The MAJORANA DEMONSTRATOR

Introduction

The MAJORANA DEMONSTRATOR is a mixed array of enriched and unenriched germanium crystal detectors that will search for the neutrinoless double beta decay ($0\nu\beta\beta$-decay) of the ^{76}Ge isotope. Specific goals of the MAJORANA DEMONSTRATOR are:

1. To demonstrate a path forward to achieving a background rate below one count/tonne/year in the 4 keV region of interest (ROI) around the 2039 keV *Q*-value of the ^{76}Ge $0\nu\beta\beta$-decay. This is required for the next generation of tonne-scale germanium-based $0\nu\beta\beta$-decay searches that will probe the neutrino mass scale in the inverted-hierarchy region (25 ~ 50 meV).
2. To demonstrate technical and engineering scalability toward a tone-scale instrument.
3. To field an instrument that provides sufficient sensitivity to test the Klapdor-Kleingrothaus claim and to be comparable with alternate approaches.

Materials Assay

To assure that Majorana Demonstrator will utilize extremely radio pure materials extensive screening program is required. We will use direct radiometric counting, mass spectrometry, and neutron activation analysis.

Radiometric Measurements

The sensitivity of direct radiometric measurements is limited to about 1 mBq/kg for routine counting times and to about 10 μBq/kg for very long (90 day) counting periods at the world's best facilities. This level of sensitivity is not sufficient for many of the MAJORANA components, and more sensitive assay techniques such as Inductively-Coupled Plasma Mass Spectrometry (ICPMS) and Neutron Activation Analysis (NAA) are needed. However, the radiometric measurements will play an important role for initial certification before an investment in ICMPS or NAA counting is made for a given material.

The Lawrence Berkeley National Laboratory (LBNL) maintains a shielded, low background counting facility (LBCF) in Berkeley and an underground facility beneath the Oroville dam (180 mwe shielding) in northern California [Smi03, Smi04]. The Oroville facility has a long history of certifying materials for many low background experiments including SNO, KamLAND, CDMS, and CUORE. Both LBNL facilities are designed to count samples with a maximum volume of two liters. The routine sensitivity of the Oroville facility is about 1 mBq/kg for ^{232}Th and ^{238}U. The primary limitation to the sensitivity is activity in the detector components. Additional low background counting facilities that are available for use by MAJORANA include: the PNNL 17A at a surface facility at the Pacific Northwest National Laboratory; a surface facility at the University of Washington; facilities at the Kimballton

Underground Research Facility; an underground facility operated by the Los Alamos National Laboratory at the Waste Isolation Pilot Plant; and the GeMPI-2 detector at the Gran Sasso National Laboratory in Italy that is one of the most sensitive radiometric assay facility in the world. Together, these six facilities have the capability to screen potential materials for MAJORANA quickly and efficiently with an average of two of these facilities screening material for MAJORANA at any given time.

We have already used a significant fraction of time at these facilities to assay samples of MAJORANA materials such as: cable materials, electronics components, plastics, lead and copper. The GeMPI-2 detector at Gran Sasso has recently completed the counting of copper with a counting time of ~150 days and provided a very sensitive measurement.

Majorana collaboration will benefit from ultrasensitive gamma counting capabilities at DUSEL. It will enable to do in house counting of components without exposing them to cosmic rays during transportation. Future one ton experiment will require many hours of screening and therefore gladly use DUSEL screening capabilities.

Mass Spectrometry

As stated, the purity levels required for MAJORANA have rendered direct radiometric counting impractical for many critical detector components. A number of analytical approaches have been evaluated for assay of copper, with Inductively-Coupled Plasma Mass Spectrometry (ICPMS) being the most promising. ICPMS is a variant of mass spectrometry that has been successfully used for ultra-trace measurements. A significant advantage is the speed of the analysis, returning results in days rather than months at the highest level of sensitivity. However, the performance of ICPMS can depend sensitively on the chemical processing of the sample. For the MAJORANA project, R&D has been pursued to greatly improve ICPMS sensitivities for Th and U in copper. Previous studies by MAJORANA collaborators coupling this ion exchange method to ICPMS give a measurement background of about 0.6 ± 0.2 μBq/kg for ^{232}Th. Further research is underway to improve this sensitivity down to the 0.1 μBq/kg level.

Installation at DUSEL sensitive ICP-MS apparatus with proper sample preparation laboratory definitely will be of great asset for Majorana project. Here again great benefit would be that assay can be done for samples that either prepared underground (electroformed copper), or were underground for long time for deactivation.

Neutron Activation Analysis

With Neutron Activation Analysis (NAA) [Soe72], a sample is activated through an exposure to neutrons from a research reactor. The short-lived ^{238}U and ^{232}Th activation products ^{239}Np and ^{233}Pa are then counted with the radiometric techniques described above. NAA has achieved sensitivity levels of better than 10^{-15} g/g in measuring trace amounts of U and Th in organic scintillators [Ang98, Hen99, Dju03]. This is three orders of magnitude more sensitive than the ICPMS measurements described above. Unfortunately, NAA will only work on materials with no long-lived activation products. This essentially limits NAA to testing plastics like Teflon® and other hydrocarbons. In particular, NAA will not work with germanium or copper.

There are at least three NAA facilities within easy access of collaborating institutions: the research reactor at the University of California, Davis McClellan Nuclear Radiation Center

(MNRC), North Carolina State University's (NC State) research and teaching reactor in its Nuclear Engineering (NE) Department, and HIFR reactor at ORNL. Post-irradiation sample counting may be performed on-site, or at the low-background counting facilities at LBNL, Oroville or Kimballton for a more sensitive assay.

Counting irradiated samples with ultralow background facility at DUSEL can bring new levels of sensitivity especially for Th measurements. To have good results for U administrative methods should be in place to let fast transportation irradiated samples from reactor site to DUSEL. Thus is necessary because of the relative short live time of ^{239}Np.