Cosmogenic Activation of Germanium Detectors in EDELWEISS III


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Background

Rare search event experiment: **small expected rate** and **radioactive background** of most of the material gives **higher rate**

**Very low background environment is needed**

**Background sources:**
- **Cosmic rays** -> deep underground sites and muon veto
- **Natural radioactivity** ($^{238}$U, $^{232}$Th, $^{40}$K) $\gamma$, e$^-$, $\beta$, n, $\alpha$ -> passive/active shielding
- **Intrinsic sources** ($^{222}$Rn, long and medium-lived cosmogenic products of target material)
- Ultimately: **neutrino-nucleus scattering** (solar, atmospheric and supernovae neutrinos)
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It can not be removed once detector is contaminated
Activation at Sea-Level

Decay rate of a radioactive isotope depends on the time of material exposure to the source of radiation ($t_{\text{exp}}$) and on the time the isotopes were allowed to decay without being exposed to cosmic rays ($t_{\text{dec}}$).

\[
\frac{dN}{dt} = P \times \left(1 - e^{-\frac{t_{\text{exp}}}{\tau}}\right) \cdot e^{-\frac{t_{\text{dec}}}{\tau}}
\]

Production rate $P$ of induced isotopes:

\[
P_i = \sum_j N_j \int \phi(E) \sigma_{ij}(E) dE
\]

- $E$ = energy
- $\sigma$ = production cross section
- $\phi$ = cosmic neutron flux
- $N_j$ = number of target nuclear isotope $j$
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Different input cosmic-ray neutron spectra, can lead to a variation in production rates of about 20-30%
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Excitation functions may account for up to a factor of 2 difference in the production rate of \(^{68}\text{Ge}\). The difference increases with the atomic number of the isotope produced.
R308 Analysis

FID Ge crystals: event ID from measurements of ionization and phonon energies

- 280 days July 14 - April 15: **160 days WS data**
- 24 FIDs for coincidence study
- **19/24** FIDs selected with > 2 days
  (13 detectors in production rate interpretation)
- Exposure of **1853 det·days**
- Hourly online **threshold <2 keV**
- Ionization resolution **<400eV**
- Chi-2 selection - pulse template reconstruction
  - Efficiency loss **<1%**
- Fiducial selection
  - Clean sample, no surface leakage
R308 Analysis

FID Ge crystals: event ID from measurements of ionization and phonon energies

Fiducial Event
Surface Event

surface gammas
surface betas

133Ba γ AmBe neutron
R308 Analysis

FID Ge crystals: event ID from measurements of ionization and phonon energies

Heat energy (keV)

Fiducial ionization energy (keV)

\(^{133}\text{Ba}\) \(\gamma\) AmBe neutron

Surface gammas

Surface betas

Heat-only events
- Best energy estimator
- 19 detectors
- 1853 det. days
- ER fiducial selection

Efficiency corrected spectrum
- Fiducial volume cut
- $E_{\text{fid}} > 3.5\sigma$ ionization
- Online trigger threshold
Rejecting multiple events reduces the Compton background by almost a factor of two while having no effect on tritium decays.

- Best energy estimator
- 19 detectors
- 1853 det.days
- ER fiducial selection
- + single selection
- Best energy estimator
- 19 detectors
- 1853 det. days
- ER fiducial selection
- Single selection
- + Tritium β-decay ($Q_\beta = 18.6$ keV)
  + EC decay of isotopes
  + Compton background

**K shell Lines** @ 10.37, 9.66, 8.98, 6.54, 5.99, 4.97 keV

**EDELWEISS**

**Single hits**

**Compton (S):** 0.089±0.002 cts/kg/day/keV

**Tritium:** 0.94±0.06±0.10 cts/kg/day/keV
Single/Coincidence @ 2 keV:
Understanding of global Compton behavior

The multiple-hit spectrum is compatible with the expectation that only the $^{65}\text{Zn}$ and, possibly, $^{54}\text{Mn}$ peaks, are contributing to a flat Compton background below 20 keV.
@ 0.8 keV:
Understanding of
- low-energy
structure down to 1 keV
- efficiency model

