Electron Capture Spectroscopy and Isotope Production: Research Toward A Neutrino Mass Measurement


Los Alamos National Laboratory

J. Hayes-Wehle, R.D. Horansky, V. Kotsubo,

D.R. Schmidt, J.N. Ullom NIST

National Institute of Standards and Technology
Neutrino Mass via Endpoint Spectroscopy

Anti Neutrino via Beta Decay of Tritium

Neutrino via Electron Capture of $^{163}\text{Ho}$

Large Spectrometer - KATRIN

Transition Edge Sensor in a Cryostat
**163Ho Endpoint and Neutrino Mass Sensitivity (Simulation)**

- Endpoint simulation for $10^{14}$ decays and a spectral resolution of 1 eV

![Graphs showing 1 Bq for 1 day and 10 Bq for 1 month](image)

Neutrino mass sensitivity for Q-2.8 KeV (green line)
### 163Ho Isotope Production

**J. W. Engle et al., NIM B, 311 (2013) 131-138**

<table>
<thead>
<tr>
<th>Incident Particle</th>
<th>Target</th>
<th>$^{163}$Ho Production Rate (atoms/hr)</th>
<th>$^{166m}$Ho Production Rate (atoms/hr)</th>
<th>$^{163}$Ho/$^{166m}$Ho Atom Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) 16 MeV $p^+$</td>
<td>nat Dy</td>
<td>$10^{14}$</td>
<td>$10^{4-5}$</td>
<td>$10^{9-10}$</td>
</tr>
<tr>
<td>(b) 24 MeV $p^+$</td>
<td>nat Dy</td>
<td>$10^{15}$</td>
<td>$10^{0-9}$</td>
<td>$10^{0-9}$</td>
</tr>
<tr>
<td>(c) 40 MeV $\alpha$</td>
<td>nat Dy</td>
<td>$10^{14}$</td>
<td>$10^7$</td>
<td>$10^5$</td>
</tr>
<tr>
<td>(c) 40 MeV $\alpha$</td>
<td>$^{161}$Dy</td>
<td>$10^{10}$</td>
<td>$10^4$</td>
<td>$10^7$</td>
</tr>
<tr>
<td>(d) $10^{14}$ $\alpha$</td>
<td>$^{162}$Er</td>
<td>$10^{13-15}$</td>
<td>$10^{10-12}$</td>
<td>$10^{5-7}$</td>
</tr>
<tr>
<td>neutron/cm²/sec</td>
<td></td>
<td>(per mg $^{162}$Er)</td>
<td></td>
<td></td>
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</tbody>
</table>

- Proton irradiation of Dy or neutron irradiation of Er
- Greater radio-isotopic purity is achievable using charged particle irradiations
Isotope Separation

- Chemical separation to isolate $^{163}$Ho from irradiated dysprosium target

- High performance liquid chromatography (HPLC)
  - Cation exchange resin
  - $\alpha$-HIBA as eluent
  - UV-Vis detection
  - Post column detection reagent 4-(2-pyridylazo)resorcinol
Transition Edge Sensor for Measurement

- Superconducting film biased with a constant voltage in the transition region between its normal and superconducting states

- Current flowing through film changes flux in inductively coupled SQUID to produce voltage signal.

\[ \Delta E \sim (k_bT^2C)^{1/2} \]
Cryostat and Dedicated Electron Capture TES

- Pulse Tube Cryostat
- Detectors at 90 mK
- EC - TES (350x350 um)
- Total C ~ 1pJ/k
Absorber (Deposition and Diffusion Bonding)

- Electroplating: metallic, thin, uniform deposition
- Pressure (deform Au)
- Heat (400°C)
- Time (1 hr)
- Inert atmosphere
  - Avoid oxidation of embedded material

Electroplated LANL-made $^{55}$Fe

Electroplated commercial $^{55}$Fe
Electron Capture Spectroscopy of embedded $^{55}$Fe

- Electroplated $^{55}$Fe in diffusion bonded Au
- Absorber C $\sim 0.17$ pJ/K, 33x45x18 µm, diffusion bonded to TES structure
- Total C $\sim 1$ pJ/K
- 9.0+-0.2 eV Resolution

Counts are per 1.00 eV bins
SUMMARY

- Isotope Production via Proton Irradiation
- Isotope Separation via HPLC
- Transition Edge Detector with SQUID readout in Cryostat
- Dedicated Electron Capture TES with total C of ~1 pJ/K
- First test with surrogate EC uses $^{55}\text{Fe}$
- Resolution obtained better that 10 eV

Outlook
- First measurement with $^{163}\text{Ho}$ planned for this year
- Increase channel count by RF multiplexing