A TENA Based Interrogation Setup for the Detection of SNM Utilising ^{4}He Scintillation Detectors

AWE NUCLEAR SECURITY TECHNOLOGIES

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This work presents initial steps toward assessing the feasibility of using high-pressure helium-4 (He-4) scintillation detectors in an active-interrogation system utilising the Threshold Energy Neutron Analysis (TENA)[1][2] technique for the detection of special nuclear materials (SNMs). The proposed setup consists of a deuterium–deuterium (DD) based Inertial Electrostatic Confinement (IECF) fusor as the interrogation source, arrays of Arktis S670 He-4 detectors, and the detection of neutrons with energies higher than the probing source (~2.45 MeV), which serves as a robust indicator of the presence of SNM.

Background

Special Nuclear Material (SNM) refers to **plutonium** and materials enriched in fissile uranium isotopes (^{235}U, ^{233}U)[3]

Active interrogation techniques rely on inducing **secondary emissions** that can act as a clear detection signature, driving interest in novel portable detection capabilities. [4] This can provide an increased effectiveness compared to a **passive system** were the **SNM shielded or concealed.**

Figure 1: Images of the uranium oxide seizures from Rousse, Bulgaria (1999)[6]

Commonly used performance standards (e.g. **ANSI N42.41-2021**) are aligned with the IAEA "Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities" requiring **active interrogation** systems to be capable of detecting **2 kg of fissile material (SNM). [5]**

Detection Technique

Threshold Energy Neutron Analysis (TENA) utilises a deuterium –deuterium **(DD)** fusor to generate neutrons through:

$$D^+ + D^+ \rightarrow \mathrm{He} + \mathrm{n}(2.45\ \mathrm{MeV})$$

The neutrons are used to interrogate a cargo, inducing fission in the presence of any potential **SNM**.

