Berkeley Low Background Facility

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I. EXCECUTIVE SUMMARY

The Berkeley Low Background Facility (BLBF) at the Lawrence Berkeley National Laboratory (LBNL) has a long history of measuring low levels of radioactivity for purposes that have evolved according to the needs of experiments and projects. The analysis of samples takes place within two unique facilities: locally at LBNL within a carefully constructed, low-background cave and remotely at the Sanford Underground Research Facility (SURF) in Lead, SD.

Over the past few decades, many experiments have utilized the low-background counting services provided by the facility to screen materials for ultra sensitive experiments such as those seeking to detect neutrinos, neutrinoless double beta decay, and the direct detection of dark matter. Experiments such as these are often situated underground to avoid backgrounds from cosmic-ray interactions. Once underground, they employ traditional shielding techniques to reduce gamma-ray backgrounds from the surrounding environment using lead, copper, water, etc. However, they typically need to go a step further and verify that the materials used to construct sensitive components of their detectors are in fact not a source of background themselves. Even trace amounts of primordial and cosmogenic radionuclides found in everyday materials are often too high to meet these experiments' strict radiopurity standards.

Over the years, the BLBF has provided low-background counting services to quantify concentrations of uranium, thorium, potassium, and other radioisotopes in a wide variety of candidate construction materials for experiments. Such experiments of note have included SNO, KamLAND, Double CHOOZ, Daya Bay, CUORE, LUX/LZ, Majorana, KATRIN, SURF, and more. Materials assayed at the facility have included a wide variety of items such as metals (stainless steel, copper, titanium), plastics (acrylic, Teflon), crystals (NaI(Tl), TeO_2), ropes, fasteners, electrical components (resistors, capacitors, circuit boards), geological samples, concretes, paints — virtually any material used or encountered in the construction of experiments. The in-house expertise is often able to provide comments or advice in addition to the results of material testing. The BLBF is open any groups or experiments seeking measurements or collaboration for a project. The vibrant community of underground experiments will benefit from the expertise and long-term operation of the BLBF.

II. HISTORY

The Berkeley Low Background Facility was born in the 1950s after the Health Physics department was tasked with evaluating the little-known backgrounds generated in the surrounding area of the Bevatron at LBNL. Many samples and activation foils were used in the characterization of equipment, but counting activities were significantly hindered by stray neutrons from the nearby accelerator. As a result, a new low-background counting laboratory was constructed at a greater distance from the accelerator and with specialized construction to reduce backgrounds (see Sec. III A for description). Over the years the purpose of the counting facility evolved with the needs of local projects and science experiments. From the 1950s to 1970s the BLBF was involved in surveys to assess the extent of fallout from atmospheric weapons tests, among other local projects. Ultimately, the construction of the surface counting laboratory produced local procedures for quantifying the primordial radionuclide content of rocks and soils for various projects, which subsequently led to a natural transition to low-background material assay for nuclear and particle astrophysics experiments.

Eventually, a second counting site was added underground at the Hyatt Power plant in nearby Oroville, CA. In the summer of 1975 when A.R. Smith established contacts there with the California Department of Water Resources (DWR) Oroville Division. The initial interest was to study the potential use of radon as an earthquake indication system using water sampled from deep in the concrete core of the dam structure and several local wells. Years later,

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in an effort to detect neutrinoless double-beta decay, it quickly became apparent that the surface LBNL counting site would not be suitable for such an experiment due to cosmic rays, which created too much background to search for a signal expected to be very small. Due to heightened competition at the time, the UCSB/LBNL experiment was quickly relocated underground to the Hyatt Power Plant in Oroville thanks to an existing working relationship with the facility. The nearly 600 feet of overburden at the site (approximately 530 m.w.e.) greatly reduced cosmic-related backgrounds. The (unenriched) HPGe-based neutrinoless double-beta decay experiment ran from 1985 to the early 1990s there, and established lifetime limits for the rare decay process of ^{76}Ge in the detectors, [1] and [2], as well as an early search for dark matter (WIMPs) [3].

In the meantime, it was realized that this underground experiment site was useful not only for the in-house experiments, but for future generations of experiments taking place all over the world. Before the end of the UCSB/LBNL experiment, an additional detector was installed in a separate shield for R&D measurements of candidate construction materials to service other low-background experiments. The underground location allowed for greater sensitivity for such low-background counting than what could be done on surface. For nearly 25 years, the Oroville site has provided important material testing services to a number of successful neutrino and dark matter experiments.

Recently, the counting system at the Oroville site was moved to the Sanford Underground Research Facility (SURF). Counting operations at the Oroville location were shut down in early 2014 and operation at SURF began in July 2014.

