Background characterization for the GERDA experiment

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on behalf of the GERDA Collaboration

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Outline

- Physics motivation and goals of the GERDA experiment
- Experimental setup and status of Phase-I data taking
- Analysis of Phase-I data:
  - measurement of the $T_{1/2}$ of $2\nu\beta\beta$ decay of $^{76}\text{Ge}$
  - background due to alpha-induced events
  - decomposition of the background spectrum
- Conclusions
Motivation

GERDA experiment is searching for the neutrinoless double beta (0νββ) decay of $^{76}\text{Ge}$.

**Neutrino accompanied double beta decay (2νββ)**

$$(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$$

- SM process, observed
- $T_{1/2} \sim (10^{19} - 10^{24})$ yr
- Rarest decay measured in lab
- Experimental signature: continuous spectrum of the sum of electrons kinetic energies

**Neutrinoless double beta decay (0νββ)**

$$(A, Z) \rightarrow (A, Z+2) + 2e^-$$

- Non SM process: $\Delta L = 2$
- More rare than 2νββ
- Experimental signature: peak at $Q_{\beta\beta}$
GERDA experiment is searching for the neutrinoless double beta (0νββ) decay of $^{76}$Ge.

**Limit:** $T^{0\nu}_{1/2}(^{76}\text{Ge}) > 1.9 \times 10^{25}$ y (90% C.L.) from HdM Collaboration

**Claim:** $T^{0\nu}_{1/2}(^{76}\text{Ge}) = 1.2 \times 10^{25}$ y

**Phase-I:** $T_{1/2} > 2 \times 10^{25}$ y → test the claim

**Phase-II:** $T_{1/2} > 10^{26}$ y

For a higher sensitivity on the $T_{1/2}$

→ larger exposure

→ lower background rate around $Q_{\beta\beta}$

▷ Background characterization & suppression

[Phys. Rev. D 74, 092003 (2006)]
**Experimental setup**

**GERDA @ LNGS of INFN, Italy**

- HPGe detectors directly submerged in LAr
- High-purity shields: LAr, H₂O

- Active muon veto: detection of Cherenkov radiation in water
- Minimal amount of screened material around the detectors

The Gerda experiment for the search of $0\nu\beta\beta$ decay in $^{76}$Ge

[EUR. PHYS. J. C (2013) 73:2330]
Phase-I data-taking

Phase-I started on 9 November 2011 with 3 $^{nat}\text{Ge}$ and 8 $^{enr}\text{Ge}$ (from HdM and IGEX) coax detectors

2 $^{nat}\text{Ge}$ detectors removed, 5 $^{enr}\text{Ge}$ BEGe detectors deployed on July 2012

$^{enr}\text{Ge}$ mass for physics analysis: 14.6 kg (coaxial) and 3.6 kg (BEGe)

**Energy resolution:** FWHM at $Q_{\beta\beta} = 4.5$ keV (mass weighted average for the $^{enr}\text{Ge}$ coax detectors)

**Stability:** energy resolution within $\sim 0.5$ keV, energy scale within $\sim 1$ keV.

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**Picture:**

- **Projected exposure**:
  - Spring 2013: 20 kg·yr exposure → can check the claim
  - Summer 2013: Transition from Phase I to Phase II starts
Phase-I background spectrum

9 November 20 11 – 5 January 2013
Live time: 340.94 days
Detectors: 6 enrGe coax (14.63 kg)
Total exposure: 13.65 kg × yr

Background components:
No contribution at $Q_{\beta\beta}$
$^{39}$Ar ($Q_{\beta} = 565$ keV), $2\nu\beta\beta$, $^{40}$K, $^{228}$Ac

Contribution at $Q_{\beta\beta}$
- $^{42}$K ($^{42}$Ar) → $Q_{\beta} = 3.5$ MeV, $E_\gamma = 2.4$ MeV
- $^{214}$Bi ($^{238}$U) → $Q_{\beta} = 3.3$ MeV,
  $E_\gamma = 2.1, 2.2, 2.4$ MeV
- $^{208}$Tl ($^{232}$Th) → $E_\gamma = 2.6$ MeV
- $^{60}$Co → $Q_{\beta} = 2.8$ MeV
- $\alpha$-induced events (from isotopes in $^{238}$U chain)

