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The MAJORANA DEMONSTRATOR: A Search for Neutrinoless Double-beta Decay of Germanium-76

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Abstract. The observation of neutrinoless double-beta decay would show that neutrinos are Majorana particles and provide information on neutrino mass. Attaining sensitivities for neutrino masses in the inverted hierarchy region requires large, tonne scale detectors with extremely low backgrounds, at the level of 10^{-3} counts keV^{-1} t^{-1} y^{-1} or lower in the region of the signal. The Majorana collaboration is constructing the Demonstrator, an array consisting of 40 kg of p-type point contact germanium detectors, at least half of which will be enriched to 86% in ^{76}Ge. The primary aim is to show the feasibility for a future tonne scale measurement. With a sub-keV energy threshold, the array should also be able to search for light WIMP dark matter. This paper presents a brief update on the status of constructing the Demonstrator including an electroforming facility that is now operating underground at the Sanford Underground Research Facility.

1. The Majorana Demonstrator

Neutrinoless double-beta decay ($0\nu\beta\beta$) is the only viable technique to determine the Dirac-Majorana nature of the neutrino[1, 2]. The observation of $0\nu\beta\beta$ in two or more different isotopes would provide compelling evidence that neutrinos are Majorana particles and that lepton number is violated. Reaching the neutrino mass scale associated with the inverted mass hierarchy will require a half-life sensitivity on the order of 10^{27} y for ^{76}Ge, corresponding to a signal of a few counts or less per tonne-year in the $0\nu\beta\beta$ peak located at 2038-keV. To observe such a small signal, one will need to limit backgrounds in the region of interest to ~ 1 count per tonne-year (2.5×10^{-4} counts keV^{-1} t^{-1} y^{-1}). The Majorana collaboration is constructing the Majorana Demonstrator with the aim of achieving such low backgrounds while also testing the Klapdor-Kleingrothaus claim[3], of neutrinoless double-beta decay in ^{76}Ge.

The Demonstrator array will consist of an array of ^{natural}Ge and 86% enriched ^{76}Ge high purity germanium (HPGe) detectors contained in an ultra-low background structure that maximizes the concentration of crystals while minimizing the amounts of structural materials[4, 5, 6]. Two ultra-pure electroformed copper cryostats are being fabricated, each of which will contain up to 35 close-packed P-type point-contact (P-PC) germanium detectors[7]. The cryostats are within a graded shield surrounded by structural and additional gamma and neutron shielding materials, which are themselves surrounded by an active veto system (Figure 1). The array will located at the 4850 ft level of the Sanford Underground Research Facility (SURF) in Lead, SD.

2. Underground Electroforming

In typical materials uranium (U) and thorium (Th) decay-chain contaminants are found at levels of μg/g to ng/g, which will produce unacceptable backgrounds in the Demonstrator. It has been shown that electroforming copper in a carefully controlled and clean environment allows one to produce ultra clean copper, with U and Th below the level of 10^{-12} g/g[8]. Copper has mechanical, thermal, and electrical properties that are suitable for the Demonstrator's cryostats, detector mounts, and inner shield.

We have completed and put into operation an advanced electroforming facility that is located underground near the Ross shaft at the 4850 ft level at SURF. At this depth, cosmogenic backgrounds are negligible compared to those that would be produced by cosmic ray bombardment of copper on the surface of the earth. The electroforming facility is divided into a class 1000 cleanroom and an anteroom, which contains data acquisition (DAQ) computers and a gowning area. Particle counts within the clean room are well below 1000 per cubic foot, with typical values well below 100 during normal operations. A slow controls and