L/K ratio = 0.113 ± 0.008 (statistical error only)

The efficiency model is robust for energies above 2.0 keV
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Good correlation history vs decay rate

Strong tension @5.9σ (stat) with previous measurement
Avignone et al.
Agreement < 2σ with ACTIVIA calculation

Model estimates from P=34.4 to P=79 nuclei/kg/day
Cosmogenic Activation of Germanium Detectors in EDELWEISS III

Tritium

Relative error bars of the decay rate are more important

IGEX upper limit in tension with any estimates

Agreement $< 2\sigma$ with ACTIVIA calculations

Model estimates difference up to one order of magnitude

$^3\text{H}$ Decay Rate (nuclei/kg/d)

Saturation Fraction

$P$: $82\pm12\pm18$ nuclei/kg/d
Summary

<table>
<thead>
<tr>
<th></th>
<th>This work</th>
<th>Cebrian (Ziegler)</th>
<th>Barabanov (Gordon)</th>
<th>Mei</th>
<th>Zhang (I)</th>
<th>Klapdor (II)</th>
<th>Avignone</th>
<th>Exp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^3$H</td>
<td>82±21</td>
<td>46$^{(a)}$</td>
<td></td>
<td>27.7</td>
<td>48.3</td>
<td>&lt;21$^{(E)}$</td>
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<td>210</td>
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<tr>
<td>$^{49}$V</td>
<td>2.8±0.6</td>
<td>1.9$^{(a,b)}$</td>
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<tr>
<td>$^{65}$Zn</td>
<td>106±13</td>
<td>38.7$^{(a)}$</td>
<td>77</td>
<td>37.1</td>
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<tr>
<td>$^{55}$Fe</td>
<td>4.6±0.7</td>
<td>3.5$^{(a)}$</td>
<td>6.0</td>
<td>8.6</td>
<td></td>
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<td>8.4</td>
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<tr>
<td>$^{68}$Ge</td>
<td>&gt;71</td>
<td>23.1$^{(a)}$</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>58.4</td>
</tr>
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(a) semi-empirical cross sections
(b) MENDL-2P database cross sections.

(a*) and (b*) ACTIVIA calculations including a potential 10-h flight of Ge powder.

(I) GEANT4 calculations
(II) ACTIVIA calculations
Conclusions

Cosmogenic activation of materials can compromise the sensitivity of ultra-low background experiments via the production of long-lived isotopes at Earth’s surface due to nucleons. Tritium contribution dangerous due to continuum beta decay shape and lifetime of 17.79 year.

First direct measurements of tritium and $^{49}$V, $^{55}$Fe and $^{65}$Zn in germanium also presented. A lower limit of $^{68}$Ge is discussed, too.

Tritium production rate in Ge of $82\pm21$ nuclei/kg/d.

Minimize exposure to cosmic rays, better control of cosmogenic activation.

Production rates of $^3$H, $^{49}$V, $^{55}$Fe, $^{65}$Zn and $^{68}$Ge estimates with ACTIVIA code.

The main sources of uncertainty in the calculations come from difficulties on
- precise evaluation of inclusive production cross-sections
- accurate description of cosmic ray spectra
 -> More measurements might help constraining the model
Thank you!
Data taking acquisition ~1 year

$^{68}\text{Ge}$ and $^{65}\text{Zn}$ half-lives < 3y decay rate not constant
-> rate corrected by $\exp(\text{tau})$

Tritium half life of 17.79 y decay rate constant

In addition for $^{68}\text{Ge}$, 90 days have been excluded in the analysis to avoid $^{71}\text{Ge}$ contamination due to AmBe neutron calibration
Cosmogenic Activation of Germanium Detectors in EDELWEISS III

\[ \tau(3^H) = 17.79 \text{ year} \]

\[ \tau(65\text{Zn}) = 0.96 \text{ year} \]

\[
\frac{dN}{dT} = P \times (1 - e^{-\frac{t_{\text{exp}}}{\tau}}) \times (e^{-\frac{t_{\text{dec}}}{\tau}})
\]

Last value proportional to the rate measured in the detectors

FID844 (standard history)
FID827 (longer texp2)