# IPNDV Working Group 3: Technical Challenges and Solutions
# Nuclear Material (8)—Technology Data Sheet

*August 25, 2016*

**Nuclear Material (NM) Technology Name:** Muon Tomography

**Physical Principle/Methodology of Technology:**

Muon Tomography is an imaging technology that uses the ambient muon flux available everywhere on earth. Muons are created by the interaction of cosmic rays with the upper atmosphere, and pass through the surface of the earth at the rate of roughly one per second for an area the size of the human hand. Like X-rays or neutrons, muons can be used to image the object they pass through, as a result of being scattered by the nuclei in the object. Muons are preferentially scattered by heavy nuclei, so are particularly sensitive to nuclear material (while being less sensitive to lighter nuclei such as that found in container walls). Muons are much more deeply penetrating than X-rays, neutrons, or gamma-rays, and cannot be easily shielded, making them particularly attractive to nuclear security and safeguards verification activities.

In X-ray and neutron tomography, the image is created by radiograph (particles are absorbed or scattered away and not detected). In Muon Tomography, a two-dimensional radiograph can similarly be created (but with greater penetration than either X-rays or neutrons), or alternatively a 3D image can be created by computer algorithms that reconstruct the muon tracks and changes in track direction caused by scattering.

Muon tomography has an inherent restriction on fidelity of image due to the low natural muon flux, which provides inherent protection of sensitive geometry data. The natural muon flux also cannot be shielded by the host to tailor the image.

The history of Muon Tomography goes back to the 1950s and 1960s, when muons were used in various experiments to image geological features and large man-made structures—including a famous application by nuclear scientist Luis Alvarez, where he imaged the interior structure of the Pyramid of Chephren in Giza.

**Potential Monitoring Use Cases** (pre-dismantlement, dismantlement, post-dismantlement, storage stage):

Muon Tomography can be used to detect the presence or absence of heavy nuclei consistent with warhead material.

**Used to measure U, Pu, or U and Pu:**

No.

**For detection technologies, what does the method determine/measure** (e.g., presence of nuclear material, isotopics, mass, etc.):

Muon Tomography does not have the sensitivity to identify the exact mass of the heavy nuclei that may be present. For instance, depleted uranium cannot be distinguished from HEU or Pu and possibly other heavy elements like Pb or W.

**Physical Description of Technology** (e.g., approximate size, weight):

Because the radiation for Muon Tomography is a constant and natural phenomenon over the surface of earth, this verification technology involves only detection and analysis systems. Muon systems are typically composed of several muon detector ion layers, each approximately 1 m × 1 m × a few 10s of cm. The detection system is currently available as a large prototype but a portable version is under development by the Department of National Defence in Canada that can be assembled in the field by two people, and transported on a standard pallet.

Along with the detection system there would be a separate rack for power supplies, computer, and data analysis capability.

**Time Constraints** (e.g., measurement times including distance from object, time to install the equipment):

The setup time for the equipment will be several hours, as required by the heavy equipment and associated instrumentation. This technology is time-limited by the low natural muon flux, and in general measurement time will determine the accuracy of the image. The minimum detection time would be about 20 minutes. The measurement time is likely to be several hours in order to be sensitive to some characteristic, e.g., shape, mass, etc. For material on the scale of a warhead, the measurement times are expected to be much longer.[1]

**Infrastructure Requirements** (e.g., electrical, liquid nitrogen, etc.):

Other than transportation requirements for the detection and analysis systems, there are no extraordinary requirements for this technology. Shielding is not required for the imaging radiation.

**Technology Limitations/Variations** (e.g., detection limits for nuclear material, operational temperature range, differences in technology detector materials):

As discussed there are image-fidelity limitations due to the low natural muon flux, which can be used to some advantage as an "inherent technology barrier."

**Information Collected by the Technology** (used to help determine if an information barrier is required for use):

A Muon Tomograph could provide an image of a warhead, thus it would require an information barrier.

**Technology Development Stage** (e.g., commercially available, development stage):

Muon Tomography is in development at several laboratories. A large prototype is in operation at CNL Chalk River Laboratories. A portable version of this technology is in development for use in the field.

**Cost Estimate:**

The first prototype unit based on this technology is expected to cost in the range of €300,000–500,000.

[1] For more information, see D. Schwellenbach et al., *Passive Imaging of Warhead-like Configurations with Cosmic-Ray Muon Tracking Scanners*, LAO-17-12, available at http://www.decisionsciences.com/wp-content/uploads/2013/09/report-2013-NSTec-Research-Development-Fiscal-Year-2012-Annual-Report-MMPDS.pdf.

