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.

Kouzes et al., *Nuclear Instruments and Methods in Physics Research A*, **584**, 383-400 (2008)

^{3}He Detectors: A Gold Standard for Neutron Detection

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

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

- Negligible sensitivity to gamma radiation.
- ^{3}He proportional counters are mechanically stable in many environments, operationally stable over many years of use.
- Wide variety of uses.

Kouzes et al., *Nuclear Instruments and Methods in Physics Research A*, **623** 1035-1045 (2010)

^{3}He Supply Problem

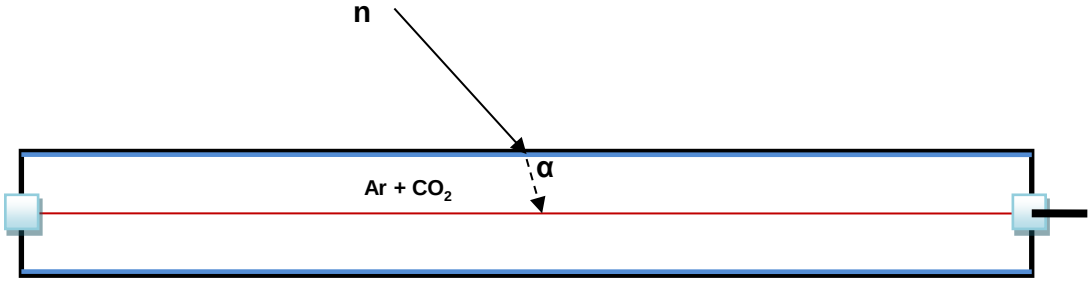
- Helium-3 is a by-product from beta-decay of tritium.
- Helium-3 is extracted from nuclear weapon stockpiles to maintain tritium concentrations (primary source).
- Reduced nuclear weapon stockpiles, and increased use of ^{3}He has created a supply problem.
- Alternative neutron detection technology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

Boron-Lined Neutron Detection

- Based on thermal neutron capture by ^{10}B (3840 barn):

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

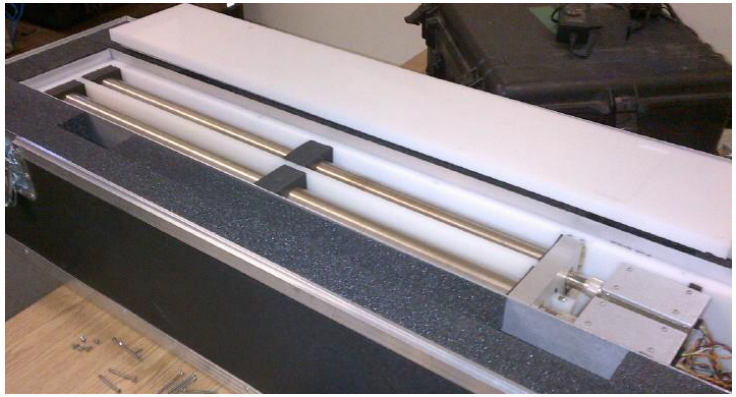
- Individual straws are lined with ^{10}B-enriched B_4C
- Charged α and ^{7}Li particles are detected in a proportional gas chamber



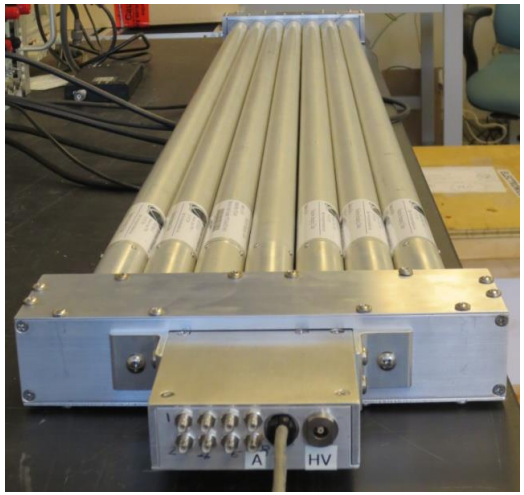
Comparison of Boron-Coated Straws with ^{3}He Detector

Three key parameters:

- Absolute neutron detection efficiency ($\varepsilon_{abs\ n}$),
- Intrinsic efficiency of gamma rays detected as neutrons (gamma insensitivity) ($\varepsilon_{int\ \gamma}$), and
- Gamma Absolute Rejection Ratio in the presence of neutrons (GARRn).



