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Passive Imaging of SNM with Cosmic-Ray Generated Neutrons and Gamma-Rays

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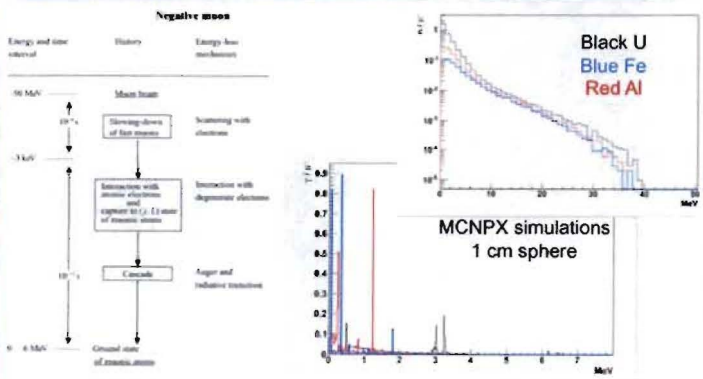
Concept

We present a novel concept of the SNM imaging system based on cosmic-ray muon tracking in coincidence with neutron/gamma detection. The cosmic-ray flux at sea level is about 1 muon/sq.cm/minute. It is composed of nearly equal numbers of μ+ and μ−. In previous work, we have demonstrated that these muons can be used to image nuclear threats in relatively short times by measuring their multiple scattering through objects. Here we propose to image nuclear objects by combining tracking of the muons into a scene with measurements of the secondary particles produced when the muons stop in dense potentially fissile materials. We use multiple drift tube planes to trace incoming cosmic rays. Plastic scintillator serves as a detector of outgoing neutrons and gamma-rays. Additionally, the same plastic scintillator is used to estimate the energy of incoming cosmic-rays. We use a coincidence of n/gamma detection with the initial cosmic-ray trigger to suppress the background. The fissions produced by the stopped μ− generate fission chains that die away after several (~5) fissions. Each fission produces ~10 energetic gamma rays and ~2.5 neutrons. Although a self-shielding needs to be considered, it is likely that tens of neutrons and gamma rays will escape from the object of typical configuration. The efficiency of detecting at least one of the products within ~100 ns could be close to 100% for a detector of reasonably large solid angle (~2 ster). Ten minutes of data should produce 50 trajectories from μ− stopped in 20 kg of U. These numbers can be scaled for other size objects. Our approach has no active source, and therefore it is safe for humans and has no effect on the object under inspection. The detectors are scalable and portable. The drift tubes of the detectors are sealed and do not need the gas replenishment. Detection and localization of SNM is achieved with automatic reconstruction algorithm, which can be run at a standard computer.

MCNPX Simulations

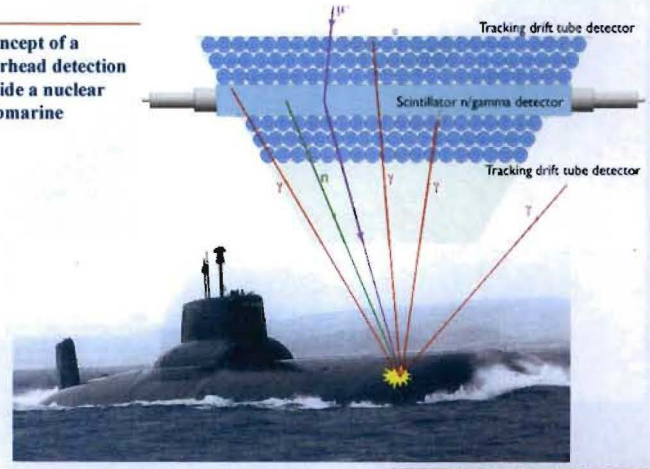


$$\mu^- + p \otimes (A-1) \rightarrow n + \nu_\mu + (A-1)^*$$ ➡ Fission in U or Pu

Fission yield per neutron stop =
0.068 ± 0.013 for U-238 and 0.142 ± 0.023 for U-235
Multiplication via k-eff further enhances U-235 signal
Background: cosmic-ray showers

Delayed component accounts for 91% of fissions in U-238 and 88% in U-235
Mean lifetime = 77.2 ± 0.4 ns for U-238 and 71.6 ± 0.6 ns for U-235
Easily separable from neutron time-of-flight signal
4" x 4" DU Target @ LANL: 14 stops per minute = 1.0 fissions per minute

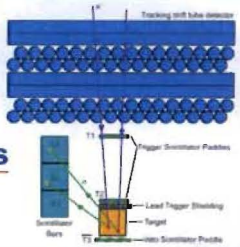
Concept of a warhead detection inside a nuclear submarine



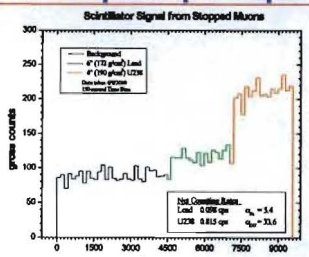
Advantages of Warhead Imaging with Cosmic-rays

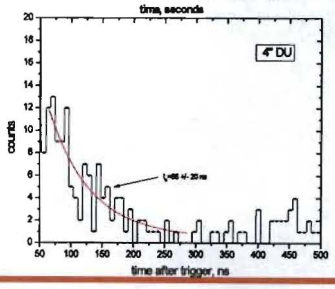
- Passive method: safe for humans and will not apply an artificial radiological dose to the warhead.
- Cosmic rays are much more penetrating than gamma or x-rays. Warheads can be imaged in a container behind significant shielding and in presence of clutter.
- Exposure times depend on the object and detector configuration (~few minutes if optimized).
- While SNM detection can be reliably confirmed, and discrete SNM objects can be counted and localized, the system can be designed to not reveal potentially sensitive details of the object design and composition.
- Existing detectors and electronics are scalable and portable, and have been demonstrated to operate for several month with little or no human intervention. Gas is not flammable and doesn't need replenishment. Detection and localization of SNM is achieved with automatic reconstruction algorithms.

Portable cosmic-ray muon tracking detector



Proof—of-principle experiments





Testbed setup: Trigger scintillator "telescope" constrains directionality of incoming muons. Large scintillator bars S1, S2, S3, detect secondary neutrons, gammas, etc. produced from muons stopping in target. High multiplicity of secondary particles enables nearly 100% efficiency even for small (~π/2) solid angle. Pb shielding prevents natural target radiation from causing spurious triggers