Summary of "1-km Vertical Space" working group

at the DUSEL meeting April 24-26, 2008 at Lead, SD

(revised June 30, 2008)

Five physics experiments were so far proposed for the vertical shafts at DUSEL:

(a) NNbar - Search for neutron to antineutron transitions $n \to \bar{n}$
(LOI #7, contact person Yu. Kamyshkov/UT)

(b) Cold atom interferometry for detection of gravitational waves
(new proposal, contact person Mark Kasevich/Stanford University)

(c) Search for mirror matter transitions: neutrons to mirror neutrons $n \to n'$
(new proposal, contact person Anatoly Serebrov/PNPI, Russia)

(d) Facility for the studies of physics of atmospheric cloud formation
(LOI #33, contact person John Helsdon/SDSMT)

(e) Study of diurnal Earth rotation
(LOI #23, contact person Bill Roggenthen/SDSMT)

The following table compares basic requirements of the vertical experiments proposed for the DUSEL:

Experiment → Description ↓	NNbar Search	Atom Interferometry	Mirror n Search	Cloud Physics	Diurnal Rotation
Shaft length	1.5 km	1 - 4 km	1.5 km	0.5 - 1 km	0.1 – 1.5 km
Tube diameter	4 - 5 m	0.3 m	4 - 5 m	3 - 5 m	1 m
Straightness†	< 10 cm	< 5 cm	< 10 cm	< 50 cm	< 10 cm
Verticality	< 50 mrad	< 10 mrad	< 50 mrad	< 100 mrad	< 10 mrad
Pressure	< 10 μPa	< 0.1 μPa	< 10 μPa	± 0.2 atm	(< 10 μPa)
Mag. shield	~ 1 nT	~ 1 nT	~ 1 nT	N/A	N/A
Purpose of experiment	$n \to \bar{n}$ appearance	gravity wave detection	neutron disappearance	atm. physics facility	E&O facility

† Straightness can be defined as a maximum deviation from the straight line fitting the geometrical centers of the horizontal cross sections of the shaft (or installed tube).

In the assessment of the working group, the first three experiments (a), (b), and (c) can share a common setup in space and time and will require a magnetically shielded vacuum tube in a straight vertical shaft with a length of ~ 1.5 km and diameter 4-5 m. Due to the small diameter (30 cm) of the atomic interferometry tube, it can be mounted on the side of the larger NNbar vacuum tube. Experiments are expected to be able to start operation after 2017 and will continue for 3-5 years (neutrons) and for >10 years (gravity wave detection). The very preliminary cost estimate of the NNbar experiment ranges from $169M to $342M and includes the reactor, infrastructure, engineering, contingencies and, in the higher-cost limit, the construction of a new vertical shaft. Neutron mirror transition search assumes essentially parasitic operation to NNbar with a rather small incremental cost. Instrumentation in the atomic interferometry experiment is expected to cost around $3M, while the costs of the construction of the tube, vacuum system, and infrastructure are not yet developed.

The cloud physics setup (d) will require a separate shaft with a length of 0.5-1 km and diameter 3-5 m. The proposed cloud physics setup is understood likely to become a facility for a practically infinite number of experiments in the atmospheric physics of cloud formation; with each experiment lasting from a week to a month. The cloud and precipitation formation can be studied as a function of chemical and physical composition of air, temperature, temperature gradients, pressure, velocity of air mass, turbulences, etc. Staged construction of the vertical cloud facility assumes a first stage without the temperature and pressure regulation ($3-4M); a second stage with temperature control ($30-50M); and a third stage with pressure regulation (cost estimate for this stage is not yet developed).

Measurement of diurnal Earth rotation proposed for DUSEL (e) will be less accurate than the measurements performed by NASA, but, unlike NASA measurements, can be performed at DUSEL continuously. The consensus of the working group was that demonstration of diurnal Earth rotation, together with the Foucault pendulum, can be a wonderful E&O project for the smaller existing shafts at DUSEL; no vacuum tube will be needed for a demonstrational experiment. After the completion of NNbar experiments, the long 1.5 km vacuum tube can be made available for continuous measurements of diurnal rotation.

Selection of an appropriate vertical shaft, engineering development of vertical construction, infrastructure, cost estimate, feasibility demonstration, and other issues seem to be common for all proposed vertical experiments. These developments, as was realized by the working group, can be combined in the development of the common "VERTICAL FACILITY" at DUSEL for the proposed vertical experiments. Due to the substantial cost of the Vertical Facility and the additional time needed for engineering development and feasibility demonstrations, the working group assumed that the Vertical Facility construction and experiments should develop as a next stage and a new dimension of the DUSEL scientific program, with the funding obtained through the next "Vertical MREFC" proposal, possibly combining NSF and DOE resources. However, feasibility and engineering studies and the work on the proposal preparation for the DUSEL Vertical Facility need to be started at the present time. Funding resources for this work are assumed to be requested through DUSEL S4 and S5 processes, as a support of the development of the future scientific program at DUSEL beyond the “Initial Suite of Experiments.”