III. FACILITY DESCRIPTIONS

The BLBF at LBNL maintains counting stations in two unique locations: a surface site at LBNL and an offsite location formerly located in Oroville, CA, but now relocated to SURF. Typical analysis of samples always begins at the surface location where sample counting times are typically restricted to at most a few days per sample. Pending the results of the surface counting and depending on the requestor's needs, the sample may or may not be sent to the underground HPGe spectrometer for more sensitive counting, which may take up to two weeks of counting time. By pre-screening the samples on the surface, it allows for more efficient use of the underground detector by prioritizing samples that actually benefit from the added sensitivity.

A. Surface LBNL Low Background Laboratory

The low-background counting laboratory at LBNL was developed to have very thick walls of concrete, which shield the inner cavity from not only external gamma rays, but also neutrons due to a high water content. By selecting a low-activity source material, the room would then provide the desired shielding with the added benefit of not introducing significant radiation itself into the internal cavity. Raw materials for cement plants in California and all over the United States and Canada were counted to find a suitable source material. Nearly 140 samples were tested and ultimately a cement from the British Columbia Cement Company was selected for construction. The aggregate used was a low-activity serpentine. The search for source materials and construction of the counting room is detailed in References [4] and [5].

The counting laboratory was made in a single pour of concrete, where the walls on all sides of the room are approximately 1.5 meters thick, including the floor and ceiling. Typical concretes have uranium and thorium concentrations up to the ppm level or higher, whereas the source materials used for the lab space contained concentrations of these isotopes on the ppb level. The result is an inner space that has environmental gamma backgrounds up to 1000 times lower than typical construction. An added benefit of such a space is that Pb shields do not need to be as thick, and some measurements do not require shielding at all.

B. Sanford Underground Research Facility

The BLBF has installed recently its remote HPGe detector underground at SURF, which has been underground for over ten years at the Oroville counting site. The counting station is situated 4850 feet underground in the east counting room of the Davis Cavern. Figure 1 shows the spectrometer and the counting room. The detector shielding is outfitted with a gaseous N_2 line through the sample cavity to purge and exclude radon from interfering with sample counting. Various components of the system and sample counting will be managed remotely and with assistance from SURF. Here the shield was reconstructed and contains an inner cavity that is taller than in its previous configuration at Oroville by 15 cm (6 inches). Additional upgrades to the shielding, including the addition of a several-hundredyear-old Pb layer (so as to be lower in ^{210}Pb activity) are under consideration as well. A second HPGe counting system is also being planned for the remote site at SURF.

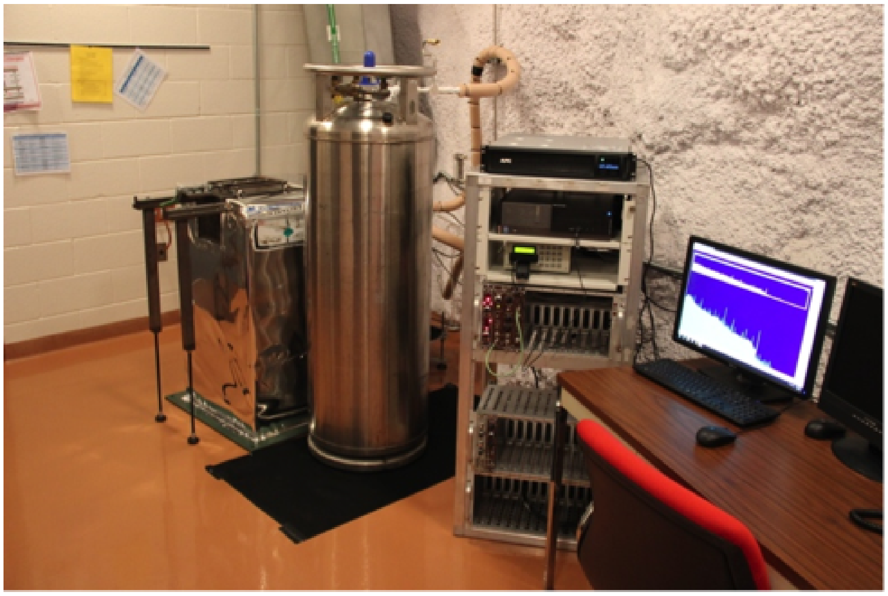

FIG. 1: The Berkeley Low Background Facility remote counting station at SURF.

IV. EQUIPMENT AND SENSITIVITIES

The surface low-background counting facility at LBNL utilizes two HPGe spectrometers: a 115% n-type and a 85% p-type with relative efficiency at 1332 keV to a $3'' \times 3''$ NaI(Tl) detector. The larger of the two is the primary low-background detector in use. It is an ORTEC GMX Series detector with a cryostat configuration LLB-HJ, an upward looking detector with a remote preamp that resides external of the Pb shield near the dewar, and a magnesium endcap. The second detector is an ORTEC GEM with an XLB-SL cryostat configuration, which is side-looking. The shielding around each detector is a minimum of 4 inches of low activity Pb with a 0.5 inch inner layer of OFHC copper. Boil-off liquid nitrogen is used to create a slight over pressure to exclude and purge airborne radon from the counting cavity.

