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Development of a lithium fluoride zinc sulfide based neutron multiplicity counter

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ABSTRACT

The feasibility of a full-scale lithium fluoride zinc sulfide (LiF/ZnS) based neutron multiplicity counter has been demonstrated. The counter was constructed of modular neutron detecting stacks that each contain five sheets of LiF/ZnS interleaved between six sheets of wavelength shifting plastic with a photomultiplier tube on each end. Twelve such detector stacks were placed around a sample chamber in a square arrangement with lithiated high-density polyethylene blocks in the corners to reflect high-energy neutrons and capture low-energy neutrons. The final system design was optimized via modeling and small-scale test. Measuring neutrons from a ^{252}Cf source, the counter achieved a 36% neutron detection efficiency (ϵ) and an 11.7 μs neutron die-away time (τ) for a doubles figure-of-merit (ϵ^2/τ) of 109. This is the highest doubles figure-of-merit measured to-date for a ^{3}He-free neutron multiplicity counter.

1. Introduction

Neutron multiplicity counting is a non-destructive assay technique that relies on time correlation between detected neutrons to characterize aspects of neutron emitting samples [1,2]. Neutron multiplicity counters (NMCs) have historically used ^{3}He as the neutron detecting material because ^{3}He has: a large (n, p) cross section for thermal neutrons, high gamma-ray-to-neutron distinguishability, and ^{3}He is non-toxic and non-corrosive. NMCs built with ^{3}He proportional-counter tubes are mature and reliable technology that have been in deployment for many years [3,4]. A desire to reduce the time requirements for non-destructive assay of fissile samples along with the recent concern about continued availability of ^{3}He prompted investigation into alternative detectors for neutron multiplicity counting [5,6].

NMCs are used to determine plutonium mass, neutron self-multiplication, and the ratio of (α, n) to fission neutrons of plutonium-containing samples [7]. Different NMCs have different performance characteristics and may be optimized for specific assay applications, but they are often compared to each other with a doubles figure-of-merit (FOM) based on neutron detection efficiency (ϵ) and neutron die-away time (τ) and is defined for this paper as ϵ^2/τ [8] .

A full-scale lithium fluoride zinc sulfide based neutron multiplicity counter (LiNMC) was constructed and characterized. The LiNMC design was most influenced by the Epithermal Neutron Multiplicity Counter (ENMC) [3], the current highest performing NMC. For example, the LiNMC was designed to occupy the same footprint. Though not known at the time of development, the LiNMC independently adopted similar features to a previous lithium-based neutron coincidence counter designs [9]. The LiNMC's ϵ, τ, and FOM were determined using ^{252}Cf neutron sources. Another quantity of interest in the development of ^{3}He-free detectors is the gamma-ray sensitivity or in other words the number of gamma-ray induced events that are spuriously counted as neutron induced events (ϵ_γ). The gamma-ray sensitivity of the system was determined using ^{137}Cs and ^{60}Co gamma-ray sources. The effect of the gamma-ray sensitivity on the measurement of τ and ϵ was negligible, though its effect on plutonium mass determination must be taken into account [10]. The purpose of this paper is to report the

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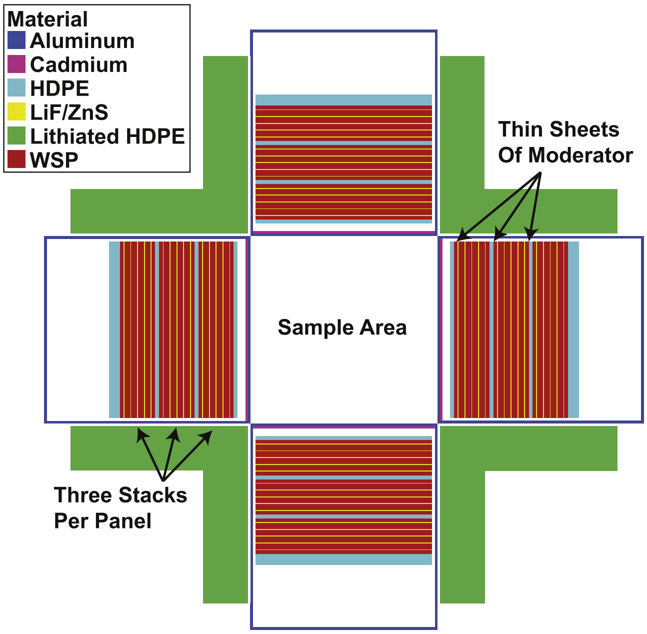
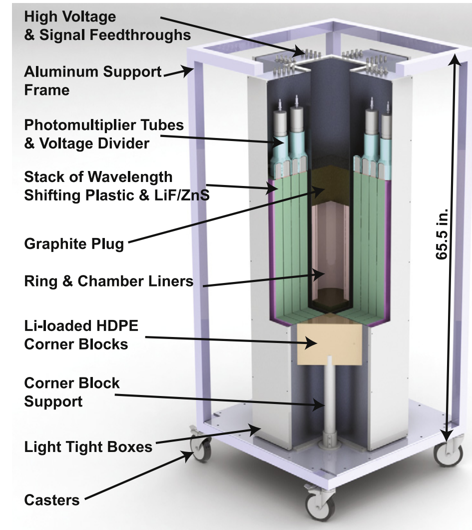


