Low Level Counting Infrastructure and Requirements

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Summary and Working Group Charge

Many experiments that will be performed at DUSEL require materials with very low trace radioactivity. This working group studied in detail the associated infrastructure required to perform assays of these materials, produce ultrapure materials, and participate in R&D on the next generation of higher sensitivity detectors for both screening and experiment. Members met during the Solicitation 1 Workshops, as well as two independently sponsored synergy workshops at PNL and Minnesota where members of the working group explored other applications in earth sciences, national security, and health sciences. The working group members and their affiliations are listed at the end of the report. The outline of what a low background counting facility would look like in the DUSEL era has been studied by subsets of this working group over the last decade in many contexts, most importantly in the previous Homestake NUSEL initiative, from which much of this information is gleaned [1,2].

1. Introduction

The common thread in the search for rare events or weakly interacting particles is their need for an environment free of background from cosmic rays and natural radioactivity. Every component which goes into these experiments must be radiopure to such a high degree that even the best screening facilities available in shielded sites at the earth's surface are insufficiently sensitive. Therefore it is absolutely essential that space be reserved underground for shielded screening of components. These ultra-sensitive screening detectors can also be used by geology, microbiology, environmental science, and national security applications to identify radioisotopes, date samples, and measure tracers introduced into hydrological or biological systems.

2. Current Situation

As a function of depth and increasing sensitivity, the situation in the US today is a decentralized set of detectors dedicated to specific research projects at surface sites, a few shallow depth sites which have evolved into user facilities, and a few deep sites which are struggling to provide the ultra-low counting needs for the next generation of double beta decay, solar neutrino, and dark matter experiments. There has not, to date, been much dialogue with other fields that might also benefit from the ultra-low counting sensitivities available at deep sites. DUSEL provides a motivation to enhance this user base by establishing user communities that will naturally be drawn to underground science (nuclear and astroparticle physics, geology, and microbiology).

Although the background is reduced significantly by moving screening detectors underground, it is not possible to exploit extreme depths, since backgrounds internal to the detectors themselves become the limiting factor beyond an overburden of 1500 mwe. In figure 1, this is explicitly shown for a sample of operating high purity germanium detectors at several sites. Moreover, for many practical applications, the counting time itself would become prohibitively long. Thus, except for the ultra-low background, whole body counting facility described in section 3.3, an underground screening facility does not have to be deeper than roughly 2000 mwe, even accounting for improvements in the purification of germanium crystals and new shielding materials.

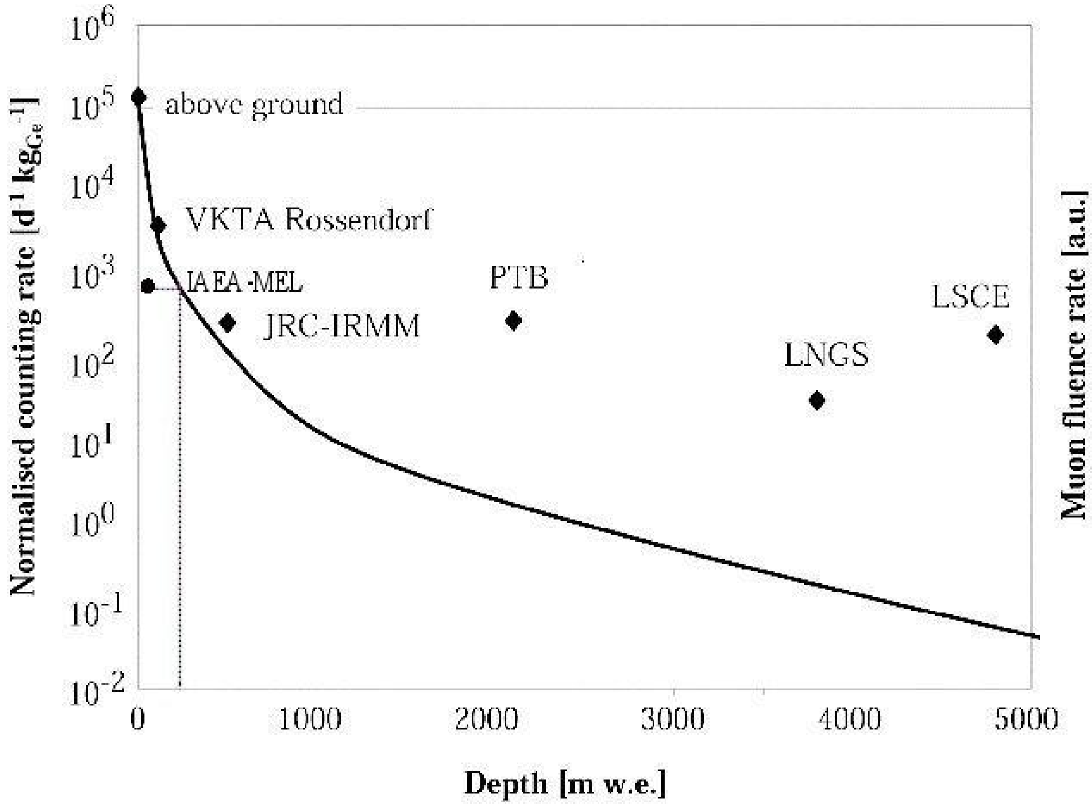


Figure 1. Integral background counting rates of HPGe detectors (from 40 to 2700 keV) divided by the mass of the Ge-crystal as a function of the operating depth of different underground laboratories. The solid line shows the muon fluence rate in arbitrary units normalised to the background counting rate above ground. The IAEA-MEL detector includes active shielding. [22]

