LOW-BACKGROUND COUNTING SYSTEMS COMPARED

H. S. MILEY, R. L. BRODZINSKI, J. H. REEVES

Pacific Northwest Laboratory,* Richland, Washington 99352 (USA)

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A comparison of special low-background germanium counting systems used at the Pacific Northwest Laboratory will be presented. These vary from specially modified instruments in the laboratory to low-cosmic-exposure detectors operated deep underground. The underground detectors have copper cryostats completely electroformed from low-background copper. Electroforming is a process analogous to zone refining in its ability to remove chemical impurities. Shielding techniques and their merit are compared as to difficulty and benefit. Active cosmic veto is directly compared to passive overburden shielding. Special attention is paid to cosmic activation of the cryostat and the germanium crystal itself.

Introduction

In order to build a germanium detector of sufficiently low background to measure the double-beta decay\(^1\) of \(^{76}\text{Ge}\), 7.6% naturally abundant in germanium detectors, the Pacific Northwest Laboratory (PNL) Nuclear Chemistry Department has developed a number of unique low-background germanium gamma-ray spectroscopy systems. These range from laboratory based, cosmic shielded detectors to deep underground, specially constructed detectors. These systems have numerous interesting applications including high-sensitivity radioisotopic counting and exotic physics experiments.

Examples of the exotic experiments done with these detectors include placing limits on the lifetime of the electron,\(^2\) sensitive searches for weakly interacting particles,\(^3\) and the various hypothesized double-beta decay modes in \(^{76}\text{Ge}\) and other isotopes.\(^4\) Each of these experiments has enjoyed the highest signal-to-noise ratio in the raw data of any experiments designed to make the measurement.

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Lessons learned from each generation system have added to improvements of the next, and a number of environmental and other samples have been counted in the systems spun off by this effort. Sample counting on these systems has produced much of the sparse data available in the low-background community concerning the viability of materials for other low-background research efforts. Other sample counting activity has supported scientific experiments such as space exposure activation, agricultural studies, and groundwater research.

The detector production techniques used for these detectors are conceptually simple: eliminate sources of radioactivity within the detector crystal, cryostat, and shield. This is accomplished by screening potential component materials through sensitive radioisotopic counting. Up to thousands of times the quantities of a material expected to be used in a low-background application are analyzed in the best available counting equipment. In this way, the sensitivity of the next generation detector is simulated. An example is vacuum grease. Several entire tubes of silicone low-vapor-pressure grease were counted recently to ensure that milligram quantities would not contribute contamination to future detection systems.

A technique to reduce the amount of radioactivity within a construction material is the copper electroforming process, which works analogous to zone refining by transferring copper across a bath while holding back chemical impurities. Current is passed through CuSO₄ solutions from a copper anode to a specially prepared stainless steel mandrel to produce copper components. These are then stored underground until detector assembly. The use of copper in place of other materials has significantly reduced background levels due to the high chemical purity attainable in copper and due to the fact that copper has no long-lived isotopes.