Fig. 1. A to-scale schematic of a horizontal slice through the center of the detector. The aluminum panel boxes where designed to accommodate up to four detector stacks. The as-built detector report in this work has only three detector stacks per panel as shown in the figure.



(a) Labeled cutaway render.

(b) Picture of the detector as built.

Fig. 2. Two views of the detector. Panel (a) is a schematic view with both exterior and interior elements labeled. Panel (b) shows the actual device with the data acquisition computer hooked up to one panel and an overhead gantry to aid in inserting samples.

construction of a full-scale LiF/ZnS based NMC and its performance characteristics and compare it with other currently available NMC systems.

2. Design and construction

Initial LiNMC development was based on Monte-Carlo N-Particle (MCNP) [11] simulations of the ENMC and was then modified to account for the LiF/ZnS technology. These modifications included changing the system from a circular symmetry to square symmetry, replacing the ^{3}He proportional tubes with LiF/ZnS and WSP sheets, reducing the HDPE in the detector regions, implementing modules to hold the detector regions, and implementing lithiated HDPE in the corners. Development followed an iterative process between simulation and experimental measurement, with the most promising designs being kept and refined. Designs were generally kept that increased ϵ or reduced τ to maximize the FOM, or that reduced ϵ_{γ}.

The core neutron detecting component of the LiNMC is a stack of EJ-426HD LiF/ZnS sheets and EJ-280 wavelength shifting polyvinyl toluene plastic (WSP). Each stack uses five sheets of 0.5 mm thick LiF/ZnS material with 0.5 mm of polyester backing on each side. The LiF/ZnS material is composed of ≈10 μm diameter grains of LiF and ZnS suspended in a hydrogenous binder. The Li used in the manufacturing was enriched to 95% ^{6}Li. These five neutron detecting sheets were sandwiched between WSP. The four interior pieces of WSP are 7.0 mm thick and the two exterior pieces 3.5 mm thick. The EJ-426HD LiF/ZnS sheets and EJ-280 WSP sheets were both produced by Eljen (Eljen Technology, Sweetwater, TX). Each stack had a 9821B Series PMT (Electron Tube Enterprises, Uxbridge, UK) on each end and was optically isolated to eliminate inter-stack cross talk. These detector elements are visually depicted in Figs. 1 and 2.

The LiNMC uses three detector stacks in each of four light tight modules arranged around a 20.3 cm wide by 20.3 cm deep by 71.0 cm high sample chamber. The sample chamber utilizes a vertically adjustable sample stand and is completely surrounded with 0.51 mm thick cadmium. 15.2 cm graphite plugs are placed above and below the sample chamber, and the corners of the LiNMC are filled with stacks of (7.56 weight% natural lithium) high-density polyethylene (HDPE) blocks from Shieldwerx (Bladewerx LLC, Rio Rancho, NM) in an “L” configuration 77.0 cm tall, and 5.1 cm thick, with 20.3 cm long arms. The purpose of this design choice is to moderate and reflect fast neutrons into the detector stacks while eliminating the slowest neutrons. The lithiated HDPE is a highly cost effective means of increasing ϵ and reducing τ.

The neutron detection process of the counter begins with the capture of a thermal neutron by the ^{6}Li. The resultant triton and alpha particles exit the micron sized LiF grain, traverse a low Z binder material and excite a fluorophore grain of silver activated ZnS. The scintillation light from the relaxation of the ZnS is absorbed and re-emitted by the WSP leading to more efficient transport of photons to the end of each stack than relying solely on total internal reflection. At the end of each stack a PMT collects the light and produces a signal that is fed directly into the data acquisition system. Placing PMTs on both ends of the