In determining the size and throughput required for the LBCF, it is important to quantify the number and type of samples which current and proposed experiments intend to process and compare projected needs to the availability of such infrastructure. Surveys of experimental needs completed over the last year by this Working Group indicate that the total number of samples requiring some sort of screening for current and next generation dark matter, solar neutrino, and double beta decay experiments **far exceed any realistic single-site LBCF**, and are needed **before DUSEL comes online**. The chart below includes data from experiments expecting to run in the next few years (EXO, MEGA, SuperCDMS, XENON) as well as estimates from DUSEL experimental modules and national security applications. It sorts the screening by year and sensitivity limits, broadly defined in sections 3.1 and 3.3 of this document. The jump in demand in 2010 corresponds to the overlap of near term future experiments and the start of screening for DUSEL experiments.

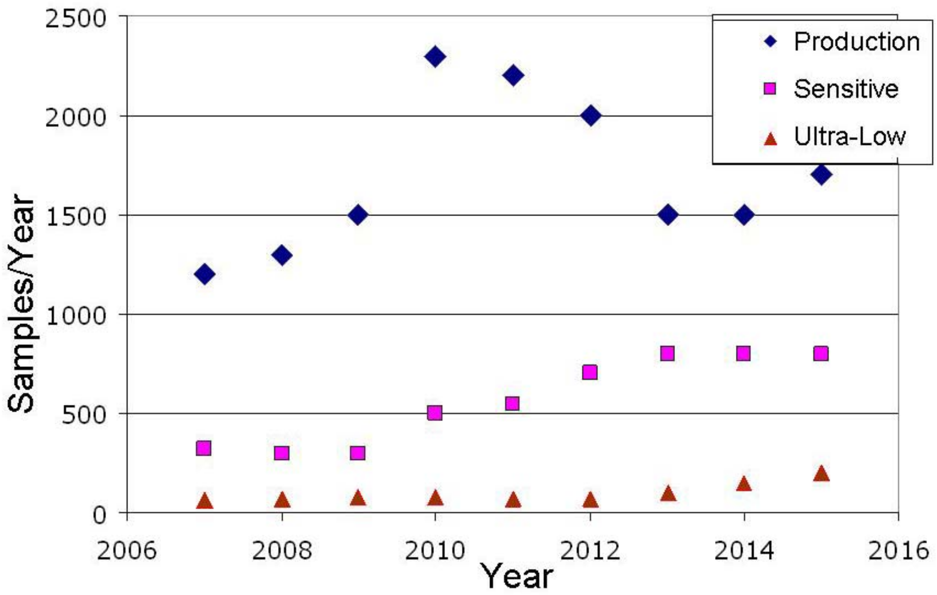


Figure 2. Screening needs for double beta decay, solar neutrino, dark matter experiments and geomicrobiology. Based on surveys filled out by current collaborations (2005) and DUSEL working groups.

It is therefore vital that the funding agencies be urged to support increased infrastructure in screening now at existing underground sites, such as Kimballton, Soudan, and WIPP. Waiting until the DUSEL era to invest in screening infrastructure will seriously impact the construction of the next generation of dark matter experiments, as well as frustrate the design process itself, lacking adequate knowledge of material purity.

2.1 Alternatives to Counting

For many applications, low level counting is not necessarily the best technique for screening materials. Radioisotope identification can be done using surface techniques and mass spectrometry. Most research universities and many companies offer services for a fee. University fees are often very cheap for faculty, and companies offer quicker turn-around for a higher charge. There is no point in duplicating these functions in a DUSEL LBCF, however it may be useful to forge user agreements with existing nearby labs or encourage commercial analytical labs to open branches in geographical proximity to the DUSEL site. A summary of the more common techniques available follows:

2.1.1. Surface analysis

Ion Beam Analysis (IBA) utilizes high-energy ion beams to probe elemental composition non-destructively as a function of depth to several microns with a typical depth resolution of 100-200 angstroms. The energy distribution of backscattering ions (RBS = Rutherford Backscattering Spectroscopy) quantifies the depth distribution for a given element. Distinctive characteristic X-rays emitted from the different target elements (PIXE = Particle-Induced X-Ray Emission) upon beam bombardment ensure the accurate identification of similar mass elements. Additional simultaneous measurements include forward-recoil spectrometry (FReS) or a NaI scintillator detector for Nuclear Reaction

Analysis (NRA). These techniques can identify a monolayer of surface contamination. Electron beams for Auger Electron Spectroscopy are less sensitive; the best can find trace contaminants at the 0.1% level within 1 nm of the surface. However, it is possible to obtain depth profiles of 100 nm or more with a sputter gun. Spot size can be small enough (5 microns) to do an x-y probe of contaminants on the surface.

