model

Possible future US Program:
  ◆ Heron - rotons in LHe
  ◆ Clean - scintillation in LNe
  ◆ LENS - liquid scintillator
Solar neutrinos

Possible future US Program:
- Heron - rotons in LHe
- Clean - scintillation in LNe
- LENS - liquid scintillator
Nucleon decay & long-baseline $\nu$

- Large multipurpose detectors
  - Long-baseline neutrinos
  - Proton decay
  - Supernova observatory

UNO: ~20 SuperK (fid.)

LANNDD - Liquid Argon Neutrino and Nucleon Decay Detector

Water cherenkov

LANNDD 100 kton
EarthLab

• EarthLab report grew out of NSF’s 2002 Neutrino & Subterranean Science (NeSS02) workshop
  ◆ “A Subterranean Laboratory and Observatory to Study Microbial Life, Fluid Flow, and Rock Deformation”

• Interrelated processes
  ◆ rock stress → porosity/permeability → fluid flow → bioactivity → chemical activity → rock breakdown/mechanics

• Need an underground laboratory to study processes
  ◆ Biological
  ◆ Hydrological
  ◆ Geomechanical
  ◆ Geochemical

“A more comprehensive understanding of this coupling is critical to interdisciplinary research ranging from earthquake engineering to bioremediation to exploration for new groundwater resources.” --www.earthlab.org
Scientific Rationale

Societal Imperatives

- **Resource Recovery**
  - Petroleum and Natural Gas Recovery
  - In Situ Mining
  - HDR/EGS
  - Potable Water Supply
  - Mining Hydrology

- **Waste Containment/Disposal**
  - Deep Waste Injection
  - Nuclear Waste Disposal
  - CO₂ Sequestration
  - Cryogenic Storage/Petroleum/Gas

- **Site Restoration**
  - Acid-Rock Drainage
  - Aquifer Remediation

- **Underground Construction**
  - Civil Infrastructure
  - Mining
  - Underground Space
  - Secure Structures

Both GeoHydrology and GeoMechanics

Mainly GeoHydrology

Mainly GeoMechanics

Courtesy of Derek Ellsworth
Geological studies: instrumenting the rock

- Evaluate coupled thermal, hydrological, mechanical and chemical processes surrounding the potential repository
- 50-m long by 5-m diameter
- Maximum drift wall temperature reached ~ 200°C
- Water, gas, and rock samples collected from boreholes for geochemical and isotopic studies
- Reaction-transport modeling performed prior to and during test

Drift Scale Test at Yucca Mountain’s WIPP site - Waste Internment Pilot Project

Adapted from D. Ellsworth & E. Sonnenthal
Dusel/EFI Symposium, 10 Dec 2004

Dan Akerib, Case Western
The EarthLab Underground Observatory

Surface laboratories

The Deep Flow and Paleoclimate Laboratory and Observatory

The Induced Fracture and Deformation Processes Laboratory

The Deep Coupled Processes Laboratory

The Ultradeep Life and Biogeochemistry Observatory

The Deep Seismic Observatory
Induced Fracture Processes Laboratory

- Evaluate and refine models of fracture initiation and propagation
  - Resource recovery
  - CO2 sequestration
  - Waste isolation
- Examine effects on proximal fluid flow and transport including proppants
  - Wellbore interaction effects
  - Pressure solution in fractures
  - Examine roles of different propellants
- Examine roles of fractures in bacterial colonization
- Examine the long-term stability and durability of underground openings

http://www.earthlab.org/

Courtesy of Derek Ellsworth
Deep Coupled Processes Laboratory

- Characterize coupled-processes that affect critical environmental engineering, and complex subsurface Earth processes
  - CO2 sequestration
  - Waste isolation
  - In situ mining
  - Mineralization and ore body formation
- Characterize coupled processes under ambient conditions
- Chemical fate and transport including dissolution/precipitation and modification of mechanical and transport parameters
- Multiphase flow and transport
- Microbial colonization

http://www.earthlab.org/

Courtesy of Derek Ellsworth
Deep seismic observatory

- Investigate physics relating fracture formation to seismic wave propagation
- Monitor local and global seismic events and mining seismicity
- 3D array of ~60 broadband stations
- Complement transportable and permanent components of USArray