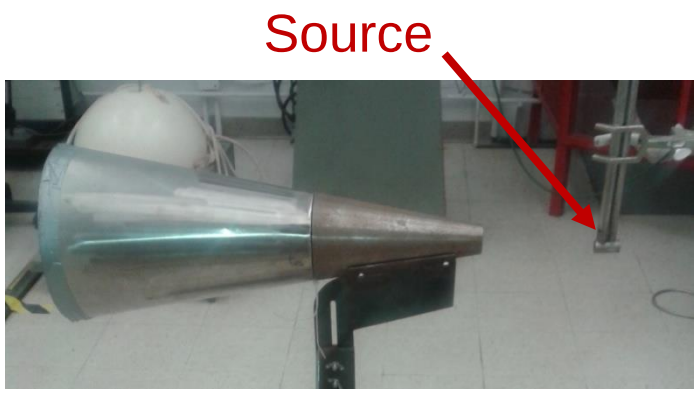
Helium-3 detector



Boron-10 detector

Neutron Detection Efficiency Tests

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



Neutron Detection Efficiency Test Results

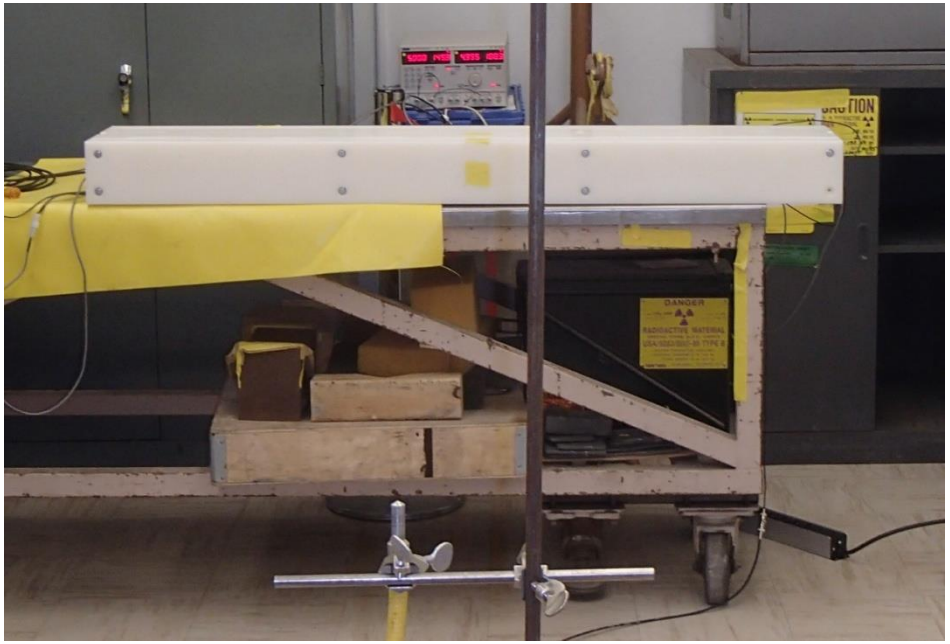
- Full, proper shadowing was only possible at 4 m.
- Estimate 2 m result through $1/r^2$ scaling from 4 m