2.1.2. Mass Spectroscopy

This suite of techniques extracts and accelerates charged ions from the sample, separates them according to atomic mass in a magnetic field, and then measures the current of ions with a detector (usually a Faraday cup) which intersects the trajectory corresponding to the correct charge-to-mass ratio for the element in question. The sensitivity thus depends on both the mass resolution of the magnetic spectrometer, as well as details of the sample dispersion technique by which atoms or ions are introduced and accelerated into the channel.

Inductively-coupled Plasma and Thermal Ionization (ICPMS, TIMS) must first put the sample into solution using various combinations of concentrated acids or bases. In TI a filament is coated with the solution and then heated, whereas for ICP, a flow of argon gas converts the liquid sample into a fine aerosol. A portion of the sample aerosol is then directed through the center of an argon plasma torch, where the atoms are ionized. All samples must be background subtracted using a blank (the dilute solution without sample) and normalized to a standard (pure trace element in same solution) since the ionization efficiency depends on the element. Machines capable of probing to ppb levels are typically found in Geology and Chemistry departments in many Universities and also in many commercial analytic labs, but are limited by ionization efficiency. To break the ppb barrier requires clean room conditions to avoid contamination of blanks and standards, as well as chemical purification techniques to avoid the isobaric interferences caused by other isotopes or ion complexes with the same mass. In North America, only the Institute for National Measurement Standards (Chemical Metrology) of Canada is currently able to process samples down to tens of ppt (useful for limits of U/Th in bulk materials).

Secondary Ion and Glow Discharge (SIMS, GDMS) release sample atoms via surface bombardment. In the case of SIMS, an ion beam sputters the surface and the released ions enter the spectrometer, whereas for GDMS the bombarding ions come from a low pressure DC plasma discharge cell in which the sample is the cathode. The sputtered neutral atoms are then ionized in the plasma and extracted into the mass analyzer for separation and detection, whereas sputtered positive ions simply fall back onto the sample and don't make it into the spectrometer. Thus GDMS is not as matrix-dependent as SIMS. Both techniques can be used to form a depth profile as the sputter proceeds. Conductive materials are easiest to analyze by GDMS, though electrodes can be formed. GDMS is excellent for identifying trace elements in bulk samples down to hundreds of ppt.

Accelerator Mass Spectroscopy (AMS) is done at a number of centers around the country, typically where tandem accelerators used for nuclear research have been retooled for this application. After an initial spectrometer step to remove background, the ions are accelerated to MeV energies and passed through a second magnetic analyzer, where detection is typically by ion chambers and multi-wire ion counters, achieving parts per $10^{15.}$ in some cases. Since this sensitivity can be achieved in a few hours on samples smaller than 1 mg (where simply counting the decays would take several human lifetimes), AMS has become the technique of choice for ^{14}C dating. It is expensive and not available locally; instead, a number of labs have sprung up to prepare and isolate samples (e.g. from cores [3]) and then take care of sending the samples off and keeping track of the results. These dedicated accelerators have specialized features which preclude combining them with the DUSEL accelerator module.

2.1.3 Neutron Activation Analysis

Even though technically a counting technique, the enhanced signals generated by Neutron Activation Analysis (NAA) means that this technique does not need a shielded underground site to achieve ppt sensitivity. A source of neutrons is required to initiate a neutron capture interaction with the sample. This is generally a reactor with fluxes of 10^{13} n cm^{-2} s^{-1}, but new deuterium-tritium plasma generators are approaching this intensity [4]. The resulting compound nucleus forms in an excited state, almost instantaneously de-exciting into a more stable configuration through emission of one or more characteristic prompt gamma rays. In many cases, this new configuration yields a radioactive nucleus which also decays by emission of one or more characteristic delayed gamma rays, but at a much slower rate according to the unique half-life of the radioactive nucleus. Observing the prompt gammas during irradiation is called PGNAA, but the more common procedure is to remove the sample from the reactor and observe the delayed gammas, usually via high purity germanium detectors. Since shipment of samples irradiated at US research reactors can be arranged in a time scale of 2 to 3 days, short-lived products are most efficiently counted at the irradiation site. For many longer lived activation products the DUSEL gamma screeners can be used. A typical exercise would be counting ^{239}Np ($t_{1/2}$=2.36 d) and ^{233}Pa ($t_{1/2}$=27 d) from ^{238}U and ^{232}Th.

The technique is limited by the nuclear properties of the trace element and the substrate which it is contaminating. Approximately 30% of the elements do not have reactions that can be probed in this way and for those that do, the activation of the substrate can mask the lines. Detection limits assuming interference-free spectra range from 1 pg of Eu to 100 pg of U to 10 ng of K. [5]. To reach the ppt range or below, the elements of interest are typically chemically separated from interfering side activities [6].

2.2 Counting at Shallow Sites

Low level counting that can be done in shielded environments on the surface is usually performed by a high-purity germanium detector (HPGe) or NaI crystals equipped with a PMT. These are commercial devices that are usually dedicated to a specific project. All the national labs have such detectors and many will negotiate a “use for others” contract with outside users. Many university groups also have dedicated machines. The great need here is for coordination and integration of these facilities. LBL has maintained a surface site (bldg 72) surrounded by low activity concrete, currently housing NaI counters and a 130% HPGe detector, while also running an 80% p-type HPGe at the nearby Oroville Dam (80 mwe). PNNL operates a shielded facility on its site and, together with the University of Washington, manages a 4' x 8' space located under the nearby Lower Monumental Dam (37 mwe) with two sets of coincident HPGe detectors.