A typical detection setup is shown in Fig.2

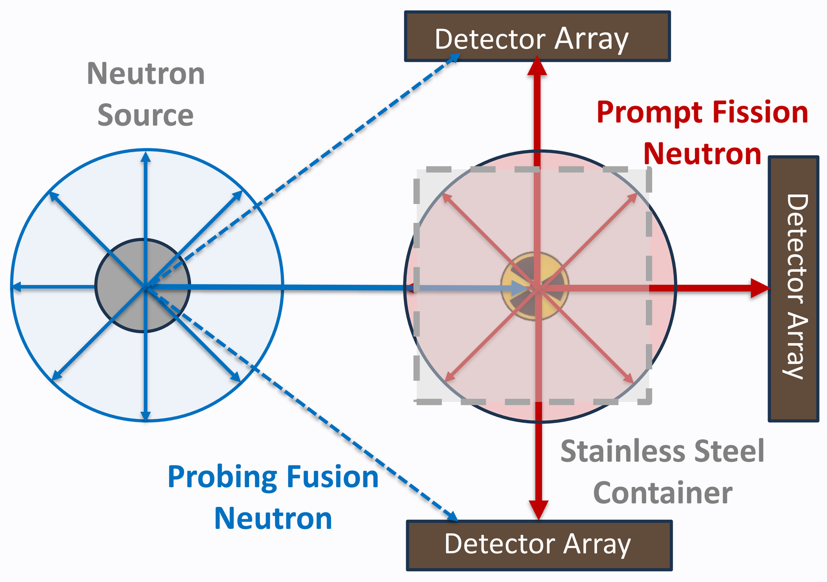

Figure 2: Diagram of Typical Experimental Setup

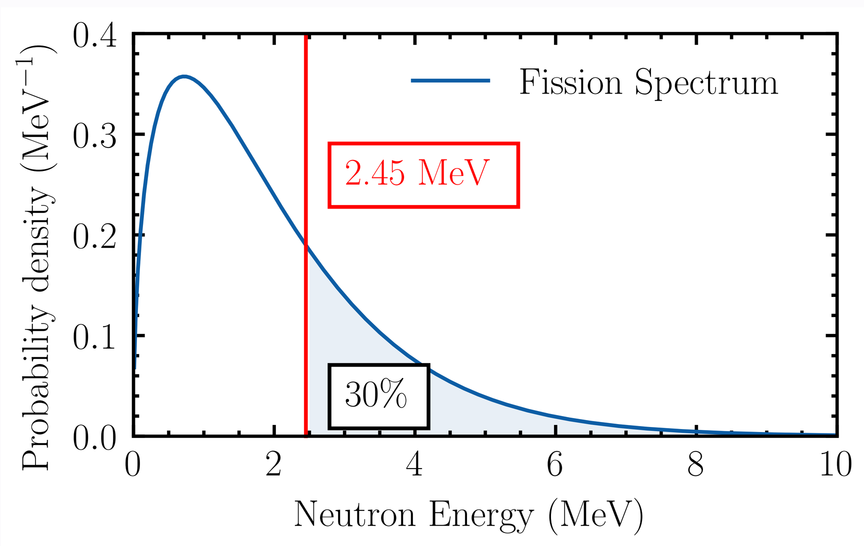

Figure 3: Fission Neutron Probability Density Function

Approximately 30% of secondary neutrons will have **energies greater than the probing source**, generating a distinct energy signature. Detecting this signature provides a **robust indicator of the presence of SNM.** [1]

The detector contains **high-pressure (~180 bar) helium** (^{4}He) as the active medium.

Fast neutrons interact primarily via **elastic scattering** on ^{4}He nuclei, producing energetic recoil helium atoms.

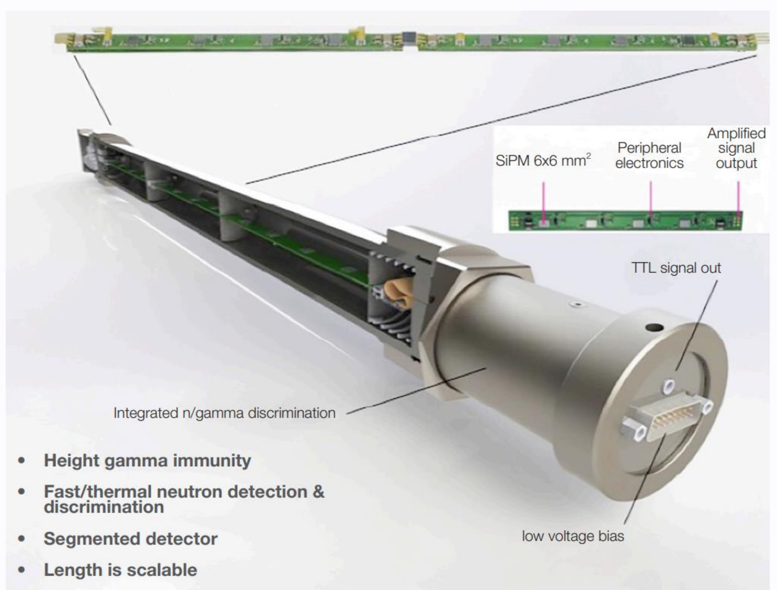

Figure 4: Diagram of Arktis S670 Detectors [7]

- Recoil ^{4}He atoms excite and ionise the gas, generating ultraviolet scintillation photons (λ ≈ 80 nm).
- A wavelength-shifting (WLS) material converts the UV scintillation light to visible wavelengths (λ ≈ 420–450 nm).
- Existing literature reports an **energy resolution of between 50-20% [8].** Energy deposition spreading will be applied in post-processing.