The primary spectrometer for low-background assay used at the surface site (the 115% n-type) is surrounded by an active muon veto system. The veto system is composed of five panels of 2.5-cm thick (Eljen Technology) EJ200 scintillating plastic, which are connected to thin strips of EJ280 wavelength shifting plastic that absorbs and remits the scintillation in line-of-sight with a small Hamamatsu R1924A PMT connected at the end. More information about the system and its configuration can be found in Ref. [6].

The detector underground offsite is an ORTEC 85% p-type HPGe spectrometer, which is GEM series with a LLB-HJ cryostat configuration. Around it is a shield that has an outer layer of low-activity Pb that is 20.3 cm (8 inches) thick surrounding a 1.27 cm (0.5 inch) thick inner layer of OFHC copper. The inner cavity is purged with boil-off nitrogen to create a slight over pressure to exclude radon from the counting cavity. The detector has been underground for over ten years at the Oroville counting site with a short surface time encountered during its relocation to SURF. The copper and Pb in the shielding has been underground for more than 20 years, also with a short surface time during relocation to SURF. The inner cross section of the cavity is approximately 17.8 cm^2 (7 in^2) with over 20 cm of headroom above the end cap of the detector.

Typical sensitivities for the counting systems are displayed in Table I. Figure 2 shows a comparison of the detector background at the Oroville site and at its new location at SURF.

TABLE I: Sensitivity for U,Th, and K at each LBF location for ≈1-kg samples counted for approximately 1 week. Sensitivity for the setup at SURF has surpassed that at the Oroville site.

Isotope/Chain	LBL Surface Facility	SURF Facility 4300 m.w.e.
^{238}U chain	500 ppt (6 mBq/kg)	50 ppt (0.6 mBq/kg)
^{232}Th chain	2000 ppt (8 mBq/kg)	200 ppt (0.8 mBq/kg)
K	1000 ppb (30 mBq/kg)	100 ppb (3 mBq/kg)
^{60}Co	1.5 mBq/kg	0.15 mBq/kg

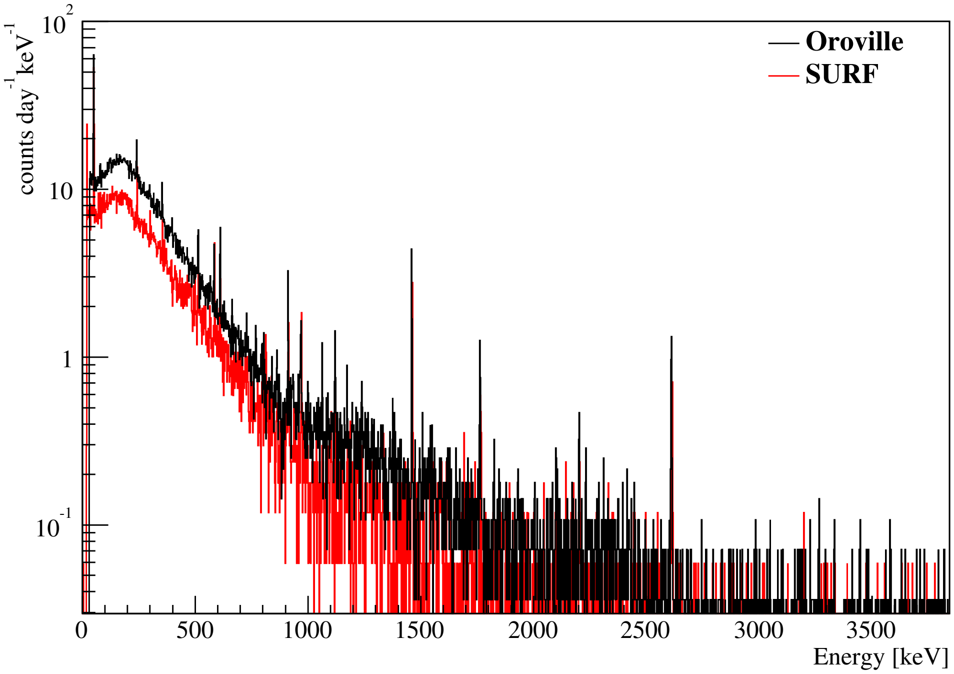

FIG. 2: Comparison of shielded (N_2 purged) backgrounds at Oroville and SURF. The backgrounds at SURF are approximately 30% lower than that at Oroville, due to some minor improvements in the shield configuration.