2.3 Counting at Deep Sites

Three deep sites in the US have made infrastructure investments leading to potential low background counting centers. The Waste Isolation Pilot Plant in Carlsbad, NM is at a depth of 1600 mwe within a layer of bedded, impermeable salt. WIPP [7] is a DOE facility with a fully developed infrastructure and a heavy Los Alamos National Lab presence with an Earth and Environmental Science office located at Carlsbad. Although fundamental science is only an add-on to its primary mission, LANL and WIPP established a clean room to house the Majorana collaboration's segmented multi-element germanium arrays (SEGA and MEGA), and is also adding facilities to service the EXO double beta decay experiment.

A second site is the Kimballton mine [8] operated by the Chemical Lime Company in Giles county, Virginia. Virginia Tech is the lead institution, also developing this site for the LENS solar neutrino experiment. Kimballton's proximity to the Naval Research Labs make it a promising site for secure applications involving homeland security and treaty verification and plans are already underway to make this a reality.

The third deep site is the Soudan iron mine (2090 mwe) in northern Minnesota [9], which is already home to the MINOS and CDMS experiments. Currently 2 HPGe are being used to count samples for XENON and Majorana collaborations as part of the SOLO facility. The proportional tube panels which line the Soudan2 proton decay hall have been repaired and a new DAQ installed. This creates a 14 x 12 x 33 m^3 user space with time-stamped muon veto information already in place. There are plans to turn this space into a fully equipped LBCF with the addition of a water shielding pool and beta screening.

3. Requirements for a DUSEL LBCF

The design of a DUSEL LBCF should attempt to provide complementary services to those that already exist, while recognizing that additional throughput in conventional screening is also required. The LBCF should be one of the first modules constructed, in order to provide screening and prototype space in preparation for experiment deployment. This still leaves a 3-5 year gap in screening resources available to DUSEL-era experiments that are even now constructing prototypes, designing shielding, and estimating backgrounds. Bridge money needs to be made available immediately to increase screening infrastructure at existing sites, before DUSEL space is available.

In Europe, ILIAS (Integrated Large Infrastructures for Astroparticle Physics) [10] was formed to integrate and enhance infrastructure among the different underground labs. Our DUSEL S1 executive summary recommends that the funding agencies, working together, begin this integration process immediately, using the many existing underground sites available. Screening and prototyping space is the obvious first step in pulling together our disparate resources under one umbrella, and DUSEL could provide the umbrella organization which supports counting facilities at existing underground sites, such as Kimballton, Soudan, and WIPP, while additional screening is established at DUSEL.

Since none of the identified DUSEL sites have deep space available from the start, the LBCF, as one of the first modules funded, must be partly at a moderate depth. This is not a problem, since for all functions other than a Borexino-like Counting Test Facility, a depth of >2500 mwe is sufficient. Such a Low Background Counting Facility must include (1) production measurement facilities, (2) a modest amount of reconfigurable space for R&D in low background counting technology, (3) ultra-low level counting, (4) production and fabrication of pure materials (including copper electroforming and water purification), and (5) infrastructure such as sample preparation, analysis capability, cryogens, radon reduction utilities, and on-site technicians.

3.1. Production measurement facility.

This aspect of the LBCF will be capable of performing conventional radiometric materials screening (alpha, beta, gamma for solids, liquids, and gases) for all major DUSEL experiments, as well as functions of experiment calibration, quality control, DUSEL facility radiological control, as well as the research applications demanded by bio and geosciences. Since there is clean fabrication and electroforming capability in the same location, it can provide materials and controls 1000-fold lower than a surface facility and an order of magnitude lower in contamination. The purpose of a production measurement facility is to provide the throughput necessary for sensitive applications, not to push the limits of sensitivity. It is the workhorse of the LBCF. This function can be shared by other sites under the DUSEL umbrella.

Low background gamma ray spectroscopy using germanium semiconductor detectors is a well-developed and mature technology which has served as the prime tool for material selection. Sensitivities down to a few hundred ppt of U and Th are routinely achieved using commercially available detectors [11]. The outstanding energy resolution gives these HPGe detectors high diagnostic power. This makes them an excellent choice for counting applications where radioisotope identification is important. All current generation solar neutrino, dark matter and double beta decay experiments have been relying heavily on this detection technique.

High sample through-put (equivalent to the availability of multiple counting stations) and good diagnostic power are needed to fulfill this task. There should be at least 8 well-shielded HPGe stations of varying sensitivities and configurations. Along with the usual planar detectors, there should be at least 2 well-type HPGes, one of which should be segmented for coincidence counting, to handle small samples (electronic components or tracer analyses for microbial samples or cosmogenic and nucleogenic isotope dating). These can be assembled from discrete crystals, such as the coincidence counter at Lower Monumental Dam or the more ambitious SEGA and MEGA [12]. The CLOVER detector (Canberra Eurysis) is a commercially available 4 to 16-fold segmented well counter that also would be well-suited to this application. With appropriate choice of low background cryostat and shielding (OFHC copper can be obtained with <100 μBq/kg U/Th contamination [13]), such coincidence detectors can reach ~10^{-11} g/g. precision counting precision for ^{238}U and ^{232}Th. [14]. This can be improved to ~10 μBq/kg or 10^{-12} g/g by fully implementing segmentation and pulse shape discrimination for gamma-ray tracking.

