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ADAPTATION OF A NEUTRON DIFFRACTION DETECTOR* TO CODED APERTURE IMAGING

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Introduction

A coded aperture neutron imaging system developed at Brookhaven National Laboratory (BNL) has demonstrated that it is possible to record not only a flux of thermal neutrons at some position, but also the directions from whence they came. This realization of an idea which defied the conventional wisdom has provided a device which has never before been available to the nuclear physics community. A number of potential applications have been explored, including (1) counting warheads on a bus or in a storage area, (2) investigating inhomogeneities in drums of Pu-containing waste to facilitate non-destructive assays, (3) monitoring of vaults containing accountable materials, (4) detection of buried land mines, and (5) locating solid deposits of nuclear material held up in gaseous diffusion plants.

Description of Work

Two-dimensional position-sensitive ^3He proportional chambers, designed and constructed[1] at BNL, have been operated at the High Flux Beam Reactor for several years in neutron-diffraction experiments to determine the structure of materials. One of these detectors was recently adapted to demonstrate the feasibility of a thermal neutron imaging system[2]. The imaging element is a uniformly redundant array[3] of rectangular apertures constructed from a thin sheet of cadmium, which absorbs thermal neutrons by resonant capture, and acts effectively as a large number of pinholes working in parallel. Position sensitive

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data is collected from two planes of perpendicular cathode wires by an array of custom hybrid preamplifiers which are connected to a charge division analog circuit. The spatial resolution is limited by the range of the proton produced by the neutron-capture reaction, and not by the electronics. The position information is transformed to digital data by means of timing pulses which are inputs to a CAMAC time-to-digital converter. The data are accumulated in a list sequencer which is read by a desktop computer running a LabVIEW program. A separate program reads the raw data and deconvolutes the image. The resulting system operates like a camera which produces false-color images of scenes containing thermal neutron sources.

Experiments were performed to demonstrate the operation of the coded aperture imaging system in detecting either a single source or multiple sources of thermal neutrons. The sources were ^{252}Cf contained in steel needles, embedded in cylinders of either polyethylene or candle wax for moderation of the fission spectrum. The typical total source strength was ~$5x10^5$ n/s. The contributions of epithermal neutrons (transmitted by the cadmium mask) and indirectly scattered thermal neutrons were quantified relative to the direct thermal neutron component by recording count rates without the Cd mask and also with a Cd shield near the source.

Results

Neutrons originating from fission or (α,n) reactions have an energy spectrum which is not efficiently detected by the ^{3}He chamber. Furthermore, these fast neutrons can pass through the cadmium sheet mask without casting a shadow from which one could obtain an image. Objects close to the source containing low-Z materials like hydrocarbons, exposed to this flux of fast neutrons, will become secondary "sources" of thermalized neutrons. The mean free path of thermal neutrons in air is about 20 m, so a significant fraction of them travel from the moderating object to the imaging system without scattering in the air. In some configurations, this direct thermal neutron flux can constitute as much as 60-70% of the detected neutrons.

With some fairly straightforward experiments, it was demonstrated that (1) the neutron imaging system can successfully detect a fission source if it is close to some moderating material, (2) a single well-moderated source generates an image with useful contrast, (3) the contrast ratio between the direct image-forming neutrons and the diffuse background is almost independent of the distance between the source and the detector, up to about 20 m.

Background noise contributions, as measured in our laboratory environment, come from (a) thermal neutrons scattered into the camera at random angles by the air, ground and surroundings (~25%), (b) epithermal neutrons which are not stopped by the cadmium mask, but still have some probability of thermalization in the ^{3}He (~10%), and (c) neutrons produced by cosmic rays. The cosmic ray contribution is negligible at short range, but becomes dominant in our experiments at ranges greater than 20 m. All of these background contributions are uniformly distributed, and will only affect the image through their statistical fluctuations. Some minor systematic nonuniformities in detector response can be removed by normalization.

The ability to distinguish a given source from the background fluctuations depends on the number of comparable objects in the scene. The background depends on the total number of neutrons, but the more sources in the scene, the smaller the fraction of the direct neutrons from any one of them. We have been able to image up to six separate sources separated from each other by about 30 cm from a distance of 3 m.

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