

# *Detection of Nuclear Threats in Large Cargo Containers*

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## **Introduction**

In 2003 scientists at the Lawrence Livermore National Laboratory, the Lawrence Berkeley National Laboratory, and the University of California at Berkeley undertook a collaborative effort. The goal of this collaboration is to develop a concept for an active neutron interrogation system that can detect small masses of contraband fissile material in intermodal cargo containers—roughly five kg of highly-enriched-uranium or one kg of plutonium—even when well shielded by thick cargo. It is essential that implementation of the concept be reliable and has low false-positive and false-negative error rates. Interrogation must also be rapid to avoid interruption of commerce; analysis must be completed in minutes. This document summarizes that effort to date and was drawn, with the exception of minor editing, from the summary in Ref. 1.

## **A new radiation signature**

We have identified a new radiation signature, unique to fissionable material, that exploits high-energy ( $E_\gamma = 3\text{--}7\text{ MeV}$ ) fission product beta-delayed gamma-ray emission<sup>2</sup>. Fortunately, this signature is robust in that it is very distinct compared to normal background radiation where there are no comparable high-energy gamma rays. Equally important, the signature yields 10 times as many high-energy delayed gamma rays as delayed neutrons. The latter are the basis of a conventional interrogation technique used on small unshielded specimens of fissile material. These high-energy gamma rays have the additional beneficial ability to readily penetrate two meters of low- $Z$  and high- $Z$  cargo at the expected density of  $\sim 0.5\text{ g/cm}^3$ . Consequently, we expect that in hydrogenous cargo the signature flux at the container wall is at least 100–1000 times more intense than delayed neutron signals used traditionally and facilitates the detection of fissile material even when shielded by thick cargo.

Experiments have verified this signature and its predicted characteristics. However, they revealed an important interference due to the activation of  $^{16}\text{O}$  by the  $^{16}\text{O}(\text{n,p})^{16}\text{N}$  reaction that produces a 6 MeV gamma ray following the 7-s beta decay of the  $^{16}\text{N}$ . This interference is important when irradiating with 14 MeV neutrons but is eliminated when

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lower energy neutron sources are utilized since the reaction threshold for  $^{16}\text{O}(\text{n,p})^{16}\text{N}$  is 10 MeV. The signature gamma-ray fluxes exiting a thick cargo can be detected in large arrays of scintillation detectors to produce useful signal count rates of  $2\text{--}4 \times 10^4$  counts per second. That is high enough to quickly identify fissile material fission by its characteristic high-energy gamma-ray emission and characteristic fast decay time. Fortunately, the fission product gamma radiation decays with a distinctive decay time-signature of up to 50–100 s that is well matched to cargo scan speeds of about one minute per container. Experimental characterization of the gamma-ray fluxes exiting thick cargos is yet to be undertaken.

**Neutron source requirements defined**

Our work led to definite requirements for the interrogation neutron source that can be met with commercially available neutron source technology. A small (2–6 m) deuteron accelerator producing about a 1 mA, 2–5 MeV deuteron beam on a deuterium or beryllium target is required. Neutrons produced by such an accelerator are kinematically collimated in the forward direction, reducing shielding requirements while increasing the neutron flux on target to meet the intensity requirement even when there is thick intervening cargo. In addition, this technology provides a very penetrating beam in the energy range 4–8 MeV while remaining below the oxygen activation threshold. Maximum counting statistics and lowest error rates in the identification occur when the beam is pulsed with a 50% duty cycle. The period for this pulsing must be comparable to the half-lives of the species that make up the signature, i.e. 10–60 sec. This is readily achieved with commercially available equipment and is well suited to rapid scanning of cargo containers.

**Unwanted collateral effects of interrogation**

Finally, we examined unwanted collateral effects of the interrogation such as neutron activation of the cargo. Even in the worst case, when 14-MeV neutrons are used and not moderated, the dose rates resulting from activation are well within limits for radiation workers within minutes after the end of irradiation and in most cases drop to levels acceptable for exposure of the general public within minutes or hours. In all cases studied, the activation levels of cargo, even under the worst-case assumptions, are low enough for the cargo to be considered non-radioactive for shipping by the Department of Transportation. Activation of agricultural products is very low as well. Although no applicable standards were identified, the levels of radioactivity predicted for neutron activation in even the worst case are much lower than the naturally present  $^{40}\text{K}$  content of many foods.

**Conclusion**

We have developed a viable concept for active neutron interrogation of cargo and its components have been evaluated experimentally. Utilization of the new gamma-ray signature for fissile material appears to promise a dramatic improvement in sensitivity for those cases where thick intervening hydrogenous cargo shields a target of interest or where the material is shielded with intentionally placed high-Z materials. New experiments and simulations are in progress to quantitatively determine the effects of cargo or intentional shielding to reduce and/or interfere with the fissile-material signature. These experiments will then be used to establish the scanning intervals required to reduce the error rates, i.e. false positive and false negative, to acceptable levels.

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## References

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