The signal from many trace isotopes can be enhanced using NAA to observe counts from short-lived isotopes produced by epithermal neutron capture; thus extending sensitivities to 10^{-12} g/g U/Th. This requires sending the samples to a reactor and the use of a radiochemistry lab to process the material, but the samples still end up being counted in a high purity germanium detector (HPGe), so throughput estimates must include these samples. If there is an accelerator module in DUSEL, activation of samples may be done on site. Whether or not they are activated on site, these samples are usually composed of a mix of different radioisotopes and are considered open sources with all the associated contamination concerns Thus DUSEL must provide a chemical processing laboratory on the surface, where radiochemical separation can be performed to suppress source-related backgrounds and where it will not compromise the background-free underground environment. The HPGe detectors used for NAA do not require extremely low background levels. Instead, they should have the best possible energy resolution and peak-to-Compton ratio to suppress side activities that may interfere with analyzing the isotope of interest.

Samples with unknown activity should not be allowed to contaminate the bank of sensitive screeners, so it is important to also have a few less sensitive screeners – retired (less efficient) HPGe and NaI counters can be so identified. These same screeners could be used for the NAA activated samples and might reside on the surface, too. A couple of commercially available alpha/beta counters (e.g. proportional wire chambers) can do quite well when located underground and purged to remove radon. They can be used to perform standard or pre-screening jobs and direct measurements of radon plateout on exposed surfaces.

Another user of the LBCF may include the national security research community. There should be a separate space, in the same LBCF facility, which can be accessed by keycard only, with electrical, mechanical and personnel isolation consistent with classified operations. The counting capability will be similar to the open facility, with dedicated HPGe and alpha counters, plus a flexible, shielded bay for detector R&D. Since some classified research is inconsistent with the essentially open nature of the rest of the facility, the security community will be operating other, more secure sites as well. Thus, the space reserved could be modest (100 m^2).

3.2. Detector R&D

Compared to gamma screening, techniques for low background counting of betas are not as well developed. Thus, experiments that require screening for alpha, beta or x-ray emission that is not accompanied by gamma emission are not well served. Low energy x rays are a background for many types of low-background experiments, especially solar neutrino projects. Assaying materials for low-energy x-ray emission in order to eliminate such activities or to quantify the effect is required. Another example is identification of ^{210}Pb contamination. ^{210}Pb and its progeny do not have a penetrating radioactivity signature. Since Pb is often used in circuitry and alpha activity within the Pb can create difficulties for the circuit, there is a need to search for samples of Pb that are low in ^{210}Pb. ^{210}Po will eventually result from any ^{210}Pb contamination, and its alpha decay can cause single-site upsets in any circuit that contains the host Pb.

Surface contaminants, such as ^{40}K and anthropogenic contaminants like ^{125}Sb and ^{137}Cs are also detectable by beta screening. Beta-emitters contaminating the surface can compromise beta rejection in solid state detectors used for dark matter experiments such as CDMS since their charge is inefficiently collected compared to that of beta's which interact in the bulk. Two novel beta counting technologies have been proposed and could be explored further in such an R&D screening development facility: a large area gaseous multiwire proportional chamber [15] and a cloud chamber triggered by scattered light.

At the activity levels needed for next-generation experiments, raw count rate is a significant limitation. 1 uBq/kg implies only 8 decays in ten days per 10 kg of sample. Methods for assaying large quantities of material can also be developed in the prototyping facility and eventually become part of the suite of screeners. For gamma screening, a typical large sample might be a sheet of copper 40 cm tall, 120 cm wide and 1 cm thick. When formed into a hollow annulus surrounding a large (1.4 kg) HPGe detector, the geometrical efficiency is only about 0.25%, leading to very long counting times. A moderate sized detector (70 cm diameter, 70 cm long, 0.29 m^3) filled with Xe at ~10 bar, has nearly an order of magnitude greater overall efficiency than a 1.4 kg Ge for low energy gamma rays from such a sample. Another example of a detector design capable of measuring the radiopurity of many large samples could be a planar sandwich of samples interspersed with NaI cystals or proportional counters. Though scintillation-proportional counters and gas ionization have worse energy resolution than Ge, this enters the LDA as the square root, and hence need not seriously impair the screening power of such devices.

Laser cooling techniques can be used to trap atoms, excite them to a metastable state, and then detect their fluorescence, thus determining abundances by directly counting atoms. AtomTrap Trace Analysis is already used for radioisotope dating and environmental monitoring [16], and has been suggested [17] as a fast turn-around method of measuring radioactive background from ^{85}Kr and ^{39}Ar to a few parts in 10^{-14}. Beta decays from these impurities are a significant background for experiments that use noble liquids as scintillation media. This apparatus is inexpensive compared to AMS and could be installed underground where it can be used to screen user samples, as well as aid in the purification of Ar, Ne, Xe.