Background index in $Q_{\beta\beta} \pm 100$ keV
0.022 cts/(keV kg yr) for 13.6 kg·yr data
excluding 1.30 kg·yr (period following detector substitutions in July):
0.017 cts/(keV kg yr) for 12.3 kg·yr
10x lower than previous experiments (HdM, IGEX)
Phase I: Measurement of the $T_{1/2}$ of $2\nu\beta\beta$ of $^{76}\text{Ge}$

** enrGe coax detectors, total exposure: 5 kg·yr **

$2\nu\beta\beta$ spectrum clearly visible with the first 126 days data

** Binned maximum likelihood fit **

** Fit window: ** 600 – 1800 keV

$\rightarrow$ above $^{39}\text{Ar}$ end-point energy ($Q_\beta = 565$ keV)

$\rightarrow$ in $E>1800$ keV range 0.02% probability of $2\nu\beta\beta$

** Background components:** $^{40}\text{K}$ and $^{214}\text{Bi}$ close source, $^{42}\text{K}$ in LAr

** Fit Parameters:** Active detector masses, enrichment fractions, background contributions, $T_{1/2}$ common parameter

$$T_{1/2}^{2\nu} = (1.84^{+0.09}_{-0.08 \text{ fit}} +0.11_{-0.06 \text{ syst}}) \times 10^{21} \text{ yr} = (1.84^{+0.14}_{-0.10}) \times 10^{21} \text{ yr}$$

<table>
<thead>
<tr>
<th>Item</th>
<th>Uncertainty on $T_{1/2}^{2\nu}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-identified background components</td>
<td>+5.3</td>
</tr>
<tr>
<td>Energy spectra from $^{42}\text{K}$, $^{40}\text{K}$ and $^{214}\text{Bi}$</td>
<td>$\pm 2.1$</td>
</tr>
<tr>
<td>Shape of the $2\nu\beta\beta$ decay spectrum</td>
<td>$\pm 1$</td>
</tr>
<tr>
<td>Subtotal fit model</td>
<td>$+5.8$ $-2.3$</td>
</tr>
<tr>
<td>Precision of the Monte Carlo geometry model</td>
<td>$\pm 1$</td>
</tr>
<tr>
<td>Accuracy of the Monte Carlo tracking</td>
<td>$\pm 2$</td>
</tr>
<tr>
<td>Subtotal Monte Carlo</td>
<td>$\pm 2.2$</td>
</tr>
<tr>
<td>Data acquisition and selection</td>
<td>$\pm 0.5$</td>
</tr>
<tr>
<td>Grand total</td>
<td>$+6.2$ $-3.3$</td>
</tr>
</tbody>
</table>

N. Becerici-Schmidt (MPI for Physics)  
GERDA Phase I
Phase I: Measurement of the $T_{1/2}^{2\nu}$ of $^{76}\text{Ge}$


$$T_{1/2}^{2\nu} = (1.84^{+0.09}_{-0.08 \text{ fit}} ^{+0.11}_{-0.06 \text{ syst}}) \times 10^{21} \text{ yr} = (1.84^{+0.14}_{-0.10}) \times 10^{21} \text{ yr}$$

Signal-to-background ratio in the fit range 4:1
→ uncertainty comparable to previous measurements despite much smaller exposure

Good agreement with reanalysis of HdM data (HdM-K, HdM-B)
Phase I: Analysis of alpha-induced background

Range of alphas with $E \sim 4$ MeV – 9 MeV
→ 14 μm – 41 μm in Ge
→ 34 μm – 113 μm in LAr

Possible origin of alpha-induced events:
→ Separate $^{226}$Ra and $^{210}$Po contaminations on thin dead layer (thinDL) surfaces.