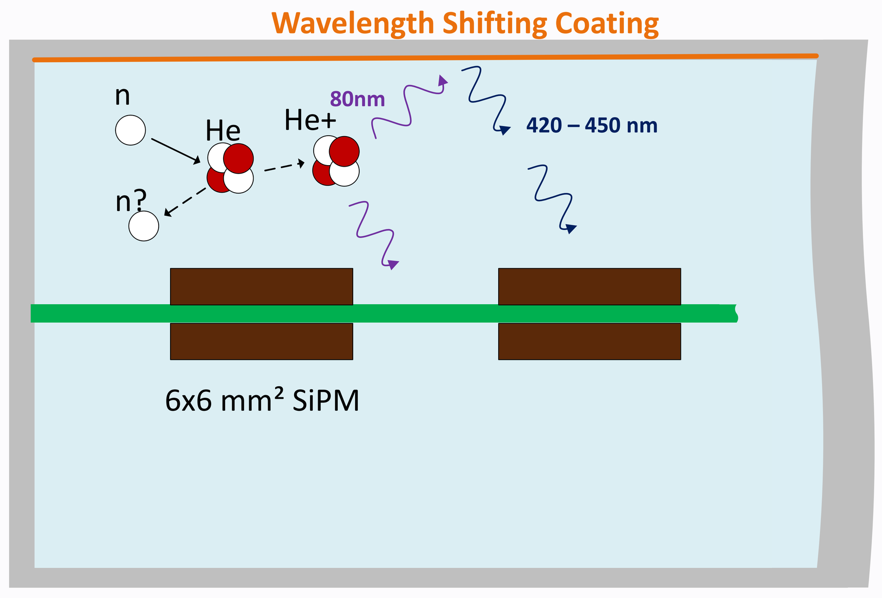

Figure 5: Diagram of ^{4}He recoil scintillation and light collection

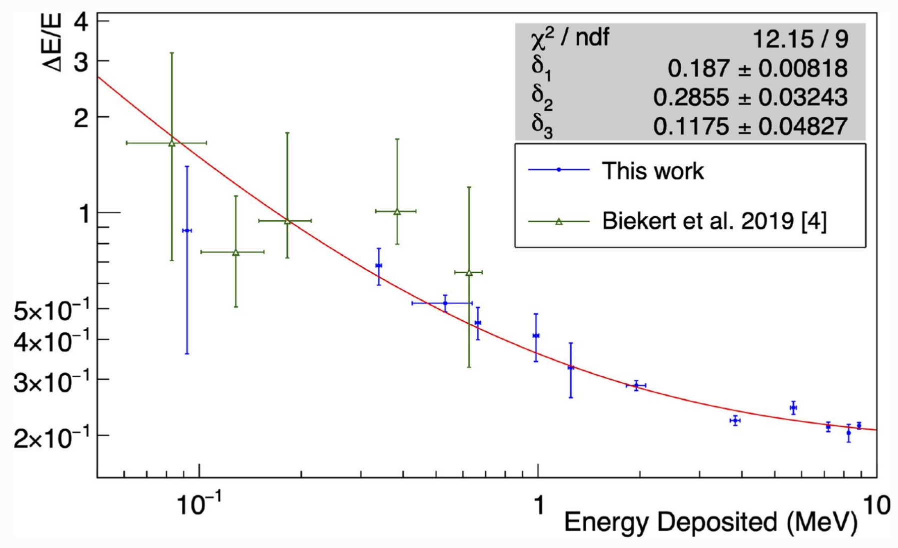

Figure 6: Experimental Energy Resolution of Arktis ^{4}He Detector

Simulation

A **Geant4** simulation based on the TENA experimental setup [1] has been developed, consisting of:

- Neutron source
- Multiple ^{4}He detectors (5 on each side)
- **20 kg masses of U0₂ (U$_{Nat}$, LEU, HALEU)**
- Stainless-steel container
- Concrete floor

Both **the energy deposited** into the ^{4}He is recorded to gain an understanding of the expected counts from the detector.