V. SERVICES AND ACTIVITIES

A. Low Background Counting of U, Th, K

Samples for low-background experiments are screened at the BLBF for uranium, thorium, potassium, and various common man-made and cosmogenic radionuclides. Typical procedure for samples is a pre-screening of up to two days, depending upon the sample, at the surface facility on the primary counter equipped with a muon veto. Pending the results of surface testing and the desired sensitivity for the requestor of the sample testing, it is then sent to the remote underground counter at SURF for additional screening that may run up to two weeks. By employing this procedure the time for the underground system is prioritized and used efficiently. Detector cavities are purged with boil-off nitrogen gas to prevent radon from interfering with sample counts.

B. Neutron Activation Analysis

The BLBF also regularly performs active measurements for a variety of projects. Some samples are irradiated at a reactor such as the McClellan Nuclear Research Center (MNRC), the MIT Nuclear Reactor Facility, or others and shipped to LBNL for trace element analysis of non-radioactive species. Some activation foils are analyzed from R&D evaluations of new equipment, such as for the purpose of characterizing beam lines. For low-background projects, in the event that passive counting does not provide adequate sensitivity for U, Th, or K (or if the sample mass is limited), neutron activation is sometimes a suitable alternative to passive gamma-ray spectroscopy. For instance, U can be indirectly assayed using neutron capture on ^{238}U to become ^{239}U, in which it quickly decays to ^{239}Np and is a good isotope for analysis to infer the initial parent concentration. However, for these purposes, the limiting factor is often the backgrounds generated by the other radioisotopes produced in the bulk matrix, so results vary for ultra low measurements of U, Th, and K via neutron activation analysis. More information about the BLBF and neutron activation analysis can be found in [7] [8]. The BLBF is currently in the process of expanding our capabilities in this technique.

C. Environmental Monitoring

Environmental measurements are regularly performed by counting HEPA air filters, automobile filters, soil, and other miscellaneous samples at BLBF. Such activities date as far back as the Chernobyl incident and renewed measurements were performed after the March 2011 tsunami in Japan and the subsequent accident at the Fukushima Daiichi Nuclear Power Plant.

In 2014, renewed public interest in the ongoing Fukushima Daiichi Nuclear Power Plant accident has prompted a series of additional measurements. In particular, much interest was generated in measuring the spread of Fukushima radioactivity across the Pacific Ocean and potentially being detectable on the west coast of North America. As such, the BLBF has partnered with the Nuclear Engineering Department at UC Berkeley to continue to produce up-to-date measurements that are available to the public. Of particular interest are various food products, such as fish obtained from the Pacific Ocean. Some of these measurements and more information can be found at the UC Berkeley Radwatch website[9] . To specifically target the spread of radioactivity in the Pacific Ocean, the Radwatch team at UC Berkeley and LBNL have partnered with California State University Long Beach to provide a series of measurements on kelp sampled from the Pacific coast from Alaska to Mexico, named Kelpwatch [10]. Kelp provides an excellent sampling medium as it absorbs metals extremely well from seawater and would presumably enhance the detection of Cs isotopes over their ambient seawater concentrations. As it turns out, the limiting factor in measuring ^{134,137}Cs are the backgrounds from other radioisotopes present in the kelp, which are absolutely dominated by potassium as it can be up to 15% potassium (of dry weight). As of early April 2014, no samples have shown the presence of ^{134}Cs, although small amounts of ^{137}Cs are present from legacy atmospheric weapons testing in the 1950's and 1960's.

D. Waste Assay

A variety of radioactive waste activities are performed for local LBNL experiments. They vary in scale from miscellaneous gamma screening of typical laboratory waste to large-scale projects from decommissioning old facilities and experiments. Many concrete shielding blocks from the former Bevatron were screened before disposal. The project is summarized in Ref. [11].

VI. SUMMARY

The BLBF at Lawrence Berkeley National Laboratory is an active screening facility specializing in low-background gamma-ray spectroscopy. A primary component of the samples analyzed at the site include the passive assay of primordial radionuclides and their decay chains (U, Th, K) for the purposes of low-background experiments. Such counting services are provided at the surface counting lab at LBNL and the underground spectrometer located on the 4850L of SURF (approximately 4300 m.w.e.). Other assays include specific searches for man-made or cosmogenic isotopes. Active screening in the form of neutron activation analysis is regularly performed as well for material treatments such as neutron transmutation doping or typical assay of elements. Various environmental measurements are also performed on soils, biota, rainwater, and air filters for a variety of projects and users. Improvements to BLBF's detector systems, including the addition of a second counting system at SURF, are in progress. The BLBF is open for projects and measurements from any user. The underground science community will benefit from the expertise and the long-term continuing operation of the facility.

Acknowledgments

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