**Additional System Functionality** (e.g., outside the monitoring use case):

Muon Tomography has applications in nuclear security and waste management for verification of spent fuel and nuclear material.

**Where/How the Technology Is Currently Used** (e.g., international safeguards, border protection):

A large prototype is in operation at CNL Chalk River Laboratories, called "CRIPT" (Figure 1), and is being used to determine the applicability to both safeguards verification of spent fuel, and waste management verification (see, for e.g., Figure 2). Recently Muon Tomography has been used to assist in the characterization of the fuel in the Fukushima reactors.

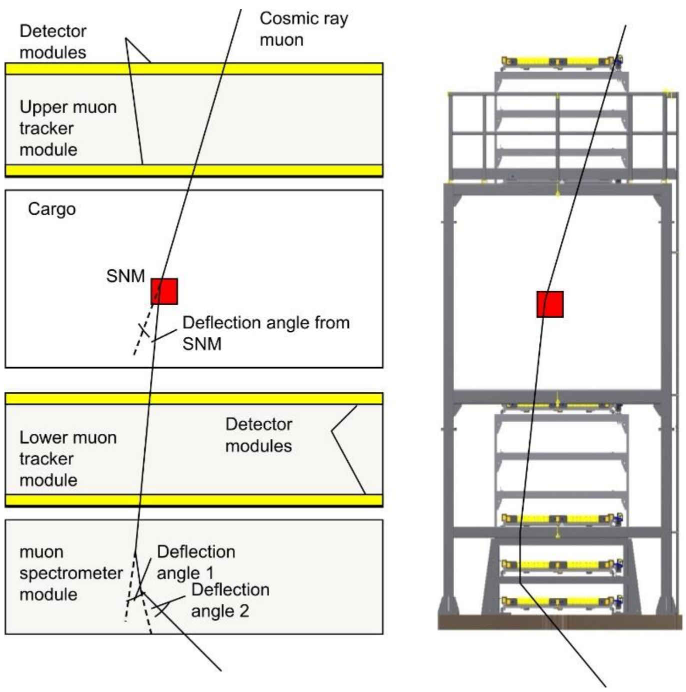


**Figure 1: Schematic of CRIPT facility. (Image Credit: CNL Chalk River Laboratories, Canada)**

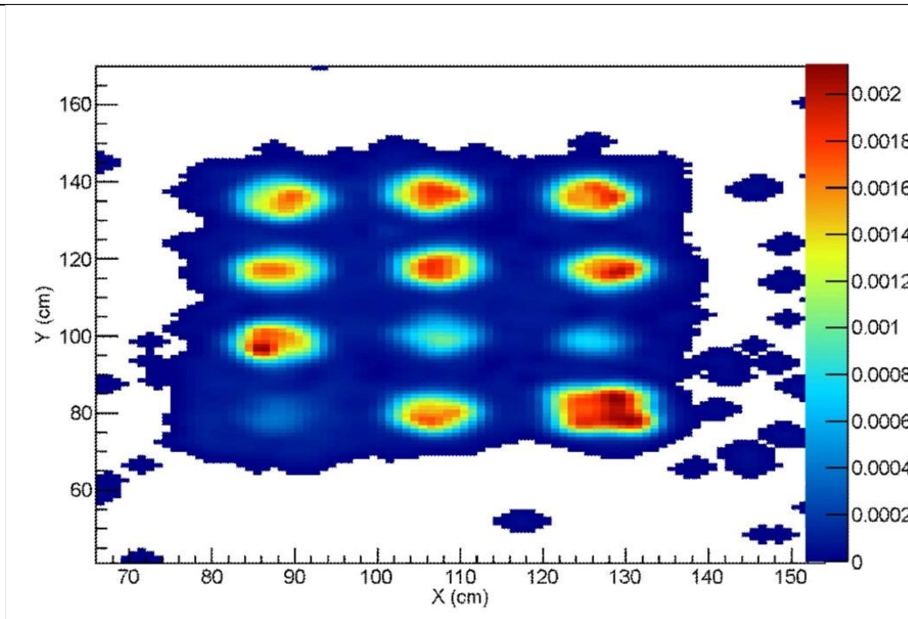


**Figure 2: Example of data from CRIPT muon detector for safeguards verification. In this image three "dummy" CANDU fuel bundles are distinguishable from eight "real" fuel bundles.**

**References:**

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