Courtesy of Derek Ellsworth
## Attributes of different geo-environments

<table>
<thead>
<tr>
<th>Sci/Eng Focus</th>
<th>Relevant Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall/Geo/Eng</td>
<td>Low-high stress</td>
</tr>
<tr>
<td></td>
<td>Low-high thermal gradient</td>
</tr>
<tr>
<td></td>
<td>Small-large site volume</td>
</tr>
<tr>
<td></td>
<td>Homogeneous-heterogeneous</td>
</tr>
<tr>
<td></td>
<td>Unfractured-fractured</td>
</tr>
<tr>
<td></td>
<td>Ramp access – shaft access</td>
</tr>
<tr>
<td>Geo-biological</td>
<td>Sterile-teeming</td>
</tr>
<tr>
<td>Geo-chemical</td>
<td>Reactive-inert</td>
</tr>
<tr>
<td></td>
<td>High-low electrochemical flux</td>
</tr>
<tr>
<td>Geo-hydrological</td>
<td>Permeable-porous to non-porous/fractured</td>
</tr>
<tr>
<td>Geo-mechanical</td>
<td>Brittle-ductile</td>
</tr>
<tr>
<td></td>
<td>Low-high stress</td>
</tr>
<tr>
<td>Geo-physical</td>
<td>Aseismic-Seismic</td>
</tr>
</tbody>
</table>

*Courtesy of Derek Ellsworth*
What will we need to do better in 20 years?
Grand Challenges

- **Resource Recovery**
  - Locate resource
  - Access quickly and at low cost
  - Recover 100% resource at chosen timescale
  - No negative environmental effect

- **Waste Containment/Disposal**
  - Characterize host at high resolution
  - Access and inter quickly at low cost
  - Inter completely or define fugitive concentration output with time

- **Underground Construction**
  - Characterize inexpensively at high resolution
  - Excavate quickly and inexpensively
  - Provide minimum support for maximum design life
  - ..................
Underground Science Laboratory
Potential for Scientific and Engineering Innovation

- Genetic materials, microorganisms with novel capabilities, biotechnology applications
- Instrumentation for monitoring/mapping in extreme environments (subsurface MEMS/NEMS imaging/sensors), applications in exobiology & underground mine mapping (robotics, lasers)
- Environmental remediation technologies (contaminated groundwater)
- CO2 sequestration field testing (leakage, impact)
- Drilling & excavation technology (rock engineering, structural support of rock masses)
- Natural resource exploitation and development

Courtesy of Derek Ellsworth

Earth’s Subsurface Microbial Ecology

- The biosphere extends deep into the subsurface
- Limited by geothermal gradient and nutrient flux
- Biomass generally low relative to the surface
- Distribution is very patchy and heterogeneous
- Rates of community metabolism very low
- Volumetrically largest part of the biosphere

Todd Stevens, Pacific NW National Laboratory
What have we learned?

Advancements in Subsurface Microbiology

- Drilling, tracer and QA/QC methodologies developed
- Extended known biosphere to 3 km
- Revealed biomass, biodiversity, unusual traits & microbes
- Linked microbial activity with geological interfaces
- Slow rates of deep subsurface microbial activity
- Indications of autotrophic ecosystems
- Insights into evolution and ecological genomics

Courtesy of Tommy Phelps
What have we learned?

- Subsurface biomass was considered insignificant but is now recognized as a major fraction of planetary biomass (likely greater than surface biomass?)
- Subsurface microbial populations are diverse, active, unusual, possess novel traits, represent an exploitable resource

Courtesy of Tommy Phelps
What kind of experiments would we like to do?

- Deep biosphere and biogeochemistry
- Limits of life and survival/tolerance/adaptation
- Evolutionary gradients, eco-genomics, and primitive life
- Fluid, energy, and organismal transport
- Impact of geological formations on life/preservation
- Test for an absence of life
- Impacts of human intervention on subsurface ecology
- Relationships to energy generation and carbon sequestration
- Study ore and vein forming/disassociation and mining processes
- Geo/bio/chemical study of a fabricated petroleum reservoir
- Carbon management in geological/hydrological repositories
- Role of faults on regional fluid (energy) migration
- Engineering, imaging, robotic, and in-situ mining sciences
- Others
Scientific Case for DUSEL: Isolation

- Longtime sequestered
- Old water
- Old sediments/rocks
- Multiple interfaces
- Access to varied lithologies
- Access to Faults/Intrusions
- Varied T, P, structure, stress
- Multiple cubic km test blocks
Key Experiments: Culture-Independent Evidence for Deep Life

Genomic advancements

- Sequencing of a microbe required ~18 months in mid 90’s
- Currently >150 microbes have been sequenced
- In 2004 TIGR discovers 1.2 million new bacteria/archea genes in the Sargasso Sea
- By 2005 JGI could sequence 400 microbes per year

Drilling for subsurface life on Mars?

