Nuclear Instruments and Methods in Physics Research A 828 (2016) 22–36

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

The MAJORANA DEMONSTRATOR radioassay program

N. Abgrall[a,s], I.J. Arnquist[b], F.T. Avignone III[c,d], H.O. Back[e,f,1], A.S. Barabash[g], F.E. Bertrand[d], M. Boswell[h], A.W. Bradley[a], V. Brudanin[i], M. Busch[j,f], M. Buuck[m], D. Byram[k], A.S. Caldwell[l], Y.-D. Chan[a], C.D. Christofferson[l], P.-H. Chu[h], C. Cuesta[m], J.A. Detwiler[m], J.A. Dunmore[m], Yu. Efremenko[n], H. Ejiri[o], S.R. Elliott[h,*], P. Finnerty[p,f,2], A. Galindo-Uribarri[d], V.M. Gehman[h,6], T. Gilliss[p,f], G.K. Giovanetti[p,f], J. Goett[h], M.P. Green[d,e,f], J. Gruszko[m], I.S. Guinn[m], V.E. Guiseppe[c], R. Henning[p,f], E.W. Hoppe[b], S. Howard[l], M.A. Howe[p,f], B.R. Jasinski[k], R.A. Johnson[m,3], K.J. Keeter[q], M.F. Kidd[r], O. Kochetov[i], S.I. Konovalov[g], R.T. Kouzes[b], B.D. LaFerriere[b], J. Leon[m], J.C. Loach[s,4], J. MacMullin[p,f], S. MacMullin[p,f,5], R.D. Martin[k,12], R. Massarczyk[h], S. Meijer[p,f], S. Mertens[a], M.L. Miller[m], J.L. Orrell[b], C. O'Shaughnessy[p,f], N.R. Overman[b], A.W.P. Poon[a], K. Pushkin[k,7], D.C. Radford[d], J. Rager[p,f], K. Rielage[h], R.G.H. Robertson[m], E. Romero-Romero[n,d], M.C. Ronquest[h,8], A.G. Schubert[m,9], B. Shanks[p,f], M. Shirchenko[i], K.J. Snavely[p,f,11], N. Snyder[k], D. Steele[h,10], A.M. Suriano[l], D. Tedeschi[c], J.E. Trimble[p,f], R.L. Varner[d], S. Vasilyev[n], K. Vetter[a,13], K. Vorren[p,f], B.R. White[d], J.F. Wilkerson[p,f,d], C. Wiseman[c], W. Xu[h], E. Yakushev[i], C.-H. Yu[d], V. Yumatov[g], I. Zhitnikov[i]

[a] Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA, USA
[b] Pacific Northwest National Laboratory, Richland, WA, USA
[c] Department of Physics and Astronomy, University of South Carolina, Columbia, SC, USA
[d] Oak Ridge National Laboratory, Oak Ridge, TN, USA
[e] Department of Physics, North Carolina State University, Raleigh, NC, USA
[f] Triangle Universities Nuclear Laboratory, Durham, NC, USA
[g] National Research Center, "Kurchatov Institute" Institute for Theoretical and Experimental Physics, Moscow, Russia
[h] Los Alamos National Laboratory, Los Alamos, NM, USA
[i] Joint Institute for Nuclear Research, Dubna, Russia
[j] Department of Physics, Duke University, Durham, NC, USA
[k] Department of Physics, University of South Dakota, Vermillion, SD, USA
[l] South Dakota School of Mines and Technology, Rapid City, SD, USA
[m] Center for Experimental Nuclear Physics and Astrophysics, and Department of Physics, University of Washington, Seattle, WA, USA
[n] Department of Physics and Astronomy, University of Tennessee, Knoxville, TN, USA
[o] Research Center for Nuclear Physics and Department of Physics, Osaka University, Ibaraki, Osaka, Japan
[p] Department of Physics and Astronomy, University of North Carolina, Chapel Hill, NC, USA
[q] Department of Physics, Black Hills State University, Spearfish, SD, USA
[r] Tennessee Tech University, Cookeville, TN, USA
[s] Shanghai Jiao Tong University, Shanghai, China

[*] Corresponding author at: Los Alamos National Laboratory, Los Alamos, NM, USA.
E-mail address: elliotts@lanl.gov (S.R. Elliott).