A Vertical experimental Facility does not exist in any underground laboratories. In this sense, vertical experiments will make DUSEL a unique laboratory in the world and give DUSEL a new vertical dimension.

Proponents of vertical experiments agreed to form the Vertical Facility (VF) Collaboration that will pursue the construction of the Vertical Facility at DUSEL; write the S4 and S5 R&D proposals for a Vertical Facility that will be focused on the common engineering aspects of the Vertical Facility development at DUSEL; and attempt to work in close contact with SUSEL technical personnel. The VF Collaboration also plans to organize in the fall of 2008 a workshop at Lead, SD, where relevant scientific and technical issues can be discussed by the VF proponents with the SUSEL personnel and the SD faculty who will be invited to participate in the VF Collaboration.

The working group has established a contact with SUESL technical personnel (Jose Alonso and SUSEL engineers) for the inventory of the vertical shafts available at Homestake. Major parameters of the shafts required for the VF design are length, diameter, straightness, and verticality. It seems that not all of these parameters are available yet from the existing Homestake drawings database. The NNbar Collaboration proposed, as a SUSEL Early Implementation Program (EIP) project, the measurement of the shaft geometrical parameters for some of the candidate vertical shafts at Homestake. Two other SUSEL EIP proposals initiated by the NNbar Collaboration are: measurement of 3D magnetic field in the vertical shaft; and measurement of thermal neutron environmental background at the main 4850-level experimental campus. The latter allows defining and controlling the amount of passive shield necessary to keep the thermal neutron background in the main campus at the environmental level when the TRIGA reactor for the NNbar experiment will be commissioned.

Engineering assistance

For preparation of the S4 proposal, besides the interaction with SUSEL technical personnel, the VF Collaboration will appreciate the engineering and program management assistance from LBL and/or from other national laboratories if the latter will be available. Initial tasks to be addressed in this work for all vertical experiments are: developing concept narratives and drawings; developing initial project WBS for capital costs; preparing design criteria; identifying and assessing candidate vertical facilities; if there is no suitable existing facility, identifying a candidate site for a new facility; evaluating shaft construction and shaft outfitting; conceptual designing of tunnels, caverns, etc.; conceptual designing of project systems; risk assessment; addressing fire/life safety aspects of conventional facilities; developing budget estimates; and developing design and construction schedules.

Reactor on site issue

During the meeting a special session of the working group was organized together with the Low Background Counting group (Prisca Cushman) on the research nuclear reactor required by the NNbar experiment. Two issues were discussed: (a) a reactor as a source of background for other DUSEL experiments and (b) the use of an on-site reactor for neutron activation analysis and radioisotopes production.

(a) The 3.5 MW TRIGA reactor at the DUSEL Vertical Facility can be installed on the surface at a distance of ~2 km from the main underground experimental campus. The effect of detection of antineutrinos as a background to other DUSEL experiments can be estimated, e.g., by rescaling the rates from the KamLAND detector, where 55 reactors with 120 GW thermal power at an average distance of 180 km are expected to produce an antineutrino detection rate of 756 events per kiloton-year (without oscillation effect). The expected detection rate for a similar DUSEL experiment with a 3.5 MW TRIGA reactor as an antineutrino source at a distance of 2 km can be ~180 events per kiloton-year. This antineutrino flux certainly can be an essential background for the geo-neutrino detection experiment at DUSEL, but, due to its controllable nature, this flux can be precisely measured. The flux of the solar neutrinos to be coped with by the major DUSEL experiments will be substantially larger than the flux of TRIGA antineutrinos. Given the large distance between the underground campus and the reactor, the background of thermal neutrons produced by the TRIGA reactor can be efficiently reduced to the level of environmental thermal neutron flux by simple passive shielding.

(b) Baseline TRIGA configuration design can be easily modified to include: standard NAA analysis, prompt γ activation analysis (popular nowadays), delayed neutron activation analysis, sample irradiation (including relatively large samples), and production of short-lived isotopes for detectors calibration. Although these are not unique features for the low background counting and are available from elsewhere, it will be convenient to have a reactor on site for these operations. An on-site reactor also can be used by the DUSEL users and local universities for teaching students (e.g., nuclear radio chemistry, analytical NAA), for artifacts dating; for geological samples dating and composition, and as forensic support for local law enforcement (from the list of applications of NAA labs).

NNbar review issue

At the November DUSEL meeting in Washington DC, the S1 Committee recommended a scientific and technical merit review for the NNbar project. The NNbar Collaboration is seeking the possibility of a major scientific and technical review of the project to be organized within the DUSEL process and with involvement from the funding agencies. Since several design and construction questions are common for all proposed vertical experiments, the working group is expecting that the review will include the whole concept of the Vertical Facility at DUSEL, together with the review of the scientific and technical merits of individual experiments. Such a review, equivalent to DOE's CD0, will be a starting point for the preparation of a Vertical MREFC proposal for the project development and funding of the DUSEL Vertical Facility.