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The Deep Underground Science and Engineering Laboratory
Site Independent Study

6 Principal Investigators
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(Nuclear Physics)
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(Geology and Engineering)
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(Geomicrobiology)
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(Microbiology)

The process
The science
Infrastructure requirements
The international context
Solicitation 1: Community wide study of
- Scientific roadmap: from Nuclear/Particle/Astro Physics to Geo Physics/Chemistry/Microbiology/Engineering
- Generic infrastructure requirements
Proposal supported by all 8 sites
Approved by NSF (January 05)
PI's went to Washington 28 February to 2 March to clarify goals and time scale

Solicitation 2: Preselection of ≈ 3 sites
- 8 proposals submitted February 28.
- Panel late April. Decisions public by late June

Solicitation 3: Selection of initial site(s)
- MRE and Presidential Budget (09) --> 2011-2015

See www.dusel.org
Solicitation 1 Organization

6 PI's responsible for the study
   in particular scientific quality/ objectivity

14 working groups
   Infrastructure requirements/management
   Education and outreach

2 consultation groups
   • The site consultation group (Solicitation 2 sites)
   • The initiative coordination group: major stakeholders (e.g. National Labs)

3 workshops building on NUSL/NESS
   Berkeley Aug 4-7
   Blacksburg Nov 12-13
   Boulder Jan 5-7

Interim report April 22 before the Sol 2 panel meets
Minneapolis workshop: 22-24 July 05=>Finalize content of report
External review à la NRC
Rolling out workshop in Washington Early Fall 05

Printed report directed at generalists
   Agencies
   OMB/OSTP/Congress cf. Quantum Universe
   +Web based reports with technical facts
   for scientists and programs monitors
Originality of the process

**Community-wide Site Independent: Science driven!**

**Multidisciplinary from the start**

Not only physics, astrophysics but Earth sciences, biology, engineering

Internal strategy inside NSF: interest many directorates -> MRE line

NSF=lead agency but involvement of other agencies: DOE (HEP/Nuclear, Basic Sciences), NASA (Astrobiology), NIH, USGS + industry

**Adaptive Strategy**

This is an experimental science facility, not an observatory

Specifically adaptive strategy to take into account

- The evolution of science
- International environment (available facilities - e.g. SNOLAB, MegaScience coord.)
- Budgetary realities

Excavate as we go ≠ LN Gran Sasso

**Potentially multi-sites**

Although some advantages of a single site in terms of technical infrastructure and visibility
not necessary provide we have a common management (multi-campus concept)

variety of rock type and geological history
closer to various universities (important for student involvement)

**Modules that can be deployed independently (in time or space)**

Decoupling of large detector from deep science

($1B-$2B)= mega-science decision taken outside the physics community
Rare Process Physics needs low cosmic-ray rates
Major Questions in Physics

What are the properties of the neutrinos?
Are neutrinos their own antiparticle?
3rd generation of neutrinoless double beta decay. (250kg -> 1 ton)

What is the remaining, and presently unknown, parameters of the neutrino mass matrix? $\theta_{13}$? hierarchy of masses? CP symmetry?

Do protons decay?
Current theories $\sim$ within factor 100 of current limits
$>$ factor 10 possible $=>$ may allow a spectacular discovery!

Immediately related to
• the completion of our understanding of particle and nuclear physics
• the mystery of matter-antimatter asymmetry

Surprises very likely!
Major Questions in Astrophysics

What is the nature of the dark matter in the universe?
- e.g. weakly interacting massive particles (WIMPs)?
- Supersymmetry? Complementary to LHC/ILC.

What is the low-energy spectrum of neutrinos from the sun?
- sun but also fundamental properties of neutrinos.

Neutrinos from Supernovae:
- Long term enterprise for galactic SN!
- Relic SN neutrinos
- Local galaxies <-> Gravitational detectors + optical ≈ 1 day later

Underground accelerator (cf. Luna)
- Nuclear cross sections important for astrophysics and cosmology

Follow on surprises and new ideas
Geoscience: The Ever Changing Earth

Processes taking place in fractured rock masses

- Cracks => Dependence on the physical dimensions and time scale involved.
- In situ investigation of the Hydro-Thermal-Mechanical-Chemical-Biological (HTBCB) interactions at work
- This understanding is critical for a number of problems of great scientific and societal importance
  - ground water flow
  - transport of foreign substances
  - energetic slip on faults and fractures.

Approach the conditions prevalent in the regions where earthquakes naturally occur

help us answer questions such as
  - Earth crust and tectonic plates motions?
  - Onset and propagation of seismic slip on a fault?
  - Prediction of earthquakes?

Requires A deep laboratory, with long term access (>20yr)

Which rock? Initially any kind would be interesting
Eventually all types should be available internationally
igneous, metamorphic and sedimentary (+salt)
**Subsurface Engineering**

**Mastery of the rock**

What are the limits to large excavations at depth?
- petroleum boreholes: 10km Ø 10cm
- deepest mine shafts: 4km Ø 5m
- DUSEL experimental areas: 10-60m at a depth between 1 and 3km

Much experience will be gained through the instrumentation and long term monitoring of such cavities at DUSEL.