Reconfigurable, shielded bays should be available for developing such new detector concepts or for housing specialized detectors or prototypes of new experiments. Modular shielding of known purity, both hydrogenous and high-Z, should be provided, along with crane coverage to reassemble these into custom rooms. This footprint should be at least 8 m x 16 m to allow for staging outside the shield and for setting up data acquisition systems.

3.3. Ultra-low Counting Facility

Although the bulk of screening can be done in the production facility, ultrasensitive screening applications (according to figure 2) will require detectors capable of handling up to 500 samples/yr. While the production facility (Section 3.1) provides convenience and cost efficiency, the ultra-low counting facility is unique and should be sited at DUSEL, although development must be proceeding elsewhere with proof of principle prototypes, in order to keep on schedule.

The next generation low background experiments (solar neutrino, dark matter and double beta decay) will need to reach background levels that are far below what can be screened in even the best HPGe counters. To achieve these levels, a combination of mass spectrometry and NAA may be useful for certain radioactive isotopes. These techniques, while powerful, do not provide an ultimate check on the total activity from all isotopes in the material, including short-lived isotopes which are essentially impossible to detect chemically. An advanced direct counting technique with orders of magnitude improvement in sensitivity is therefore needed to cover all bases. For experiments based largely on advances in material purity, such screening would play an essential enabling role.

A tank made of stainless steel or carved into rock and lined with a radon-impermeable plastic such as urylon would provide the vessel for such an ultra-low counting facility. It would be filled with pure water (~ 10^{-14} g/g U/Th) and covered by a hermetic deck with a radon-free, clean chamber above for handling and insertion of counters and samples into the water and a nitrogen purge between the water surface and the deck. Reconfigurable slots would allow for simultaneous immersion of up to 6 detectors. Additional side-entry ports can also be imagined. To prevent interference from multiple screeners, the tank should be at least 16 m in diameter. The height should be at least 10 meters. This will insure at least 4 m of water shielding around each screener to reduce cosmogenic neutrons, as well as radioactivity from the rock itself. Bulk assay of large amounts of material to be used in shielding, supports, and front end electronics can be done here at the 10^{-13}-10^{-14} g/g U/Th level.

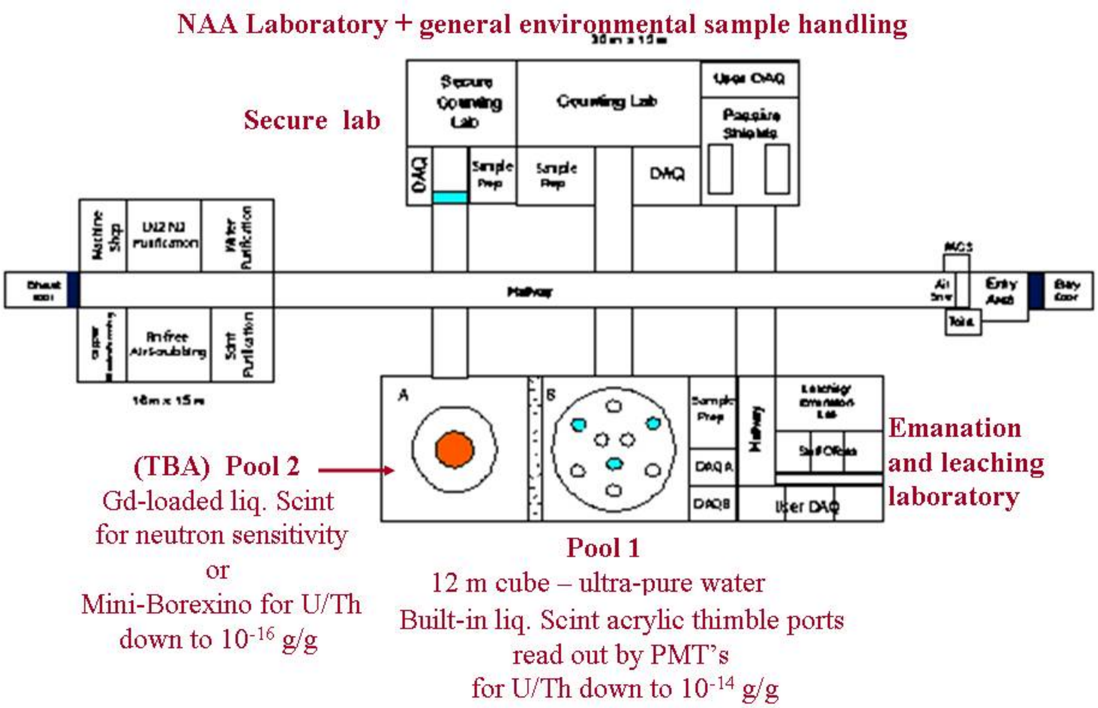
To take advantage of the water purification plant associated with the ultra-low facility, a leaching and emanation chamber should be nearby. Vacuum degassing followed by counting in small scintillator-coated cells (Lucas cells) read out by a photomultiplier tube will provide 10^{-12} g/g sensitivity to U/Th leached out of samples placed in the ultra-pure water. The footprint is roughly 3m x 1m to accommodate 3 leaching tanks with associated pumps and degassing.

