Development of a low neutron emission calibration source for the GERDA experiment

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Abstract

GERDA is an experiment under construction at the LNGS (Laboratori Nazionali del Gran Sasso, 3500 m.w.e.) in Italy. It will use an array of enriched 32Ge detectors to search for the neutrinoless double-β decay. This requires a minimized and well understood background. To reach a sensitivity of $m < 0.13$ eV in Phase II for example, a background rate of $B \leq 10^{-6}$ cts/(kg y-keV) is required. In addition to the gamma background induced by cosmic rays and natural radioactivity, neutrons from spontaneous fission and (α-n) reactions can provide a considerable contribution. 228Th has been established as a good calibration source candidate for GERDA due to its γ-emission in the region of interest around $Q_{\beta\beta} = 2.04$ MeV. The most interesting line for energy calibration is the 2.6 MeV line and its single escape peak at 2.1 MeV. This work investigates the significance of the (α-n) neutron background coming from a 232Th calibration source due to its intrinsic components under the assumption that the source will be placed permanently in the GERDA-setup. For this scenario a parking position of up to 3.5 m above the detector array during data taking is assumed. For calibration runs, the source will be moved by remote control down to the detector array. First, the neutron rate from a commercial 228Th source was estimated using the software package SOURCES4mv. Subsequently an alternative source production method has been developed and tested in order to minimize the neutron yield.

Commercial 228Th source

Commercially available sources for cryogenic applications consist of a porous ceramic contained inside a sealed stainless steel capsule, with the ceramic saturated with the isotopes. α particles emitted by 228Th interact mainly with low-Z nuclides through (α-n) reactions resulting in a neutron flux. As the ceramic is in direct contact with the radioactivity, it is the most relevant material in terms of neutron production.

Example: 228Th in a NaAlSiO4 ceramic

Assumptions:
- homogeneously distributed
- no impurities involved

<table>
<thead>
<tr>
<th>E (232Th-chain)</th>
<th>NaAlSiO4 ceramic</th>
</tr>
</thead>
<tbody>
<tr>
<td>E (MeV)</td>
<td></td>
</tr>
<tr>
<td>5.2 MeV</td>
<td></td>
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<tr>
<td>8.8 MeV</td>
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</table>

The neutron rate and spectra resulting from (α-n) reactions in a NaAlSiO4 ceramic containing 232Th were calculated with SOURCES4mv. The sum spectrum was implemented in a MC simulation in order to estimate the neutron-induced background in the energy range around $Q_{\beta\beta} = 2.04$ MeV.

SOURCES4mv – neutron rate : 3.8 $\times 10^2$ n/s/kBq
MC - Resulting neutron background : 1.1 $\times 10^5$ cts/(kg y-keV.kBq)
GERDA – total background goal : $B \leq 10^{-6}$ cts/(kg y-keV)

A reduction of the neutron background can be achieved by replacing the ceramic with materials having higher threshold energies for (α-n) reactions. This has been done by chemical and thermal treatment of 232ThCl3 in a 1 M HCl solution resulting in ThO2. The process took place in a crucible made from a ~100μm thick gold foil. Gold, with a threshold energy of ~10 MeV, does not undergo (α-n) reactions in the presence of Th-α radiation and is thus a good matrix material for the ThO2.

Custom 228ThO source

The neutron rate produced by the 228ThO source was measured with a 3He detector located in the LNGS laboratory. The neutrons are thermalized to ~0.03 eV using 12.5 cm of PE between the source and the 3He tube and counted via the energy release of 764 keV in the 3He(n,p)H reaction.

Detector efficiency: $\varepsilon_{3He} = 95\%$
$\varepsilon_{3He}$ = geometrical eff.
$\varepsilon_{3He}$ = n-thermalization eff. in PE.
$\varepsilon_{3He}$ = n-capturing eff. in 3He

Activity loss during chemical and thermal treatment

The activity loss during the treatment of the 232ThCl3 solution has been estimated by comparing the 228Th γ-spectra, taken with a 4x4cm Ge detector to Monte Carlo simulations. The nominal activity of the 232ThCl3 solution was given at 20 kBq, and the best fit between data and Monte Carlo simulations resulted in an activity of 20.2 ± 0.4 kBq.

Before treatment: 228Pb/228Ra = 10.7 ± 0.2
1h after treatment: 228Pb/228Ra = 3 ± 0.1
2 month after treatment: 228Pb/228Ra = 10.4 ± 0.3

Results

The activity loss during the treatment of the 232ThCl3 solution has been estimated by comparing the 228Th γ-spectra, taken with a 4x4cm Ge detector to Monte Carlo simulations. The nominal activity of the 232ThCl3 solution was given at 20 kBq, and the best fit between data and Monte Carlo simulations resulted in an activity of 20.2 ± 0.4 kBq.

20kBq ThO2 source - Neutron measurements

The activity loss during the treatment of the 232ThCl3 solution has been estimated by comparing the 228Th γ-spectra, taken with a 4x4cm Ge detector to Monte Carlo simulations. The nominal activity of the 232ThCl3 solution was given at 20 kBq, and the best fit between data and Monte Carlo simulations resulted in an activity of 20.2 ± 0.4 kBq.

→ no measured activity loss during the treatment of the 232ThCl3 solution.