Could early life in the subsurface have survived the Hadean bombardment?
Emerging cross-disciplinary themes

• Begin to recognize opportunities across fields...
   GeoEngineering + GeoBiology - common theme to instrument and manipulate large volumes of rock at a variety of depths and materials
   GeoBiology wants pristine environments
    • investigations on the first wave into a new region
   Creation of large caverns desired by physicists are frontier research projects in GeoEngineering
    • UNO - “that’s big -- could take 10-15 years to figure out how to build that cavern…”

• ...and incompatibilities
   Physicists want large stable environment
   GeoEngineers want to make rock bursts (!)
Context, history, & past attempts

• Existing labs/sites - some examples
  ◆ WIPP, Soudan - too shallow
  ◆ Gran Sasso - oversubscribed; not deep enough to satisfy long-term science goals
  ◆ SNOlab - deep but modest in scale

• Current imperative
  ◆ The science is excellent
  ◆ Proven track record of US program
  ◆ US pioneering role
    ◆ Chlorine expt marked beginning of neutrino astronomy
    ◆ IMB proton decay (concurrent with Kamioka) ruled out early GUTs, 1987a, atmospheric neutrino 'anomaly'
    ◆ Gallium technique
  ◆ Strong US involvement today (eg, SNO, SuperK)
  ◆ Opportunity for the US future program to take the lead by establishing a large deep underground multi-purpose lab

• Previous US attempts
  ◆ Early 1960’s - Alvarez, Pevsner, Reines
  ◆ Early 1980’s - Mann & Sharpe (Yucca Mtn.); UC Irvine (San Jacinto)
Legacy of most recent attempt

• Ongoing interest in the science
• Triggered by Homestake site concept - cease of mining operations
• Discussion/proposals of 4 sites
  ◆ Homestake
  ◆ San Jacinto
  ◆ Soudan
  ◆ WIPP
• Foundered politically…
• Important legacy
  ◆ Attention of the scientific community
    • NRC Q2Cosmos, NRC-NFAC, NSAC LRP, …
  ◆ Bahcall report and Homestake “Science Book” still very relevant to defining the program
New NSF process

We’ve been brought together by an extraordinary set of crosscutting scientific opportunities

- To realize these grand opportunities, we must work together – the hallmark and strength of NSF
- The purpose of this meeting is to lay out the NSF plan for proceeding and hear your feedback
New NSF process

- 3 solicitations - charge to community:
  - Restart the process - build on the recent workshops (Lead, NeSS02, EarthLab), reports (Bahcall, NRC Neutrinos & Beyond, Quarks to the Cosmos)
  - Lead with the science - “Solicitation 1” - planning grant(s) to define science and infrastructure requirements (Sept ‘04)
    - Recognize on “day one” the interdisciplinary nature of this field and build that into the planning process
    - Reality: science modules - let’s get started and at least do something - even if we may not be able to do everything right away
    - Attempt to decouple the science planning from the site selection
  - Site development grants - “Solicitation 2” - proposals to develop site plan and how infrastructure needs for science and engineering modules could be met (March ‘05)
    - Time lag relative to S1 but not sequential - attempt to benefit from early work
  - Full proposal development - “Solicitation 3” - including suite of initial experiments
    - Down select to 1 or 2 sites for S3 awards
  - Review at NSF - initiate Major Research Equipment Facility Construction process (MREFC)
Solicitation 1 status

• Goal: single response from the community
  ◆ Berkeley workshop (Aug ‘04)
  ◆ Coming together of diverse fields
  ◆ Watershed event for the physicists: these other guys mean business!