If the location of the water pool is shallower than 5000 mwe, an active muon veto shield on the outside would reduce the neutron background produced in the water shield by another factor of 100 or so, bringing it down to the level of that produced by muons in the rock. Natural progression to an even more sensitive bulk assay could include replacing the water with Gd-loaded scintillator and instrumenting the walls with photodetectors. However, rather than retrofitting a facility which is still doing useful screening, it would be better to build a second, even more sensitive screening pool, envisioned as a mini-CTF

[18] like that built by Borexino at Gran Sasso. It is not included in the LBCF footprint, since it should be located deeper, in an experimental hall that will be available later, in recognition of the longer development time required.

Designs of the ultra-low background counting facility have been formulated by many groups [1,2]. The Homestake report includes figure E-16 (see below), which is an example of an LBCF which combines both production and ultra-low background elements. Since none of DUSEL sites will have deep access immediately, this design should be modified to put the production elements in first at a moderate depth and the low background elements later in a deeper location. Other than the CTF, there are no proof of principle prototypes. Such a tank of purified water or liquid scintillator could be built at a current underground site and provide both an engineering prototype of the ultra-low DUSEL facility, as well as serve the community as a screening facility for designing the next generation of experiments that will be sited at DUSEL. Water is the most cost-effective shielding available for large installations or multiple smaller screeners, and has become even more attractive as the cost of ancient lead has skyrocketed.

<u>Figure E-16 from the Homestake Reference Design</u>



3.4. Purification and Fabrication

It is important to further reduce the level of radioactive contamination in the large mass of support materials and internal electronics. Radionuclides are produced in copper from cosmic ray induced interactions when copper is above ground. Therefore, electroforming must be performed underground in order to produce copper (and other metals) containing < 1uBq/kg. Current experience suggests that with 8 baths running, approximately 1 ton/week could be electroformed. In addition to the baths, which require fume hoods and filters to trap corrosive fumes, the electroforming room should be provided with radon-free air to ensure that the radon daughters are not incorporated into the materials. The electroforming room should be self-contained and cover an 8m x 5m footprint. There should be clean fabrication machining available to form the metal into cryostats and inner shield liners. This might include a clean lather, mill and small tools.

The lead shielding for screeners and for DUSEL experiments, is itself a source of prompt γ-rays, due to the beta-decay of the ^{210}Bi daughter of ^{210}Pb from the decay of uranium present in the lead ore, and requires an inner lining of ancient lead where the original ^{210}Pb contamination has been significantly depleted by radioactive decay (22 yr half-life). A small facility to melt archaeological lead in a tungstate crucible in a pure inert gas atmosphere, can both clean up impurities, as well as provide a means to form the pure lead (or indeed, standard lead) into bricks or other shapes.

DUSEL experiments will also require purification of water, liquid scintillator, noble liquids and gases. Since purified water will be required for many applications, as well as for the LBCF screening tank itself, investment in such a plant is appropriate common infrastructure. This must include radon assay of the water through vacuum degassers followed by a cold trap. For other liquids and gases, adsorption is a safe and easy method which allows for selective removal of many impurities, from Rn and Kr to water and CO_2,from a range of gases [19] depending on the appropriate choice of adsorber (usually carbon-based columns with differing pore size). Distillation can also be used when boiling points differ, for example to remove Kr, O_2, N_2, H_2, and He from xenon or ^{210}Pb from liquid organic scintillator [20]. This process can be dangerous, for example, when heating liquid scintillator above the flash point of pseudocumene. Water extraction can also be used in conjunction with distillation or on its own. After the saturated water is stripped, dry nitrogen is flowed through the scintillator to remove water traces and oxygen, as well as soluble impurities such as Rn and Kr [ref 21]. These three techniques, adsorption, distillation, and water extraction have enough specificity that it is unclear how to provide them as common infrastructure. It may be worthwhile to anticipate several groups collaborating on such systems and provide nearby space. In any case, benchmarking their achieved purity will require access to screeners.

Backgrounds inherent in the HPGe screeners themselves (e.g. from ^{60}Co and ^{68}Ge) can be reduced by growing the germanium crystals underground. A project like this, including below surface fabrication, can be financed as an SBIR in conjunction with Canberra or Princeton Gamma Tech, rather than by DUSEL, and the product sold to the experiments as needed. Such financing schemes could also apply to copper electroforming and production of purified materials, so long as there is an appropriately large market.

3.5. Additional Infrastructure

The facility should be large enough to house the suggested initial complement of detectors, allow for future expansion, and be able to accommodate a number of user operated experiments. It should be equipped with an overhead crane serving all measuring stations. The minimum size, which would take advantage of economy of scale, would be a 50 m long room which is 20 m wide and 20 m high (required for crane coverage and for a top-loading tank with a clean room on top). A mezzanine in the other sections of the room would accommodate 2 stories worth of screening detectors and computers/office space.

A class 100 sample staging area is needed to prepare samples for counting. This chemical laboratory needs several fume hoods and be allowed to use and dispose of acids and organic solvents. A high purity water supply will be needed to perform sample cleaning and a supply of pressurized, radon-free nitrogen gas is needed to dry samples after cleaning.

