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Gamma-Ray Mirrors for Non-Destructive Assay (NDA) of Spent Nuclear Fuel (SNF)

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Safeguards Technology Fact Sheet

Gamma-Ray Mirrors for Non-Destructive Assay (NDA) of Spent Nuclear Fuel (SNF)

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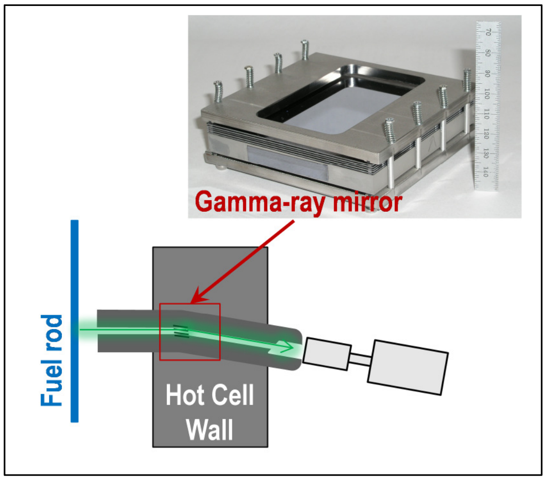
Description:

- Use gamma-ray mirrors as a band-pass filter.
- Allows direct measurement of highly radioactive materials such as spent nuclear fuel with sensitive detectors.
- Weak lines of interest can be focused onto a detector for high efficiency measurements.
- Strong lines and continuum radiation of no value are not passed.
- TRL = 3

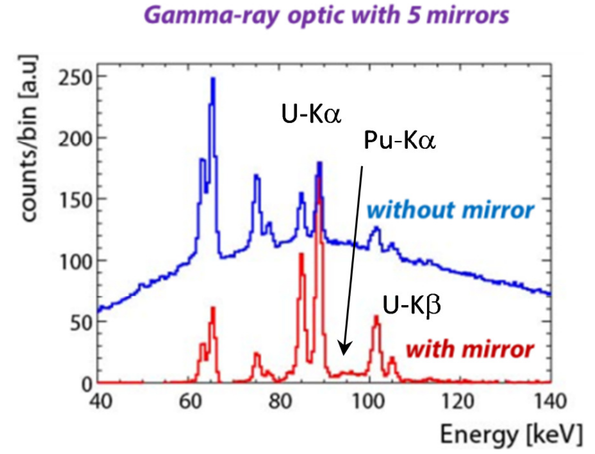


Applications:

- Safeguards: Allows direct measurement of specific lines from fissile species with typical detectors. For spent nuclear fuel, allows application of non-destructive analysis to address burn-up determinations, shipper-receiver differences, fissile content, etc. Similarly, allows direct on-line monitoring of fissile material in processing equipment.

Performance:

Recent proof-of-principle tests with flat mirrors on spent nuclear fuel have improved the detectability of K-flourescence radiation from U and Pu. The planned development of highly "nested" focusing optics could increase the solid angle and further improve background ratio, potentially to as large 1:10,000. High energy gamma-ray mirrors that reflect up to 80 keV are the basis for two hard x-ray telescopes on the NASA NuSTAR satellite. The multilayer mirror technology has been demonstrated at discrete energies from 60 to 645 keV; an energy band of interest for safeguarding fissile materials. With coatings deposited on curved substrates, optics for use in the near field have also been assembled. These systems can be tailored to pass only selective bands of radiation to a spectrally sensitive detector to achieve high background rejection rates.



Results from spent nuclear fuel showing improved signal-to-noise ratio in detecting atomic K-fluorescence

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Physical Specifications:

- Background rejection: 1:10^3 to 1:10^4, dependent on design.
- Solid angle: 1×10^{-6} to 1×10^{-4}, dependent on level of "nesting."
- Operating distances: 4–7 m.
- Currently used with high-energy-resolution detectors (e.g., HPGe); potentially suitable for use with modest-energy-resolution, PMT-based detectors (e.g., CsI).
- Cost per optic $10,000 to $100,000, dependent on level of nesting.

Operational Specifications:

- Designed for fixed installation to measure SNF pellets, fuel rods, or assemblies.
- Setup time: characterization of the gamma-ray optic, detector and support structures prior to shipment to SNF facility allows installation of system in <4 hours.
- Measurement time: tens of minutes.
- Radiation Sources: Standard 1-10 μCi ^{137}Cs source calibration.

Background:

- Total external reflection of x-rays at grazing incidence by Compton (1923).
- Theory of grazing incidence optics developed by Wolter (1952).
- First x-ray telescopes developed for astrophysics (1965).
- Extension to energies above 10 keV with depth-graded multilayers (1992).
- Fabrication of highly-nested, multilayer-coated, hard X-ray telescopes (2000–2003) [1].
- First use of multilayer optics for pre-clinical nuclear medicine imaging (2004) [2].
- Launch of first 80 keV X-ray telescope (2012) [3].
- Demonstrations of multilayers at 370 keV (2013) and 645 keV (2014) [4,5].
- Demonstration of gamma-ray mirrors with ^{241}Am (2012) [6].
- Demonstration with Spent Nuclear Fuel (2013) [7].

Future Development Goals:

- Develop and test focusing optics specifically tailored to the Spent Nuclear Fuel problem.

References:

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7. J. Ruz et al., "Direct Measurement of ^{235}U in Spent Fuel Rods with Gamma-ray Mirrors," submitted to *Nuclear Instruments and Methods A* (2014).