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# Coded Aperture Imaging in Many-Pin Fuel Bundles

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As part of the experimental fast reactor safety research program at Sandia Laboratories for the Nuclear Regulatory Commission, the problems of fuel motion imaging in safety tests on a variety of facilities (ACPR UPGRADE, TREAT, TREAT UPGRADE, STF, CABRI) are being studied. Coded aperture imaging of both neutrons and gamma rays from many-pin fuel bundles is being studied. We report here realistic, detailed calculations on gamma ray coded aperture imaging in many-pin bundles, and preliminary experiments on coded aperture imaging with fast neutrons.

Realistic signal calculations are valuable for determining feasibility, since the necessary reactor experiments (assuming a suitable one is available) are costly and time-consuming, and may not permit wide variation of parameters. In gamma ray imaging, such issues as the attenuation of signal by the test fuel and containment, the role of scattering in contributing to the signal or the background, the signal changes resulting from fuel removal, and optimization of the coded aperture system itself, can be studied.

A 37-pin bundle in STF was taken as a typical case. Monte Carlo gamma ray transport calculations were performed separately for the test section (using a slab geometry[1]) and for the coded aperture system (using a cylindrical geometry[2]). Only fission gamma rays originating in the test fuel were treated, using a measured initial gamma spectrum[3] and distinguishing between scattered and unscattered gamma rays as they emerged from the



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test section. The variations in energy deposition in the scintillator of the coded aperture system were calculated to statistical accuracies of a few percent for point sources representing emission from various regions of the test section.

Figure 1 shows the calculated photon emission from various zones of the test section slab geometry. The unscattered photon emission drops by a factor of about seven from the near to the far side of the fuel bundle. The scattered component is never dominant in the fuel region, and decreases more rapidly than the unscattered component. However, the scattered component from the near-side steel containment wall , which is not directly characteristic of fuel motion, is somewhat larger than the total fuel-region emission. Calculations with a void in the central fuel-region zone have been performed to study the influence of scattering on measurement of fuel motion. Since the scattered radiation is considerably softer than the unscattered radiation, introducing a 7 mm Ta filter into the coded aperture system enhances the relative signal change caused by fuel voiding.

In summary, the gamma ray coded aperture calculations reported here have used realistic geometries and detailed initial gamma ray spectra, and also treat the problem of scattered radiation for the first time. The calculated magnitude of signal agrees with experiment within the experimental uncertainty.[4] These calculations have shown that the scattered background from the containment is comparable to the total signal from the fuel region, that the scattered signal from the fuel is discernible but not dominant, and that a filter in the coded aperture system significantly reduces the containment background and enhances the fractional signal change caused by fuel voiding. Further work will study the effects of varying fuel distributions on the calculated signal, and attempt to optimize the coded aperture design.

In neutron coded aperture imaging our initial goal is to develop a system that is inherently insensitive to gamma ray and low-energy neutron backgrounds. In particular, by using the greater sensitivity of coded apertures one may be able to obtain useful neutron images using fast-neutron-induced fission in depleted uranium, in spite of its low detection efficiency. Initial experimental work has been performed at the Sandia $Cf^{252}$ source facility with an integrating detector sensitive only to fast neutrons (Lexan and depleted uranium), in order to measure modulation of fast neutrons and to explore feasibility of analogue reconstruction of images. Fast neutron modulations of about 50 percent have been observed with 25.4 mm of steel (in good agreement with simple theory), by measuring fission fragment track densities in the Lexan.[5] The track density variations can be photographed clearly, which may permit analogue reconstruction of static images. Work on neutron modulation measurement for other materials, analogue reconstruction, and development of a gamma-insensitive, scintillator-type fragment detector is in progress.

## Figure Caption

Fig. 1: Photons emerging from a test section containing a 37-pin bundle viewed perpendicular to the flats. The seven fuel zones correspond to seven rows of fuel pins, and external sodium and steel layers are lumped together. The large scattered flux from the near-side steel is off-scale in this figure.

## References


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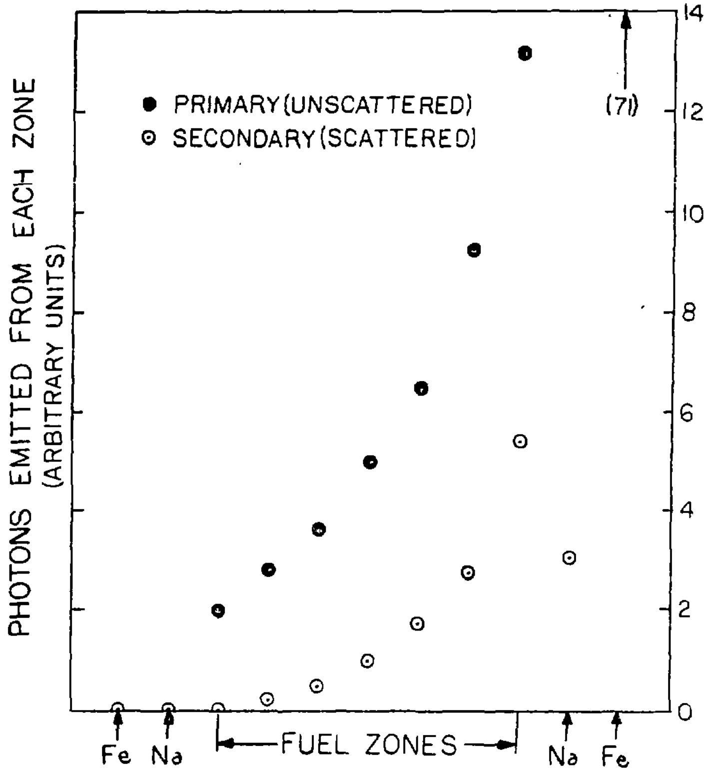

PHOTONS EMITTED FROM EACH ZONE
(ARBITRARY UNITS)
PRIMARY (UNSCATTERED)
SECONDARY (SCATTERED)
(71)
14
12
10
8
6
4
2
0
Fe
Na
FUEL ZONES
Na
Fe