• Organization
  ◆ PI group but no site proponents
    – Gene Beier, U Penn (Particle Physics)
    – Charles Fairhurst, U Minnesota (Engineering/Geology)
    – Tullis Onstott, Princeton (Biogeology)
    – Hamish Robertson, U Washington (Nuclear Physics)
    – Bernard Sadoulet, UC Berkeley (Astrophysics)
    – James Tiedje, Michigan State (Biology)
  ◆ Working groups (~15) on the various disciplines
  ◆ Site proponent contacts - 2 per site x 8 sites

• Proposal submitted Sept ‘04

• Looking for approval by Dec, so that funds ~$0.5M can be used to generate full report Jun ‘05
  ◆ Summarize All Science at DUSEL
  ◆ More workshops: Blacksburg this past Nov.(Geosci.), Boulder in January
Solicitation 2

• Expect 8 sites to make submissions
  • Cascades-Icicle Creek (WA)
  • San Jacinto (CA)
  • Homestake (SD)
    – Water is only major issue for biologists, ~1 km from flood area (virgin rock)
  • Henderson (CO)
  • Soudan (MN)
  • WIPP (NM)
  • Kimbleton (VA)
  • SNOLab (Canada)
    – Expansion to multi-purpose lab in progress

• Note: “Possibility of multiple laboratory sites, including international sites” (Turner 3/29/04)

• Formal NSF Solicitation issued Oct ‘04
  ♦ Sites were to respond by Jan’05 deadline
  ♦ Recently extended to March - benefit from Boulder workshop
Underground Facility

Phase I

Rectangular Hall

New Clean/Dirty Boundary

Relocated Personnel Facilities

Ladder Labs
Underground Facility

Phase II

Cryo Pit

Fraser Duncan
Surface Facility
Solicitation 2

• Expect 8 sites to make submissions
  • Cascades-Icicle Creek (WA)
  • San Jacinto (CA)
  • Homestake (SD)
    – Water is only major issue for biologists, ~1 km from flood area (virgin rock)
  • Henderson (CO)
  • Soudan (MN)
  • WIPP (NM)
  • Kimbleton (VA)
  • SNOLab (Canada)
    – Expansion to multi-purpose lab in progress

• Note: “Possibility of multiple laboratory sites, including international sites” (Turner 3/29/04)

• Formal NSF Solicitation issued Oct ‘04
  • Sites were to respond by Jan’05 deadline
  • Recently extended to March - benefit from Boulder workshop
“Modules” - Common Requirements

• Small/clean as deep as possible Physics+Geo
  ◆ Generic Dark Matter, Double Beta, Solar Neutrino
  ◆ Deep biological observatory, deep geological experiments (virgin territory)

• Large: mostly physics but geo-monitoring
  ◆ Proton decay/long baseline neutrino
  ◆ Significant geo/rock mechanics instrumentation

• Large instrumented earth science volumes
  ◆ Systematic multi-km³ instrumented “sand boxes” or feature target of opportunity (e.g. major fault or very fractured zone)
  ◆ Large scale geo/engineering experiments
  ◆ Interest for physicists?
Themes

• Unity
  ◆ Get beyond natural rivalry between sites and propaganda
  ◆ Develop common language of infrastructure requirements
    • e.g. go beyond horizontal/vertical access and identify technical needs
    • evaluate generic site-independent self-consistent scenarios
    • e.g. short distance-low energy /long distance for long baseline neutrinos
  ◆ 2 very different communities
    • Particle, nuclear astro physicists
    • Geologists, biologists, engineers
    • Understand differences and convergence

• Infrastructure requirements
  ◆ Main focus: technical requirement matrices - needed to evaluate science capability of the prospective sites

• Education and outreach
  ◆ Build in from the start
  ◆ Our common responsibility: not a specialized working group meeting in parallel
  ◆ But recognize value of central support, professionals
Summary and outlook

- NSF reopened study - motivated by desire to level paying field - strong interest Geo - possibility of multiple sites
  - e.g. Icicle as deep / with Henderson for large experiments
  - e.g. Deep could be SNOLab, with large proton decay/neutrino in US
  - (Geologist would like multiple sites)
- Main Study Report (50 pages) (from Solicitation 1)
  - Will be submitted Jun ‘05
- Down select of Solicitation 2 submissions
  - Probably 1-3 sites announced Summer ‘05
- Solicitation 3 during FY05
  - Planning grant to develop full proposal including suite of proposed experiments
- During FY06
  - Review and Decision to proceed through full MRE-NRC-NSB review
- Earliest $$$
  - If pace is maintained NSF intends to put lab costs in FY08 President's Budget
  - Occupancy: 2010 (may be optimistic) – 2012
- OSTP - Office of the Science of The President
  - Formal response to NRC Quarks to Cosmos - Interagency Working Group identifies target area of “Dark Matter, Neutrinos, and Proton Decay” and advises NSF to take lead in concept for Underground lab, and to work jointly with DOE to specify suite of experiments.
Acknowledgements