Technologies to modify rock characteristics e.g. in order to improve recovery: go beyond hydrofracture, role of biotechnologies.

**Transparent Earth**

Can progress in geophysical sensing and computing methods be applied to make the earth “transparent”, i.e. to “see” real time processes?

Remote sensing methods tested/validated by mining back.

In particular, relationship between surface measurements and subsurface deformations and stresses: important for study of the solid Earth.

**Great societal impact**

- Large underground constructions
- Groundwater flow,
- Ore /oil recovery methods and mining/boring technology
- Contaminant transport
- Long-term isolation of hazardous and toxic wastes
- Carbon sequestration and hydrocarbon storage underground (sedimentary rock)
A recent breakthrough

Fig. 2 of Earthlab report

S. African data + Onstott et al. 1998
Major Questions in Geomicrobiology

How does the interplay between biology and geology shape the subsurface?
- Role of microbes in HTMCB
  - e.g. dissolution/secretions which may modify slipage or permeability

What fuels the deep biosphere?
- Energy sources ("geogas": H2, CH4, etc.) ≠ photosynthesis?

How to sustain a livelihood in a hostile environment?

How deeply does life extend into the Earth?
- What are the lower limit of the biosphere, imposed by temperature, pressure and energy restrictions?
  - => What fraction does subsurface life represents in the biosphere?

Need for long term access as deep as possible
- Current technology requires horizontal probes (negative pressure to minimize contamination)
- Long term in situ observation and access to the walls
- Deeper bores with remote observation modules
Major Questions in Biology

What can we learn on evolution and genomics?
- Isolated from the surface gene pool for very long periods of time.
- Primitive life processes today?
- How different?
- How do they evolve? Phage?

The role of the underground in the life cycle
- Did life on the earth's surface come from underground?
- Has the subsurface acted as refuge?
  - What signs of subsurface life on Mars?

Is there dark life as we don't know it?
- Unique biochemistry, e.g. non-nucleic acid based? Signatures?

Potential biotechnology and pharmaceutical applications!
- A reservoir for unexpected and biotechnologically useful enzymes?
  - Same requirements as geomicrobiology
  + sequencing and DNA/protein synthetic facilities
Infrastructure Requirements

Adaptive strategy: Not necessarily at the same site!

Depth

Very Deep: \( \geq 6000 \text{ mwe} \)
- unique facility in the world for physics, astrophysics, earth science, biology
- easy access, long-term
  cf. SNOLab

Very Large Caverns (1Mm\(^3\))
- Deeper is better
- Limits by rock, economics
- Hopefully \( >2700\text{mwe} \) (Kamiokande)

Intermediate depths automatic

Rock type

Physics: irrelevant if “competent rock”,
Earth Sciences: Any deep site will yield a
- Eventually multiple rock types (at least internationally)

Pristine rock

Earth science/biology: not dewatered or destressed \( \neq \) Physics

Absolutely pristine for ancient life/life not as we know it
- No water contamination due to site exploration/construction or previous mining
- Variety of physical scales, long time scales
Infrastructure Requirements (2)

Distance from accelerators
Same Megaton detector for proton decay and neutrino long baseline >1000km (1500-2500 km) for neutrinos super-beams @ 3 GeV but new ideas in Europe (low energy beta beam @300MeV, 130km)

Access
Horizontal vs vertical: not a strong discriminator if large hoists 24/7/365 desirable but experiments can be automatized (but IMB experience)
Guaranteed long term access important: 20-30 years
Easy personnel access (including casual and E&O)
Proximity to universities and airport desirable

Safety and specific requirements
Proactive, meeting or exceed codes, MSHA,OSHA
But potentially dangerous experiments: large cryogenic (Ar,He,Ne), fault slippage
If strong scientific motivation, commitment from laboratory to work out adequate safety procedures

Management
Scientific direction
Common management if several sites: multiple campuses
Private ownership: can be financially beneficial, but also bring restrictions in particular long term guarantee, whole spectrum of science
Public ownership: restrictions from other activities
Infrastructure Requirements: Preliminary Conclusion

Passionate discussions in the community.