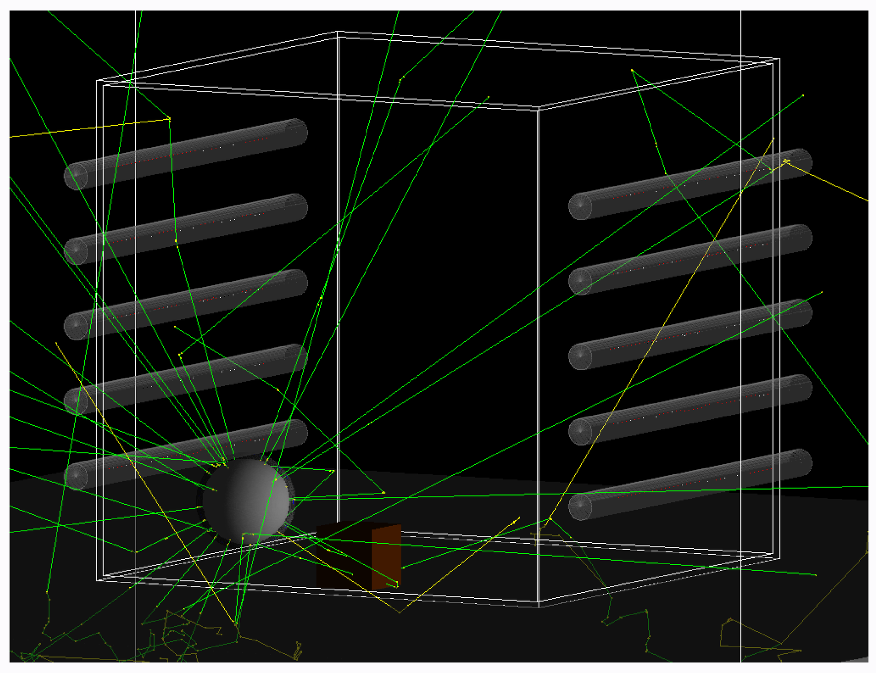

Figure 7: Geant 4 Simulation Visualisation

Results

Each simulation run consisted of $\mathbf{2 \times 10^9}$ neutrons. The results show the number of **counts per source neutron** when masses of 20 kg of **UO₂** with **varying enrichment levels** are positioned inside the container. Using the background run as the threshold **(max neutron energy of 2.45 MeV)** an **increase in the counts of higher energy deposits** with **increasing enrichment can be seen.**

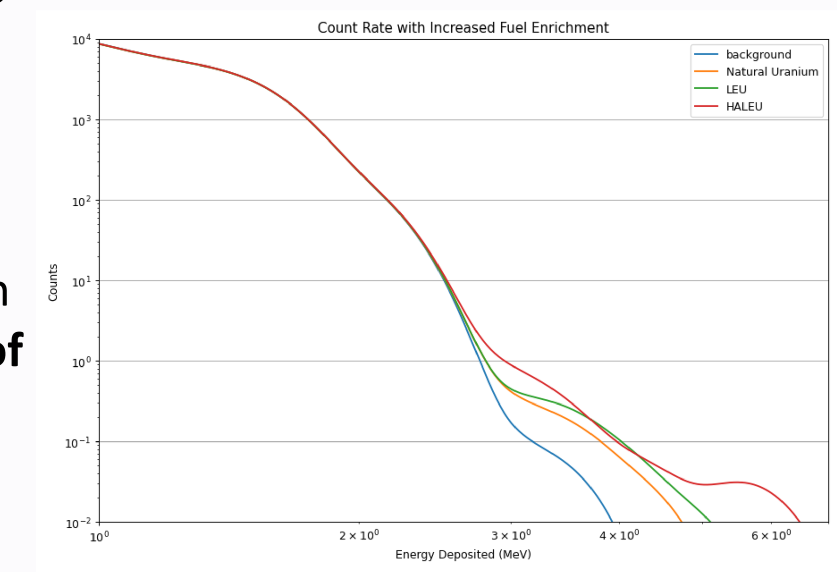

Figure 8: Simulated energy deposition data.

Discussion & Further Work

The results show that there is an **increase in high-energy deposits** into the detector when **UO2 is located inside the container**, increasing with the enrichment of the material, indicating the detection setup may be a **viable solution for the detection of SNM.**

Future work will look to

- Investigate the impact of different experimental setups varying the position of material, amount of material, number of detectors, neutron rate and shielding material
- Extend the simulation model to produce and collect scintillation light to improve the accuracy of the model.
- Compare simulation results to experimental setups

References

[1] Masuda, Kai, Yoshiyuki Takahashi, Tsuyoshi Misawa, Norio Yamakawa, Thomas B. Scott, and Mahmoud Bakr. 'Fusion Neutron Source and Array of Particle Detectors for Nondestructive Interrogation of Special Nuclear Materials'. *Journal of Applied Physics* 136, no. 11 (17 September 2024): 114503. https://doi.org/10.1063/5.0225179.

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[3]] Atomic Energy Act of 1954, as amended, §11(aa), 42 U.S.C. §2014(aa) — Definition of Special Nuclear Material.

[4] Nuclear Security Systems and Measures for the Detection of Nuclear and Other Radioactive Material out of Regulatory Control. n.d.

[5] IAEA. 'Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5)'. Text. 16 September 2016. https://doi.org/10.61092/iaea.ko2c-dc4q.

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