Nuclear Material (3)—Technology Data Sheet

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Nuclear Material (NM) Technology Name: Gamma-Ray Imaging

Physical Principle/Methodology of Technology:

Gamma-ray imaging provides the location and shape information of gamma-ray emitting radionuclides. The technology can also determine the identity, activity, and mass of these radionuclides. A key informative output for the technology is an optical image of the scene overlayed with the gamma-ray image. This aids the user in visualizing the location of the radiation.

Gamma-ray imaging techniques can be broadly separated into two groups: those based on mechanical collimation and those based on electronic collimation. There are several different mechanical collimation systems that have been developed, including: pinhole cameras, coded aperture, raster scanning, and Rotational Modulating Collimators (RMC). Compton cameras do not rely on any physical form of collimation, but instead use the kinematics of Compton scattering, as a form of electronic collimation, to determine the origin of a gamma-ray source.

A range of detector materials could be used in a gamma-ray imaging system. These detector materials have their own set of advantages and disadvantages (for example, low/high energy resolution, cryogenic cooling/room temperature operation, cost). This will not be explored in any further detail now because it is covered in the High Resolution Gamma-Ray Spectroscopy Technology Data Sheet.

Each technology variant has both its advantages and disadvantages, details of which can be seen in Table 1 below. For mechanical collimation systems, there is a general tradeoff between spatial resolution and sensitivity. For example, a high spatial resolution leads to low sensitivity and high sensitivity leads to low spatial resolution. Compton cameras have an intrinsically low efficiency, especially for low energy photons.

Table 1. Advantages and Disadvantages of Gamma-Ray Detector Systems

Technology	Advantages	Disadvantages
Pinhole Collimator	High spatial resolution, better at lower energies, direct image generation	Low sensitivity, small Field of View (FOV)—typically $40^{o}\times40^{o}$
Coded Aperture	High sensitivity, high spatial resolution, better at lower energies, good point spread function	Small FOV—typically $40^{o}\times40^{o}$
Raster Scanning	Low cost single detector option, large FOV (4π, omnidirectional), better at lower energies, can dwell on regions of interest, direct image generation	Long acquisition times
Rotational Modulating Collimators	Low cost single detector option, can be effective across wide energy range	Long acquisition times, heavy, small FOV, non-ideal point spread function, post processing needed to remove image artifacts

Compton camera	Large FOV (4π, omnidirectional), lightweight (no shielding), better at high energies	Low efficiency, unable to image low energy photons, low angular resolution compared to collimation techniques, non-ideal point spread function

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

All

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

U and Pu

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

Gamma-ray imaging can provide everything gamma-ray spectroscopy can do as well as giving the location/shape information of the radioactive material.

The method can determine/measure:

- Presence of nuclear material
- Identification of radioisotopes
- Activity
- Mass
- Location
- Shape

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

Weight range: 2.5 kg–45 kg

Size range: 18×9×9 cm–30×23×15 cm

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

Time to install: 2 minutes–5 hours. This depends on the technology variant.

Measurement time: Depends on the dose rate from the source and the intrinsic efficiency of the imaging method.

Measurement time to measure 500 g of Pu (0.1 ^{239}Pu/^{240}Pu) or 500 g of ^{235}U at 1 m from the surface of the container (order of magnitude: seconds, minutes, hours, days):

Minutes to hours

Will this method work in the presence of shielding? If so, what is the maximum amount of shielding that will still allow the method to work?

As the gamma-ray photon energies from U and Pu are low in energy, this technology will only work with small amounts of shielding. Low energy photons are easily scattered by low Z materials (i.e., explosives—but the scattered radiation can also be imaged indicating where nearby materials may occur) and easily attenuated by high Z materials (i.e., metals).

Technology Complexity (e.g., hardware, software, and ease of use by personnel):

The technologies can be complex and may involve the integration of the following components:

- Detector material
- Readout electronics (ASICS)
- Embedded computing
- Temperature regulation, cryogenic cooling
- Image reconstruction software
- Mechanical collimator
- Motors/motor controllers

The complexity of the system is hidden from the end user. Systems typically have a non-expert and expert user interface.

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

The various Commercial Off-the-Shelf (COTS) systems have a battery life of between 1 to 10 hours. They can also be operated through mains power.

Wired and wireless connectivity

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

System specific, various systems operate within the temperature range of: -20°C to +60°C.

The detector materials currently used in COTS equipment include High Purity Germanium (HPGe), Cadmium Zinc Telluride (CZT), Cadmium Telluride (CdTe), Caesium Iodide (CsI) and Bismuth Germanate (BGO). These materials have different detection efficiency and energy resolution properties.

Specific equipment limitations include:

- Compton cameras cannot image low energy photons and have a low efficiency
- Pinhole cameras have a low sensitivity when compared to coded aperture systems, as the single pinhole severely restricts the number of photons arriving at the detector
- Raster scanning is comparable to a pinhole in sensitivity
- RMC systems are slower than coded apertures but faster than pinholes

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

Gamma-ray spectrum, source identification, source activity, source mass, source location, and shape information.

An information barrier would be required.

Safety, Security, Deployment Concerns:

Gamma-ray imaging is a passive detection technology, so there will be limited safety concerns.

Security concerns may arise from the technology being able to detect sensitive information.

There are minimal deployment concerns. Most systems are deployable on a tripod and are battery powered. The only COTS system that requires cryogenic cooling is mechanically cooled and therefore does not require the use of liquid nitrogen.

Technology Development Stage (Technology Readiness Level, TRL):

There are several COTS items (TRL 9) that are available. National labs and universities are also developing technologies that are at the various TRL levels.

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

Nuclear Industry

- Decommissioning
- Area monitoring
- Inspection (hotspots)
- Health physics surveying

Safeguards

National Security

- Border protection
- First responder/emergency response

Medical imaging

- Single Photon Emission Computed Tomography (SPECT)

Astronomy

- Space-based telescopes for imaging the gamma-ray universe

Examples of Equipment:

Company Name	Equipment Name	Equipment Type	Detector Material
Canberra	Cartogram	Pinhole camera	CsI or BGO
Canberra	IPIX	Coded aperture	CdTe

Createc	NVisage	Raster scanning	CZT
H3D	Polaris-H	Compton camera	CZT
CEA	HiSPECT	Coded aperture	CZT
PHDS	GeGi	Compton camera (also pinhole mode)	HPGe
RMD	RadCam	Pinhole camera/ coded aperture	CsI