Significant impact of sites characteristics and institutional arrangements on
- Range and effectiveness of science
- Capital investment
- Operational expenses

What we told S2 panel: Restrictions are not necessarily fatal
- In our multi-site, adaptive approach, not necessary for a site to be able to meet all infrastructure requirements
- Important criterium: Ability of the site to accommodate some frontier science
- Some restrictions may be acceptable for a rapid deployment in a realistic budgetary environment
## Preliminary Modules (1)

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<th>Module</th>
<th>Science</th>
<th>Main Requirements</th>
<th>Potential additional requirements</th>
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<tr>
<td><strong>Very Deep module</strong></td>
<td>Double beta decay</td>
<td>6000 m.w.e (2400m in rock)</td>
<td>10kton cryogenic liquids (He, Ne)</td>
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<td>Solar neutrinos</td>
<td>dust control</td>
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<td>Dark matter</td>
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<td>Small geomechanical experiments</td>
<td>low e.m. noise</td>
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<td>Earthquake studies</td>
<td>pristine rock for microbiology</td>
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<td>Deepest limits of dark life</td>
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<td><strong>Very Large Cavern module:</strong></td>
<td>Combination in same detector of</td>
<td>As deep as economically feasible: 1500 m.w.e 1000km from accelerator (see text)</td>
<td>100 kton liquid Ar 100 kton scintillator</td>
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<td>1Mton</td>
<td>Proton decay</td>
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<td>Long-baseline neutrino physics</td>
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<td>Supernova physics</td>
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<td>3D monitoring of rock deformation</td>
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<tr>
<td><strong>Very Large Block Earth Science Experiments</strong></td>
<td>HTMCB experiment over multiple correlation lengths</td>
<td>Water bearing zones Pristine and non pristine Span all depth range available at the site</td>
<td>Remote oil deposit simulation (sedimentary rock)</td>
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<td>Imaging technology development, mine-back validation</td>
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<td>Sequestration studies</td>
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## Preliminary Modules (2)

| Intermediate depths | Some solar neutrinos  
Radioactive screening  
Prototyping  
Clean room  
Fabrication/assembly  
E&O observation deck | Typically  
2000-4000 m.w.e.  
(800-1600 m in rock) | Accelerator  
Shaft experiments  
(vertical access or ventilation shafts) |
|----------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Common underground spaces | Offices and interaction spaces  
Teleconference rooms  
Small machine and electronics shops | At main underground levels  
Excellent internet connectivity | |
| Surface buildings | Experiment specific and common support facilities.  
Offices/conference rooms  
E&O classrooms | Scale depends on site remoteness  
Excellent internet connectivity | |
International Aspects

International Science and Engineering!
- Not only in physics and astronomy
- But also: geo sciences geo-microbiology is a new frontier

DEEP site

Our goal: A frontier facility, unique in the world
- Depth >6000 m.w.e. + intermediate depth
- Full range of science: no restriction of geosciences and biology
- 24/7/365 easy access and long term guarantee 20-30 years
- Expansion capacity and capability to accommodate specific requirements

We are well aware of
- SNOLab approved (6000 m.w.e- INCO Mine).
- Possibility of expansion at Modane (4700 m.w.e. - road tunnel) + Baksan

Strategic advantage of a premier DUSEL on U.S. Territory
- Impact on research of U.S. unified institutional support
- Scattered and isolated effort as guests in other countries
- Initiative capability of U.S. teams and attraction of exciting projects
- Development of new technologies
- Training of the next generation of scientists and engineers + E&O

A difficult task: estimate the worldwide demand in realistic scenarios
- to put in perspective the likely limitations of SNOLab (in spite of INCO’s cooperation)

Intuition: This is the direction science goes
- Chronic over-subscription of existing facilities
- Likely positive feedback: availability will be a factor in the growth of community

We have to check!
International Aspects (2)

Large Detector + Neutrino beam

$1 B price tag => megascience
   part of inter-regional governmental negotiations

Adaptive strategy
Decouple from Deep module
   But a deep site may be a competitive advantage
Science is still evolving rapidly... No real optimization

Get prepared
How can we accelerate the convergence in the U.S.?

2 goals: have the case ready at the time of the decision of the ILC?
   2010/2012?
   ILC type process; Interregional coordination of R&D
   Common CDR and TDR??

   be ready if ILC decision is delayed otherwise the default will
   be HyperK 2013
S1 vs S2/S3

In order not to delay the decision process, some overlap of the 2 processes

S2/S3 is in charge of selection of site(s)
S1 in charge of the scientific case

But strong interest of S1 in fairness/openness of S2 process=> acceptance of the community

Our S1 goal: Maintain the dream alive
Some of us may have to overcome possible discouragement if the selection process is not picking our preferred site/type of sites.

Best road map
Important to participate in Minneapolis workshop

Potential problem: S1 should not be prisoner of S2 process: what if clear incompatibility?
Conclusions

A very interesting process

- Compelling science
- Mutual discoveries of several communities
- Emergence of an exciting set of roadmaps

We are developing powerful arguments!

Even at time of budgetary problems, important to launch new and exciting projects: DUSEL is an excellent candidate!

Still difficult questions
- Realistic estimation of the demand for Deep Site
- How can we converge in next 5 years with proton decay/long baseline neutrinos

<=Progress at this workshop
Science-Methods-Applications

Ever Changing Earth
- Fundamental processes
- Role of microbes
- Tectonics/Seismology

Applications
- Resource discovery and recovery
- Waste management
- Biotechnology

Transparent Earth
- Remote Characterization
- Surface-> subsurface

Overlap is testimony of the richness of the field

Opportunity for multiple advocacy
- NSF-DOE- Congress - Industry
- Experts-other scientists- Public at large