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

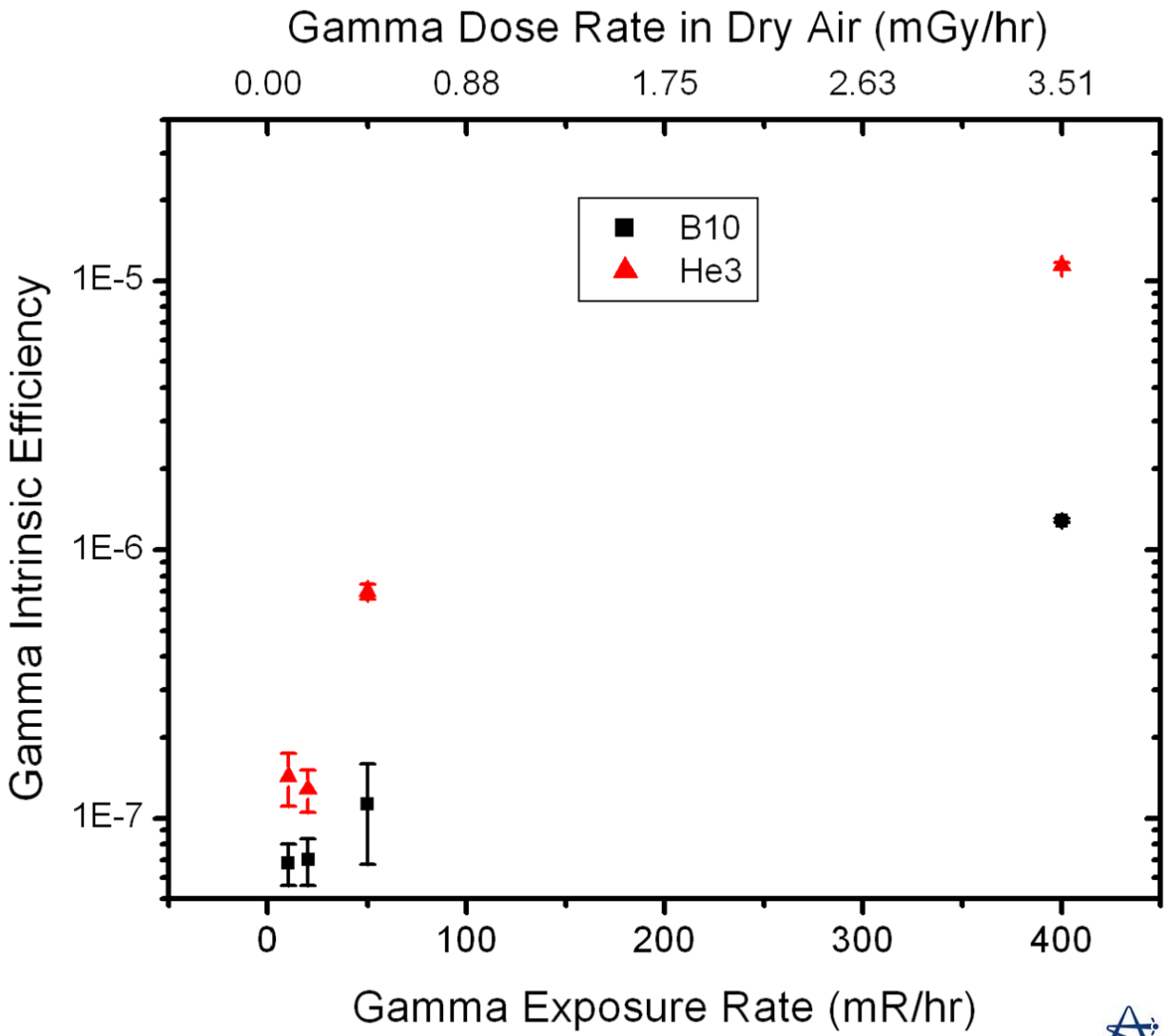
- Result, corrected for moderation: **0.84 cps/ng ^{252}Cf**
- Helium-3 detector specification: 22% efficiency per thermal neutron
- Boron-10 detector: ~6% efficiency per thermal neutron

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.