[1] Permanent address: Pacific Northwest National Laboratory, Richland, WA, USA.
[2] Permanent address: Applied Research Associates, Inc., 8537 Six Forks Road, Suite 600, Raleigh, NC, USA.
[3] Permanent address: Microsoft Corporation, One Microsoft Way, Redmond, WA, USA.
[4] Permanent address: Shanghai Jiao Tong University, Shanghai, China.
[5] Permanent address: Picarro Inc., 3105 Patrick Henry Dr., Santa Clara, CA, USA.
[6] Permanent address: Lawrence Berkeley National Laboratory, Berkeley, CA, USA.
[7] Permanent address: Randall Laboratory of Physics, University of Michigan, Ann Arbor, Michigan, USA.
[8] Permanent address: CCRi, 1422 Sachem Pl #1, Charlottesville, VA, USA.
[9] Permanent address: Department of Physics, Stanford University, Stanford, CA, USA.
[10] Permanent address: Picarro Inc., 3105 Patrick Henry Dr., Santa Clara, CA, USA.
[11] Permanent address: IBM Cloudant, Boston, 200 State St, Boston, MA, USA.
[12] Permanent address: Department of Physics, Engineering Physics and Astronomy, Queen's University, Kingston, ON, Canada.
[13] Alternate address: Department of Nuclear Engineering, University of California, Berkeley, CA, USA.

http://dx.doi.org/10.1016/j.nima.2016.04.070

A R T I C L E I N F O

Article history:
Received 15 January 2016
Received in revised form
3 April 2016
Accepted 17 April 2016
Available online 3 May 2016

Keywords:
Radiopurity
Trace analysis
Neutron activation analysis
Mass spectrometry
Mass spectroscopy
Germanium counting
Low background
Double beta decay
Majorana

A B S T R A C T

The Majorana collaboration is constructing the Majorana Demonstrator at the Sanford Underground Research Facility at the Homestake gold mine, in Lead, SD. The apparatus will use Ge detectors, enriched in isotope ^{76}Ge, to demonstrate the feasibility of a large-scale Ge detector experiment to search for neutrinoless double beta decay. The long half-life of this postulated process requires that the apparatus be extremely low in radioactive isotopes whose decays may produce backgrounds to the search. The radioassay program conducted by the collaboration to ensure that the materials comprising the apparatus are sufficiently pure is described. The resulting measurements from gamma-ray counting, neutron activation and mass spectroscopy of the radioactive-isotope contamination for the materials studied for use in the detector are reported. We interpret these numbers in the context of the expected background for the experiment.

1. Introduction: overview of the Demonstrator

The Majorana collaboration [1] will search for the neutrinoless double-beta decay ($\beta\beta(0\nu)$) of ^{76}Ge. The observation of this rare decay would indicate the neutrino is its own anti-particle, demonstrate that lepton number is not conserved, and provide information on the absolute mass-scale of the neutrino (see Refs. [2–8] for recent reviews of $\beta\beta(0\nu)$). Reaching the neutrino mass-scale sensitivity associated with the inverted mass ordering (15–50 meV) is a goal for next-generation $\beta\beta(0\nu)$ searches. This goal will require a half-life sensitivity exceeding 10^{27} yr, which corresponds to a signal on the order of a few counts or fewer per tonne-year in the $\beta\beta(0\nu)$ peak (2039 keV for ^{76}Ge). To observe such a rare signal, one will need to construct large-scale experiments with backgrounds in the region of interest (ROI) below 1 count per tonne of isotope per year ($< 1\ c/(ROI\ t\ yr)$). The Majorana collaboration [1] is constructing the Demonstrator, an array of high-purity germanium (HPGe) detectors at the 4850 ft level of the Sanford Underground Research Facility (SURF) in Lead, South Dakota [9,10]. The Demonstrator will consist of a mixture of HPGe detectors including, 15 kg fabricated from natural-isotopic-abundance Ge and 29.7 kg fabricated from Ge enriched to >87% in ^{76}Ge. These detectors are contained within two low-background copper cryostats. Each cryostat will contain seven closely packed stacks of detectors, called strings, with up to five detectors comprising each string. Figs. 1 and 2 show the Demonstrator concept.

