Efficacy of Boron-Coated Straws for Replacing $^3$He Neutron Detectors

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Neutron Detection of Radiological Materials

- Radiation portal monitors are employed to detect the trafficking of illicit radiological materials.

- Gamma ray signatures can be hampered by high level and variable natural background, impact of cargo on background environment surrounding the detector.

- Natural neutron background is much lower, shielding characteristics are different.

• Large cross-section for capture of thermal neutrons (0.025 eV):

  \[ n + ^3\text{He} \rightarrow ^3\text{H} + p + 0.765 \text{ MeV} \text{ (5400 barn)} \]

• Negligible sensitivity to gamma radiation.

• \(^3\text{He}\) proportional counters are mechanically stable in many environments, operationally stable over many years of use.

• Wide variety of uses.

3He Supply Problem

- Helium-3 is a by-product from beta-decay of tritium.
- Helium-3 is extracted from nuclear weapon stockpiles to maintain tritium concentrations (primary source).
- Reduced nuclear weapon stockpiles, and increased use of 3He has created a supply problem.
- Alternative neutron detection technology must be sought.
Boron-Lined Neutron Detection

• Based on thermal neutron capture by $^{10}\text{B}$ (3840 barn):

$$\text{n} + ^{10}\text{B} \rightarrow ^7\text{Li}^* + \alpha + 2.3 \text{ MeV (94%)}$$
$$\rightarrow ^7\text{Li} + \alpha + 2.8 \text{ MeV (6%)}$$

• Individual straws are lined with $^{10}\text{B}$-enriched $\text{B}_4\text{C}$

• Charged $\alpha$ and $^7\text{Li}$ particles are detected in a proportional gas chamber
Comparison of Boron-Coated Straws with $^3$He Detector

Three key parameters:

- Absolute neutron detection efficiency ($\varepsilon_{\text{abs } n}$),

- Intrinsic efficiency of gamma rays detected as neutrons (gamma insensitivity) ($\varepsilon_{\text{int } \gamma}$), and

- Gamma Absolute Rejection Ratio in the presence of neutrons (GARRn).

Helium-3 detector

Boron-10 detector
Neutron Detection Efficiency Tests

- Exposing to calibrated $^{252}\text{Cf}$ source
- Separate direct component of neutron counts from scattered component through shadow cone method
- Quantify efficiency in cps/ng of $^{252}\text{Cf}$ at a fixed source-detector distance
- Radiation portal monitor standard is 2.5 cps/ng $^{252}\text{Cf}$ at 2 m distance.
Neutron Detection Efficiency Test Results

- Full, proper shadowing was only possible at 4 m.
- Estimate 2 m result through $1/r^2$ scaling from 4 m

<table>
<thead>
<tr>
<th>Source-Detector Distance (m)</th>
<th>Moderator Configuration</th>
<th>$^{252}\text{Cf}$ mass (ng)</th>
<th>cps without Shadow (Total)</th>
<th>cps with Shadow (Scattered)</th>
<th>Difference (Direct)</th>
<th>Detection Efficiency (cps/ng)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1” front + 2” other sides</td>
<td>35,512</td>
<td>19,880</td>
<td>13,977</td>
<td>5,903</td>
<td>0.17</td>
</tr>
<tr>
<td>4</td>
<td>2” all sides</td>
<td>36,389</td>
<td>18,399</td>
<td>11,445</td>
<td>6,954</td>
<td>0.19</td>
</tr>
</tbody>
</table>

- Result, corrected for moderation: **0.84 cps/ng $^{252}\text{Cf}$**
- Helium-3 detector specification: 22% efficiency per thermal neutron
- Boron-10 detector: ~6% efficiency per thermal neutron
Gamma Insensitivity Tests

- Exposure to a $^{192}$Ir source (0.38 MeV average energy)
- Create different gamma-ray exposure fields with varying source-detector distances
- Gamma insensitivity is the ratio of measured detector count rate to predicted total photon rate of incidence.
Gamma Insensitivity Test Results

![Graph showing Gamma Dose Rate in Dry Air (mGy/hr) vs. Gamma Exposure Rate (mR/hr)]

- **B10**
- **He3**
Gamma Absolute Rejection Ratio Tests

- Simultaneous exposure to $^{252}\text{Cf}$ and $^{192}\text{Ir}$ sources.
- Create different gamma-ray exposure fields with varying source-detector distances; neutron source-detector distance at 2 m and 4 m.
- Dividing counts with both sources exposed by the counts with only the $^{252}\text{Cf}$ source exposed.
Gamma Absolute Rejection Ratio
Test Results

- Acceptance criteria: $0.9 < \text{GARR}_n < 1.1$

![Graph showing Gamma Dose Rate in Dry Air (mGy/hr) vs. Gamma Exposure Rate (mR/hr) with markers for 4 m and 2 m distances.](image-url)
Conclusions

• Test results were evaluated in comparison with criteria standards for radiation portal monitors.

• The present configuration performs a factor of 3 less than the minimum neutron sensitivity requirement.

• For insensitivity to gamma radiation, the BCS detector surpasses the minimum requirement, as well as a comparable $^3$He detector by a factor of 2 or more, depending on gamma exposure level.

• Gamma exposure was also demonstrated to have negligible impact on neutron counting.
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