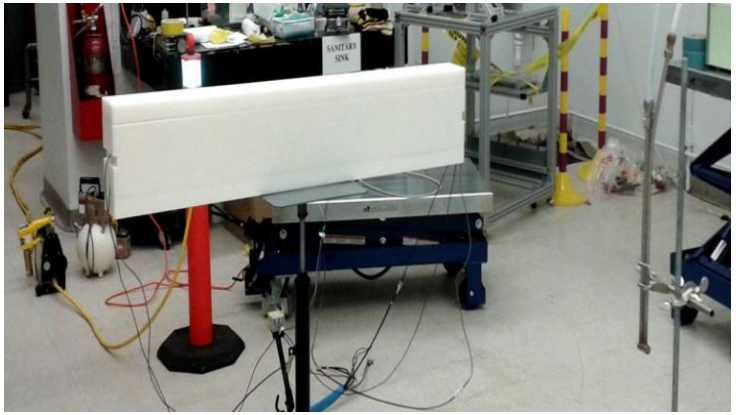


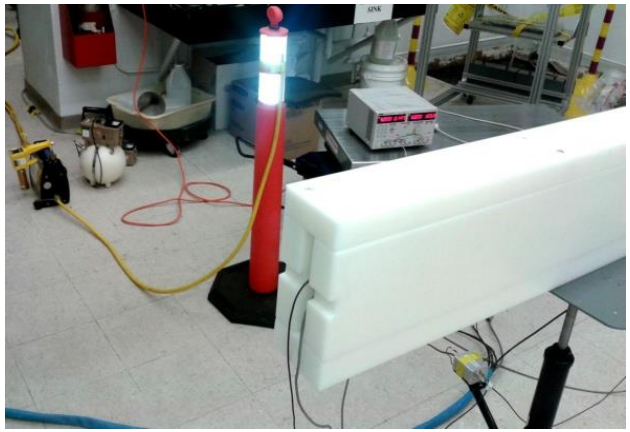
Gamma Insensitivity Test Results



Gamma Absolute Rejection Ratio Tests

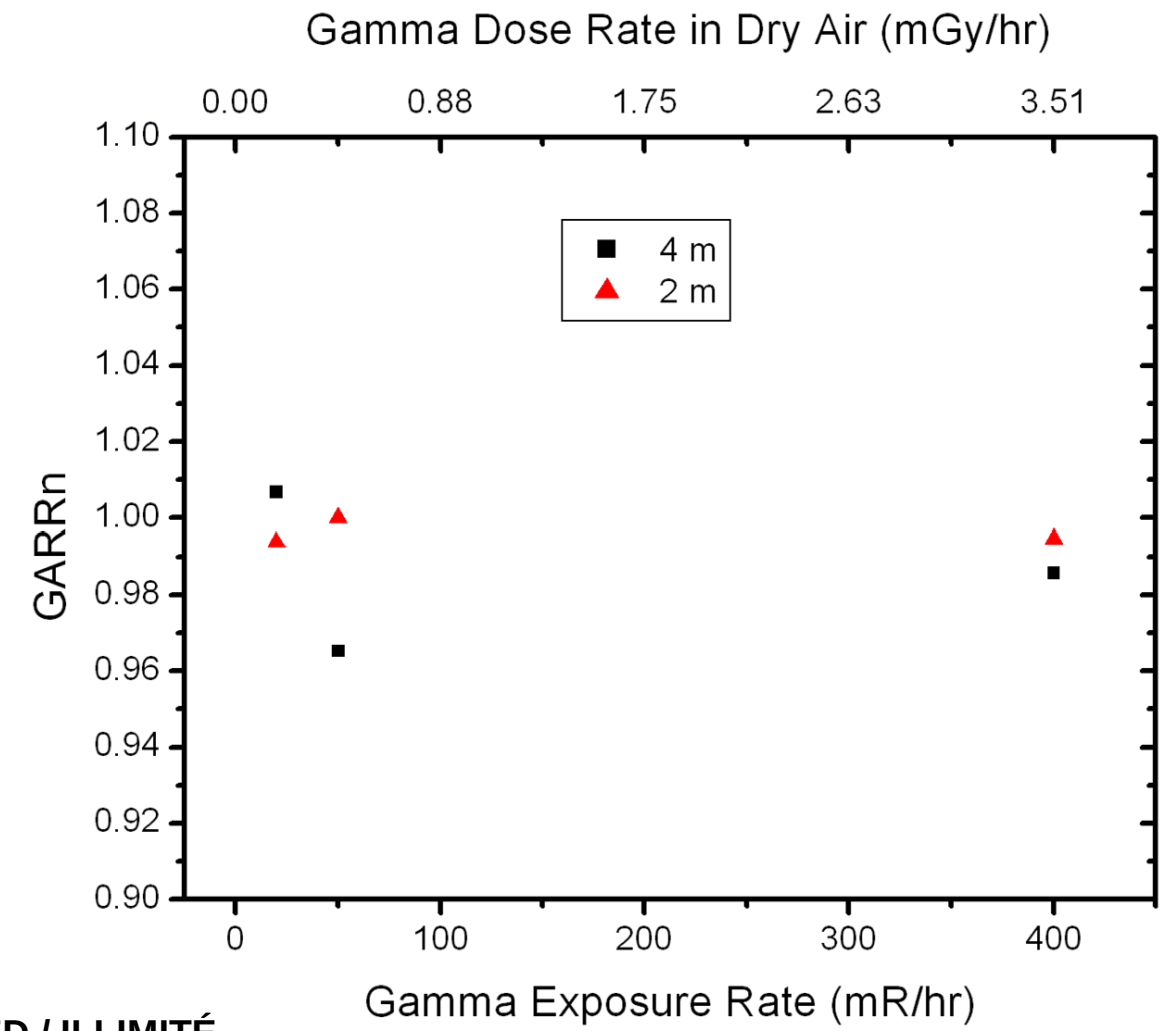
- Simultaneous exposure to ^{252}Cf and ^{192}Ir sources.
- Create different gamma-ray exposure fields with varying source-detector distances; neutron source-detector distance at 2 m and 4 m.
- Dividing counts with both sources exposed by the counts with only the ^{252}Cf source exposed.





Gamma Absolute Rejection Ratio Test Results

- Acceptance criteria: 0.9 < GARRn < 1.1



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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