$^{226}$Ra ($E_\alpha = 4.8$ MeV, $T_{1/2} = 1600$ y)

$^{222}$Rn ($E_\alpha = 5.5$ MeV, $T_{1/2} = 3.8$ d)

$^{218}$Po ($E_\alpha = 6.0$ MeV, $T_{1/2} = 183$ s)

$^{214}$Pb ($T_{1/2} = 0.45$ h)

$^{214}$Bi ($T_{1/2} = 0.33$ h)

$^{214}$Po ($E_\alpha = 7.7$ MeV, $T_{1/2} = 164$ μs)

$^{210}$Pb ($T_{1/2} = 22.3$ y)

$^{210}$Bi ($T_{1/2} = 5.01$ d)

$^{210}$Po ($E_\alpha = 5.3$ MeV, $T_{1/2} = 138.4$ d)

$^{206}$Pb (stable)
Phase I: Analysis of alpha-induced background

226Ra ($E_\alpha = 4.8$ MeV, $T_{1/2} = 1600$ y)
222Rn ($E_\alpha = 5.5$ MeV, $T_{1/2} = 3.8$ d)
218Po ($E_\alpha = 6.0$ MeV, $T_{1/2} = 183$ s)
214Pb ($T_{1/2} = 0.45$ h)
214Bi ($T_{1/2} = 0.33$ h)
214Po ($E_\alpha = 7.7$ MeV, $T_{1/2} = 164$ μs)
210Pb ($T_{1/2} = 22.3$ y)
210Bi ($T_{1/2} = 5.01$ d)
210Po ($E_\alpha = 5.3$ MeV, $T_{1/2} = 138.4$ d) (stable)

Expectation →
Exponential ($T_{1/2} = 138.4$ d)
+ constant event rate
Constant event rate
Phase I: Analysis of alpha-induced background

Results from fitting the event rate distributions (details in the backup):

<table>
<thead>
<tr>
<th>C [cts/day]</th>
<th>N₀ [cts/day]</th>
<th>T₁/₂ [days]</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(3.5 MeV &lt; E &lt; 5.3 MeV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>expo</td>
<td>9.26 ± 0.26</td>
<td>138.4 ± 0.2</td>
<td>0.11</td>
</tr>
<tr>
<td>expo + const</td>
<td>9.11 ± 0.44</td>
<td>138.4 ± 0.2</td>
<td>0.87</td>
</tr>
<tr>
<td>(5.3 MeV &lt; E &lt; 7.5 MeV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>const</td>
<td>0.57 ± 0.16</td>
<td>0.09 ± 0.02</td>
<td></td>
</tr>
</tbody>
</table>

Given a strong prior probability on the half life parameter

- \( ^{226}\text{Ra} (E_α = 4.8 \text{ MeV}, T_{1/2} = 1600 \text{ y}) \)
- \( ^{222}\text{Rn} (E_α = 5.5 \text{ MeV}, T_{1/2} = 3.8 \text{ d}) \)
- \( ^{218}\text{Po} (E_α = 6.0 \text{ MeV}, T_{1/2} = 183 \text{ s}) \)
- \( ^{214}\text{Po} (E_α = 7.7 \text{ MeV}, T_{1/2} = 164 \mu\text{s}) \)
- \( ^{214}\text{Pb} (T_{1/2} = 0.45 \text{ h}) \)
- \( ^{214}\text{Bi} (T_{1/2} = 0.33 \text{ h}) \)
- \( ^{210}\text{Pb} (T_{1/2} = 22.3 \text{ y}) \)
- \( ^{210}\text{Bi} (T_{1/2} = 5.01 \text{ d}) \)
- \( ^{210}\text{Po} (E_α = 5.3 \text{ MeV}, T_{1/2} = 138.4 \text{ d}) \)
- \( ^{206}\text{Pb} \text{ (stable)} \)
Phase I: Analysis of alpha-induced background

MC simulations to model the energy spectrum:

1) $^{210}\text{Po}$ on thinDL surface
2) $^{226}\text{Ra}$ & daughters on thinDL surface
3) $^{222}\text{Rn}$ & daughters in LAr close to thinDL surfaces

thinDL thickness: 300 ... 600 nm

$^{226}\text{Ra}$ ($E_\alpha = 4.8$ MeV, $T_{1/2} = 1600\text{ y}$)
$^{222}\text{Rn}$ ($E_\alpha = 5.5$ MeV, $T_{1/2} = 3.8\text{ d}$)
$^{218}\text{Po}$ ($E_\alpha = 6.0$ MeV, $T_{1/2} = 183\text{ s}$)
$^{214}\text{Pb}$ ($T_{1/2} = 0.45\text{ h}$)
$^{214}\text{Bi}$ ($T_{1/2} = 0.33\text{ h}$)
$^{214}\text{Po}$ ($E_\alpha = 7.7$ MeV, $T_{1/2} = 164\text{ \mu s}$)
$^{210}\text{Pb}$ ($T_{1/2} = 22.3\text{ y}$)
$^{210}\text{Bi}$ ($T_{1/2} = 5.01\text{ d}$)
$^{210}\text{Po}$ ($E_\alpha = 5.3$ MeV, $T_{1/2} = 138.4\text{ d}$)
$^{206}\text{Pb}$ (stable)
Phase I: Analysis of alpha-induced background