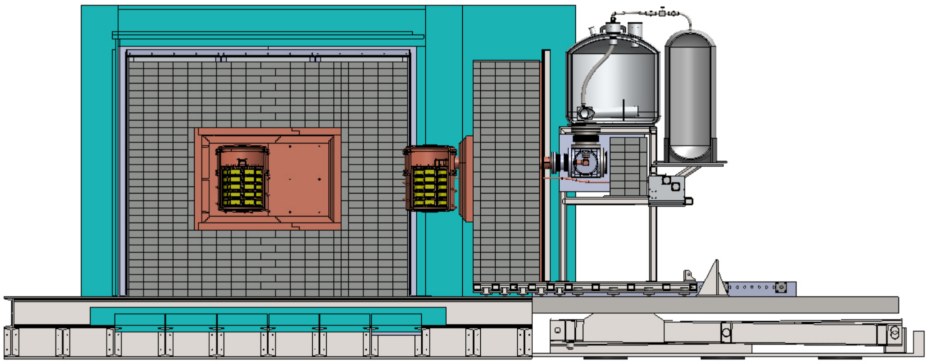

Figure 1. Cross-sectional view of the MAJORANA DEMONSTRATOR, with one cryostat inserted and another being positioned for insertion into the shield. Cryostats are mounted 'n moveable transporters allowing assembly and testing before installation into the shield. The cryostat vacuum system is visible for the cryostat on the right. The graded shield consists of electroformed copper, commercial copper, lead, a radon exclusion volume, an active muon scintillator veto, and a polyethylene neutron moderator. For scale, the inner Cu volume where the cryostats are inserted is 20" high, 20" wide, and 30" in length.

environmental monitoring system continuously monitors a variety of parameters including temperature, humidity, conductivities of baths, voltages and currents of electoforming power supplies, leakage into electroforming baths secondary containment, nitrogen flow rate, particle count, radon level, and oxygen levels. This system allows remote access, monitoring and control. A similar electroforming facility has also been established in a shallow underground laboratory, 37 m.w.e., at Pacific Northwest National Laboratory (PNNL).

Ten large electroforming baths have been setup and are now operating at SURF, Figure 2), and another 6 baths are are in operation at the PNNL facility. Each bath consists of a rectangular tank, 24"L x 24"W x 36"H, a cylindrical baffle, and cover, all contained in a secondary container. The baths will accommodate cylindrical stainless steel mandrels up to 13" diameter and 23" long. All components are constructed of high density polyethylene. Each bath and mandrel undergoes a rigorous cleaning and etching procedure prior to use. The baths contain an electrolyte solution composed of a simple acid sulfate system of ultra pure copper sulfate, sulfuric acid, and water. The electroformed copper that is being produced will be used to fabricate cryostats and internal components, detector mounting and string hardware, as well as the inner shield plates (typically 20" x 20" x 0.5") for the DEMONSTRATOR. Deposition rates are conservatively estimated at 0.002" per day.

3. Construction Status

Over 20 kg of ^{natural}Ge P-PC HPGe detectors have been acquired and characterized. For the enriched detectors, an initial order of 30 kg of GeO_2 enriched to 88% ^{76}Ge has been produced at the electrochemical plant in Zelonogorsk, Russia. The material was shipped to Oak Ridge, TN using ground-transportation in a steel-shielded container. It is now being stored in an underground location with 120 ft of rock overburden. (Additional material will be acquired in 2012.) The GeO_2 will be reduced to Ge and zone-refined into electronic grade Ge in partnership with Electrochemical Systems Incorporated, where a facility has been established to reduce, refine, and recycle the enriched material. A test run using natural GeO_2 has been successfully completed. A prototype cryostat is currently being fabricated using the same techniques planned for the ultra-clean cryostats. This cryostat will also be used to test the thermosyphon based

Figure 2. On the left is a view of the electroforming facility with 7 of the 10 baths visible in the photograph. On the right is a mandrel that has been lifted out of its bath for an initial inspection of the copper growth.

cooling system. It will be populated with 2-3 strings of natural P-PC detectors and mounted on a monolith transporter. A multi-stage glove box will be used to build the strings and insert them into the cryostats while within a Rn suppressed N_2 atmosphere. A dedicated underground laboratory for the DEMONSTRATOR at the Davis Campus at SURF has been excavated and outfitting is underway, with expected beneficial occupancy in the spring of 2012. The first underground cryostat, containing a mixed array of natural and enriched germanium, is expected to begin taking data in mid-2013.

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