The Demonstrator aims to show that a background rate lower than 3 c/(ROI t yr) in the 4 keV ROI surrounding the 2039 keV ^{76}Ge Q-value energy is achievable. This background level will scale to 1 c/(ROI t yr) in a future experiment based on simulations considering improved self-shielding, thicker inner copper shield, and improved cosmogenic isotope control. Hence the Demonstrator will establish the technology required to build a large-scale germanium based $\beta\beta(0\nu)$ experiment.

The Majorana collaboration uses p-type point contact (PPC) HPGe detectors. These detectors [11–14] have been demonstrated to provide both good energy resolution (<2.0 keV FWHM at 1332 keV, <4.0 keV FWHM at 2039 keV) and low-energy threshold (~ 500 eV) [12,15]. (See e.g., Fig. 1 in Ref. [15].) Each PPC detector used in the Demonstrator has a mass in the range of 0.5–1.1 kg with a mean of 0.85 kg.

This report summarizes the assay program conducted by the Majorana collaboration to ensure that the various components of the experimental apparatus have radioactive isotope contamination sufficiently low to meet the background goal. Section 2 discusses the strategy to reach the required background levels in the experiment. Section 3 describes the methods and facilities used for the assays. Section 4 summarizes the results giving the levels of radioactive contamination found in the various materials studied and describes some special techniques or materials that were investigated. Finally, Section 5 provides some conclusions based on these studies.

Numerous other such studies have been done and, in concert with the results here, there is a wealth of information available to help select materials for future projects. Other reports can be found in Refs. [16–24]. Heusser [25] wrote a nice review on low background counting techniques. The results presented in this manuscript will be made available on the online database at radiopurity.org following publication.

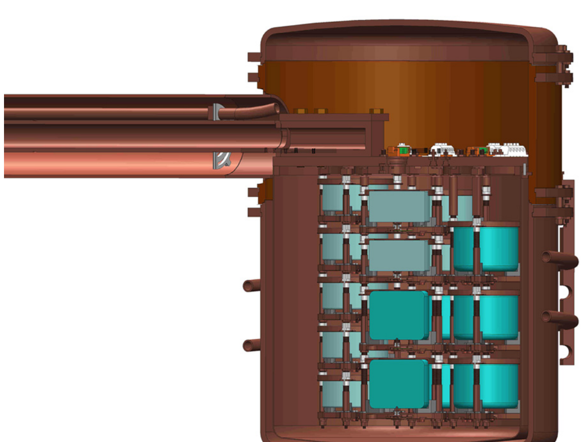

Fig. 1. A cross sectional view of a Majorana Demonstrator cryostat. The strings within each cryostat hold a mixture of natural and enriched germanium detectors.

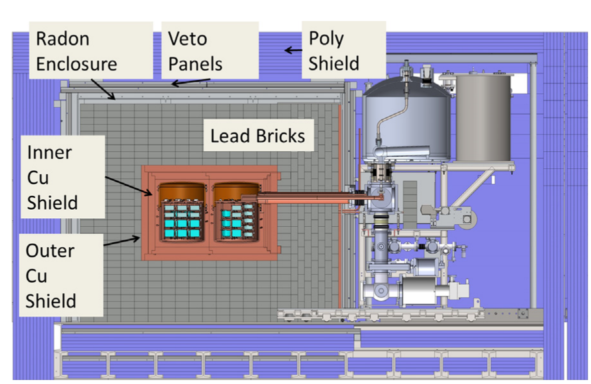

Fig. 2. The Majorana Demonstrator is shown here with both active and passive shielding in place. The outer surface of the inner Cu shield is 50.8 cm in height and 76.2 cm in length.