\( ^{enr}\text{Ge coaxials, exposure: } 13.65 \text{ kg}\cdot\text{yr} \)

**Binned maximum likelihood fit**

Fit window: 3500 – 7500 keV  
*p-value*: 0.7

Note: the model explains the \( \alpha \)-induced events in \( \text{natGe} \) detectors as well (backup)

Colored probability intervals:  
Phase I: Analysis of alpha-induced background

Extrapolation of the alpha-induced event model to ROI (160 keV):
(1939 – 2019) plus (2059 – 2139) keV

Extrapolation of the alpha-induced event model to ROI (160 keV):
(1939 – 2019) plus (2059 – 2139) keV


\[ \text{enr} Ge \text{ coaxials, exposure: 13.65 kg\cdot yr} \]

Binned maximum likelihood fit

Fit window: 3500 – 7500 keV

p-value: 0.7

Note: the model explains the \( \alpha \)-induced events in \( \text{nat} Ge \) detectors as well (backup)
**Phase I: Analysis of alpha-induced background**

**Extrapolation of the alpha-induced event model to ROI (160 keV):**

(1939 – 2019) plus (2059 – 2139) keV

- Data: 49 events
- Alpha model: $4.55^{+1.25}_{-0.95}$ events
- ~ 9% contribution from alphas

**Binned maximum likelihood fit**

**Fit window:** 3500 – 7500 keV

**p-value:** 0.7

Note: the model explains the $\alpha$-induced events in natGe detectors as well (backup)
Binned maximum posterior fit to the sum $^{\text{enr}}\text{Ge}$ coax spectrum in (570 – 7500) keV window

- fit window enlarged to include $Q_{\beta\beta}$
- background components considered in the global fit:
  - $\rightarrow$ K-42, K-40, Bi-214, Ac-228 & Th228 (beta- / gamma-induced events)
  - and alpha-induced event model
- p-value of the fit: 0.3

Work in progress: analysis with more background components, various source positions, different data sets is ongoing. Systematics under investigation.

Preliminary: Dominant background contributions around $Q_{\beta\beta}$

$\rightarrow$ K-42, Bi-214, TI-208 and alphas
GERDA Phase I started in Nov 2011 – ongoing.

Phase I background an order of magnitude lower than HdM, IGEX.

Measurement of $T_{1/2}$ of $2\nu\beta\beta$ with the first 5 kg·yr ($s:b = 4:1$)

\[
T_{1/2}^{2\nu} = \left(1.84^{+0.09}_{-0.08 \text{ fit}}^{+0.11}_{-0.06 \text{ syst}}\right) \times 10^{21} \text{yr} = \left(1.84^{+0.14}_{-0.10}\right) \times 10^{21} \text{yr}
\]

Blind analysis: 40 keV window around $Q_{\beta\beta} = 2039$ keV is blinded.

- unblinding: after 20 kg·yr exposure collected (Spring 2013)

Model the background energy spectrum before unblinding: Promising “preliminary” results!

- for the upcoming $0\nu\beta\beta$ analysis: expected number of background events, shape of the background spectrum around $Q_{\beta\beta}$

- for Phase II: understand the background sources in Phase I & mitigate it further
Backup
Phase-I data-taking

enriched coxials, 13.65 kg × yr
natural coxials, 4.69 kg × yr

scaled to exposure of enr. coxial

energy (keV)

counts/(5 keV)

$^{39}$Ar $\beta^-$
$2\nu\beta$
K-40 1461 keV
K-42 1525 keV
Bi-214 1765 keV
Bi-214 2204 keV
Tl-208 2614 keV