• B. Sadoulet
• R. Gaitskell
• S. Freedman
• H. Sobel
• M. Turner
• T. Phelps
• D. Ellsworth
• S. Elliot
• B. Lanou
• D. McKinsey
• F. Duncan
• EarthLab report
• Homestake Science Book
More information...

• August workshop (Berkeley)
  ◆  http://neutrino.lbl.gov/DUSELS-1/talks/
• SCIENTIFIC REPORTS
  ◆  Reports on underground science 2000
    •  http://www.sns.ias.edu/~jnb/Laboratory/science.pdf
  ◆  Technical Evaluation of Underground Laboratory Sites
    •  http://www.sns.ias.edu/~jnb/Laboratory/evaluation.html
  ◆  Lead workshops on underground science 2001:
    •  http://esd.lbl.gov/ESD_staff/wang/wang_eswks hp.html
    •  http://nucth.physics.wisc.edu/conferences/und science/program.html
    •  http://nucth.physics.wisc.edu/conferences/white/Homestake.html
  ◆  International Workshop on Neutrino and Subterranean Science 2002 (NeSS 2002)
    •  http://www.physics.umd.edu/events/spevents/NeSS02/
• Deep Underground Science and Engineering Lab
  ◆  http://www.dusel.org/
• NRC reports:
  ◆  Neutrino facilities
    •  http://www.nap.edu/catalog/10583.html
  ◆  Quarks to the Cosmos
    •  http://books.nap.edu/catalog/10079.html
• DOE NP Long Range Plan 2002
  http://www.sc.doe.gov/henp/np/nsac/nsac.html
• DOE Facilities for the Future 2003
  http://www.sc.doe.gov/Sub/Facilities_for_future/facilities_future.htm
• DOE HEP long-range plan and other reports
  http://www.science.doe.gov/hep/hepap_reports.htm
• OSTP report February 2004
  •  http://www.ostp.gov/html/physicsoftheuniverse2.pdf

• EarthLab
  ◆  http://www.earthlab.org
  ◆  contact: Brian McPhearson
Site links

• Cascades–Icicle Creek, WA
  - contact: Wick Haxton (haxton@phys.washington.edu)
    John Wilkerson (jfw@phys.washington.edu)

• Henderson Mine, CO
  - http://cause.mines.edu/
  - contact: Chang Kee Jung
    (alpinist@ale.physics.sunysb.edu)
    Bob Wilson (rwilson@lamar.colostate.edu)

• Homestake Mine Project, SD
  - http://www.hpcnet.org/homestake#
  - also, http://ktlesko.lbl.gov/nusel
  - contact: Kevin Lesko (ktlesko@lbl.gov)
    Willi Chinowsky (wchinowsky@lbl.gov)

• Kimballton Mine, VA
  - http://www.phys.vt.edu/~kimballton/
  - contact: R. Bruce Vogelaar
    vogelaar@vt.edu
    Bob Bodnar (rjb@vt.edu)

• Mt. San Jacinto, CA
  - http://www.ps.uci.edu/~SJNUSL/
  - contact: Hank Sobel (hsobel@uci.edu)
    Bill Kropp (wkropp@uci.edu)

• Soudan Mine, MN
  - http://www.soudan.umn.edu/NUSEL/
  - contact: Marvin L. Marshak (marshak@umn.edu)
    Earl A. Peterson (eap@umphys.spa.umn.edu)

• The Sudbury Neutrino Observatory Laboratory (SNOLAB), Creighton Mine, Ontario
  - http://www.snolab.ca
  - contact: Andrew Hime (ahime@lanl.gov)
    David Sinclair (sinclair@physics.carleton.ca)

• WIPP (Waste Isolation Pilot Plan), NM
  - contact: Roger Nelson (Roger.Nelson@wipp.ws)
    Lloyd Piper (lloyd.piper@wipp.ws)

• Green Fields Report