The laboratory needs to be well ventilated with surface air (at least one volume exchange per hour) to assure a low ambient radon level. The clean room above the water tank, the electroforming facility, and other self-contained structures should have further reduction from a radon scrubbing system. It needs access to and the capacity to process/produce radon-free nitrogen gas and liquid nitrogen, radon-free air, ultra-pure water, as well as a supporting role in the production of ultra-pure liquid scintillator.

4. The LBCF User Community

The geomicrobiology community uses radioactive tracers such as $^{35}SO_4$ or $^{14}CH_4$. Detecting ever smaller amounts of these tracers in environmental water or rock samples enables researchers to detect and quantify the extremely low, in situ, subsurface microbial respiration rates. Contamination of the tracer itself is sometimes the limiting factor, but the availability of on site, ultra-sensitive counting could enable advances in tracer purity as well. Microbiologists are also interested in developing tracer detectors with several micron scale spatial resolution in order to image microbial interactions with mineral or material surfaces (e.g. metal corrosion). Low background counting could be combined with DNA microarray to determined the phylogenetic identity of the microorganisms that have incorporated a radiotracer into their DNA. This effort could be advanced by collaborative detector R&D with physicists using the reconfigurable shielded bays.

Isotope dating will be needed by researchers engaged in underground science (geologists, hydrologists, and biologists) as well as outside users in archaelogy, limnology and forensics. The main candidates are ^{14}C and tritium, both of which would benefit from sensitive beta screening. Tritium, for example, is used to date ancient glacial groundwaters. ^{14}C is used for cores and solid samples. For microgram samples, counting is time-limited, not background limited. Thus AMS is better, giving 0.3% precision on ^{14}C: ^{12}C ratios of 10^{-14}. However, gram samples can be cheaply processed in a counting facility with modest sensitivity. Large gaseous (or gasified) samples can actually push the ^{14}C: ^{12}C ratio down to 10^{-16} with 3% precision in 100 days of counting, extending the ^{14}C dating method 10,000 years beyond what is available by any other method. In another application, trace tritium in water is tied to general water quality since it measures downward migration of contaminants, thus it is of interest to Pollution Control Agencies.

Short lived isotopes benefit from underground counting, since their utility is often detection limited. ^{137}Cs and ^{241}Am from nuclear testing are used for recent dating, since they provide a 1963 benchmark, but as the tracer decays, it requires ever more sensitive detectors. ^{7}Be, formed by cosmic-ray spallation of nitrogen and oxygen in the atmosphere has a 53 day half-life; it can be used to assess sediment mixing and marine environments. ^{210}Pb is a mainstay for sediment dating, and can also be used to date organisms, such as coral, all of which contain daughters from the U/Th chain.

Very long lived isotopes like ^{10}Be, ^{36}Cl, and ^{26}Al (cosmic ray spallation products) extend dating to ancient times and are used to study rock exposure and erosion history, meteorite studies, ground water in deep sedimentary basins, planetary physics, soil science, and climate.

Ultra-sensitive counting is useful in any medical applications where the amount of radiotracers injected must be kept to the minimum. Bodily fluids and tissue samples would be scanned. Cancer epidemiology studies using expectorated samples or lung tissue would be able to probe lower doses: ^{14}C is a tracer for particulates from combustion, other isotopes can be found in radiation workers.

There are many other applications from tracking atmospheric ^{85}Kr and ^{133}Xe for treaty verification to monitoring soft error upsets in integrated circuits free of cosmic ray background to using ^{129}I as an environmental monitor for nuclear pollution plumes. All of these users would benefit from more sensitive counting and the integration of existing underground counting sites with a central LBCF at DUSEL. They would use the same suite of alpha, beta, gamma counters for solids, liquids, and gases which we have described in the production facility (section 3.1) and will require a proper scheduling interface as well as dedicated technicians to handle samples sent from off-site. In addition, they would be major users of the sample preparation chemistry lab.

Thus we see that not only are low level counting and materials purity vital to the success of most underground experiments, but are also of great interest to many fields. The development of this DUSEL module is most likely to generate cross disciplinary activity and evolve into a genuine user facility with a fee structure. Yet the organizational infrastructure required to support these needs is in its infancy in the US. In Europe and Japan, the longer history of underground experiments at a few sites has resulted in a de facto collection of screening devices (mostly high purity germanium detectors) locally available to existing and future experiments, as well as detectors which have outlived their original purpose and can be redirected toward screening. In an effort to organize and share resources, the European Union has instituted ILIAS. Cooperation with this entity and the creation of North American integrative structure should be a formal part of the DUSEL initiative. Integration efforts within the US have already started, initiated in part by this working group. A new website http://www.hep.umn.edu/lbcf/integration allows registered members to add links and functionality. This tool will be used to form collaborations and schedule screening across all low background sites in North America, and could eventually be incorporated into a DUSEL integrative structure. This website cuts across disciplines to identify and contact all fields which might require radiometric measurements, including archaeology, forensics, national security, waste management, geomicrobiology and limnology. Thus, we envision a large and varied user community at the LBCF which will co-exist with the physics community whose needs are driving its design.

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