$\alpha$
Phase-I data-taking

enriched coaxials, 13.65 kg \times yr

enriched BEGes, 1.51 kg \times yr

scaled to exposure of enr. coax

\[ {^39}\text{Ar} \beta^- \]

\[ 2\nu\beta \]

K-40 1461 keV

K-42 1525 keV

Bi-214 1765 keV

Bi-214 2204 keV

TI-208 2614 keV

\[ \alpha \]

counts/(5 keV)
Phase-I data-taking

enriched coaxials, \(13.65 \text{ kg} \times \text{yr}\)

natural coaxials, \(4.69 \text{ kg} \times \text{yr}\)

enriched BEGes, \(1.51 \text{ kg} \times \text{yr}\)

scaled to exposure of enr. coaxial

\(\alpha\)

counts/(50 keV)

energy (keV)

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Phase-I data-taking

energy resolution for $^{228}$Th @ 2614.5 keV

Resolution (FWHM) vs. Time
Phase-I data-taking

GERDA Phase I

N. Becerici-Schmidt (MPI for Physics)

GERDA 12-11

![Graph showing the shift of 2614.5 keV peak over time with markers for different detectors. The graph includes data from November 2021 to June 2019, with horizontal lines indicating ±1.3 keV.]
Analysis of event rate distributions:

- Fit the distribution with an exponential function:
  \[ N(t) = N_0 \cdot e^{-ln2 \cdot t/T_{1/2}} \]

- Maximized quantity posterior probability:
  \[ P(\tilde{\lambda}|\tilde{n}) \propto P(\tilde{n}|\tilde{\lambda})P_0(\tilde{\lambda}) \]

- Set a prior on the half life parameter:
  \[ P_0(T_{1/2}) = \text{Gaus}(138.4 \text{ days, } 0.2 \text{ days}) \]
  half-life of $^{210}\text{Po}$

- Likelihood:
  \[ P(\tilde{n}|\tilde{\lambda}) = \prod_i P(n_i|\lambda_i) = \prod_i \frac{e^{-\lambda_i} \lambda_i^{n_i}}{n_i!} \]
  \(n_i\): raw number of counts in i-th bin
  (not scaled, not corrected for live time fraction,
  \(\lambda_i\): expectation in the i-th bin
  corrected with the live time fraction in that bin

\[ \lambda_i = \epsilon_i \int_{(i-1)\Delta t}^{i\Delta t} N_0 \cdot e^{-ln2 \cdot t/T_{1/2}} \, dt \]
Event rate distribution of events with $3500 \text{ keV} < E < 5300 \text{ keV}$ in sum $\text{enrGe-coax}$

**Model:** exponentially decaying event rate

**Parameters:**

$N_0 = (9.26 \pm 0.26) \text{ cts/day}$

$T_{1/2} = (138.4 \pm 0.2) \text{ days}$

**p-value of the fit:** 0.11

**Expectation**

$$\lambda_i = \epsilon_i \int_{(i-1)\Delta t}^{i\Delta t} N_0 \cdot e^{-\ln 2 t/T_{1/2}} \, dt$$

$$P(\vec{n} | \vec{\lambda}) = \prod_i P(n_i | \lambda_i) = \prod_i \frac{e^{-\lambda_i} \lambda_i^{n_i}}{n_i!}$$
Event rate distribution of events with $3500 \text{ keV} < E < 5300 \text{ keV}$ in sum $^{\text{enr}}$Ge-coax

Model: exponential + constant rate

Parameters:

$C = (0.57 \pm 0.16) \text{ cts/day}$

$N_0 = (7.91 \pm 0.44) \text{ cts/day}$

$T_{1/2} = (138.4 \pm 0.2) \text{ days}$

$p$-value of the fit: 0.87
Parameters:

\[ C = (0.09 \pm 0.02) \text{ cts/day} \]

p-value of the fit: 0.86
Simulated energy spectrum of different model components

- $^{210}$Po on thinDL surface
- $^{222}$Rn & daughters in LAr close to thinDL surface

Binned maximum posterior fit to the sum $^{enr}$Ge-coax spectrum in (3500 – 7500) keV window

Maximized the posterior probability using Markov Chain Monte Carlo in Bayesian Analysis Toolkit BAT:

\[ [A. \text{Caldwell et. al., Comput. Phys. Commun. 180, 2197 (2009)}] \]

