Nuclear Instruments and Methods in Physics Research A 862 (2017) ■■■–■■■

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Trace radioactive impurities in final construction materials for EXO-200

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http://dx.doi.org/10.1016/j.nima.2017.04.049

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ARTICLE INFO

Article history:
Received 12 April 2017
Accepted 30 April 2017

Keywords:
Radiopurity
Ultra-trace analysis
Neutron activation analysis
Mass spectrometry
Mass spectroscopy
Germanium counting
Alpha counting
Low background
Double beta decay
EXO
EXO-200

ABSTRACT

We report results from a systematic measurement campaign conducted to identify low radioactivity materials for the construction of the EXO-200 double beta decay experiment. Partial results from this campaign have already been reported in a 2008 paper by the EXO collaboration. Here we release the remaining data, collected since 2007, to the public. The data reported were obtained using a variety of analytic techniques. The measurement sensitivities are among the best in the field. Construction of the EXO-200 detector has been concluded, and Phase-I data was taken from 2011 to 2014. The detector's extremely low background implicitly verifies the measurements and the analysis assumptions made during construction and reported in this paper.

1. Introduction

Low energy, low-rate counting experiments such as searches for double beta decay, dark matter, and neutrino oscillations rely on access to construction materials containing the smallest possible amounts of radioactivity. The presence of radioactivity near the detector, even in ultra-trace concentrations, often causes unwanted background, potentially limiting the scientific reach of these experiments. The access to a range of low activity materials is, therefore, enabling science.

Specifically, this work was motivated by the Enriched Xenon Observatory (EXO), a multi-stage experimental research program with the purpose of detecting rare double beta decays of ^{136}Xe [1]. With EXO-200, we search for these decays in an underground cryogenic time-projection chamber (TPC) filled with approximately 110 kg of active liquid xenon enriched to 80% in ^{136}Xe. In Ref. [2] we reported on a campaign of measurements of radioactive impurities in potential construction materials for the purpose of achieving the low background rates required for successful operation. Similar measurement campaigns have been published for rare-event search efforts [3–10]. Here we augment the previously reported measurements with results obtained during the final stages of design and construction of EXO-200. Measurement techniques and conditions were generally the same as those described in Ref. [2]. As in the previous work, the radio-assay campaign described here focuses on natural radioactivity, namely ^{40}K, ^{232}Th and ^{238}U.

EXO-200 started taking data in 2011. The experiment has been described in detail in [11]. The experiment performed the first observation of the two-neutrino double beta decay of ^{136}Xe [12], placed stringent limits on the neutrinoless decay mode [13,14], and reported the most precise determination of any two-neutrino double beta decay rate [15]. The background event rate of $R_b = (1.7 \pm 0.2)\cdot 10^{-3}$ keV^{-1} kg^{-1}yr^{-1} [13,15] observed with the EXO-200 detector, around the double beta decay Q-value of $Q_{\beta\beta} = 2457.83 \pm 0.37$ keV [16], is one of the lowest in its field. A detailed background analysis has been published in Ref. [17]. This analysis compared the data-derived estimates of the activity contents of detector components with those obtained in the radio-assay program. In an alternate approach the radio-assay values were fed into the detector simulation to arrive at expectation values. Detector background predictions which were made before data-taking agree reasonably well with the observed rate. It was further noted that for most components the radio-assay program yielded stronger constraints than the data driven analysis [17]. The EXO-200 detector thus provides some validation of the data, methods and assumptions reported in this work and the previous EXO-200 component radioactivity compilation [2].

The EXO-200 materials analysis effort was structured around a detailed, GEANT 3.21 based Monte Carlo simulation of the experiment. A total background budget of 33 events per year in 110 kg of xenon (after cuts) for events in the energy interval $Q_{\beta\beta} \pm 2\sigma_{\beta\beta}$ was defined [11], where $\sigma_{\beta\beta}$ stands for the energy resolution at the Q-value. A target value of $\sigma_{\beta\beta}/Q_{\beta\beta} = 0.015$ was chosen. Major experiment components, such as the cryostat or the lead shield, were allowed to contribute 10% of the total budget while small components were given a 1% background allowance. This fuzzy scheme allowed material acceptance decisions to be made before all components had been specified and analyzed for their radioactivity content. The background allowance was then translated into a maximally allowable radioactivity content for each component by means of the Monte Carlo model. This allowance determined, in turn, the choice of analysis method. All materials and components used during the EXO-200 construction were subject to this process; no exceptions were made.

The results of the EXO-200 radioactivity screening program are reported as element concentrations, in units of g/g (grams of impurity per gram of sample). Multiplication with conversion factors of $3.17\cdot 10^4$ (Bq/kg)/(g/g) (^{40}K), $4.07\cdot 10^6$ (Bq/kg)/(g/g) (^{232}Th) and