Posterior probability:

\[ P(\tilde{\lambda} | \tilde{n}) \propto P(\tilde{n} | \tilde{\lambda}) P_{0}(\tilde{\lambda}) \]

Likelihood:

\[ P(\tilde{n} | \tilde{\lambda}) = \prod_{i} P(n_{i} | \lambda_{i}) = \prod_{i} \frac{e^{-\lambda_{i}} \lambda_{i}^{n_{i}}}{n_{i}!} \]

\( n_{i} \) number of observed, \( \lambda_{i} \) number of expected events in i-th bin

\[ \lambda_{i} = \sum \lambda_{i,M} \rightarrow \text{sum contribution of each model component M} \]

\[ \lambda_{i,M} = N_{M} \int_{\Delta E_{i}} f_{M}(E) dE \]

scaling parameter for the component M

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Phase I: Analysis of alpha-induced background

sumEnrCoax, all runs  fit window: (3500 – 7500) keV  p-value: 0.72

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mode (smallest int.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Po-210 sur</td>
<td>1205 (1160, 1240)</td>
</tr>
<tr>
<td>Ra-226 sur</td>
<td>39.5 (30.0, 55.0)</td>
</tr>
<tr>
<td>Rn-222 sur</td>
<td>20.5 (14.0, 28.0)</td>
</tr>
<tr>
<td>Po-218 sur</td>
<td>11.5 (7.0, 16.0)</td>
</tr>
<tr>
<td>Rn-222 in LAr</td>
<td>40.5 (26.0, 61.0)</td>
</tr>
<tr>
<td>Po-218 in LAr</td>
<td>22.5 (14.0, 38.0)</td>
</tr>
<tr>
<td>Po-214 in LAr</td>
<td>14.5 (9.0, 21.0)</td>
</tr>
</tbody>
</table>

Ra-226 on p+ surface:
A = 81.3/340.96/24/3600
A = 3 μBq

<table>
<thead>
<tr>
<th></th>
<th>BI [10^{-3} cts/(keV kg yr)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>alpha model</td>
<td>2.85 (2.3, 3.4)</td>
</tr>
<tr>
<td>Po-210 on surface</td>
<td>0.67 (0.64, 0.70)</td>
</tr>
<tr>
<td>Ra-226 &amp; daughters on surface</td>
<td>0.045 (0.03, 0.06)</td>
</tr>
<tr>
<td>Rn-222 &amp; daughters in LAr</td>
<td>2.15 (1.6, 2.7)</td>
</tr>
</tbody>
</table>
Phase I: Analysis of alpha-induced background

GTF112, golden data set fit window: (3500 – 7500) keV  \( p \)-value: 0.89

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mode (smallest int.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Po-210 sur</td>
<td>55.0 (40, 70)</td>
</tr>
<tr>
<td>Ra-226 sur</td>
<td>18.5 (13, 26)</td>
</tr>
<tr>
<td>Rn-222 sur</td>
<td>10.5 (6, 15)</td>
</tr>
<tr>
<td>Po-218 sur</td>
<td>9.5 (6, 14)</td>
</tr>
<tr>
<td>Rn-222 in LAr</td>
<td>17.5 (9, 25)</td>
</tr>
<tr>
<td>Po-218 in LAr</td>
<td>15.5 (9, 24)</td>
</tr>
<tr>
<td>Po-214 in LAr</td>
<td>15.5 (10, 22)</td>
</tr>
</tbody>
</table>

Ra-226 on p+ surface: 
\[ A = \frac{38}{308.37/24/3600} \]
\[ A = 1.4 \ \mu\text{Bq} \]

BI [10^{-3} cts/(keV kg yr)]

<table>
<thead>
<tr>
<th>Model</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>alpha model</td>
<td>6.4 (5.1, 7.9)</td>
</tr>
<tr>
<td>Po-210 on surface</td>
<td>0.17 (0.13, 0.20)</td>
</tr>
<tr>
<td>Ra-226 &amp; daughters on surface</td>
<td>0.16 (0.12, 0.20)</td>
</tr>
<tr>
<td>Rn-222 &amp; daughters in LAr</td>
<td>6.1 (4.7, 7.5)</td>
</tr>
</tbody>
</table>