Scintillating-Glass-Fiber Neutron Sensors, Their Application and Performance for Plutonium Detection and Monitoring

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Abstract

Most neutron detection sensors presently employ ^{3}He gas-filled detectors. Despite their excellent performance and widespread use, there are significant limitations to this technology. A significant alternative neutron sensor utilizing neutron-active material incorporated into a glass scintillator is presented that offers novel commercial sensors not possible or practical with gas tube technology. The scintillating optical fiber permits sensors with a multitude of sizes ranging from devices of a single fiber of 150μm to sensors with tens of thousands of fibers with areas as large as 5m^2 depending on the neutron flux to be measured. A second significant advantage is the use of high-speed electronics that allow a greater dynamic range, not possible with gas detectors. These sensors are flexible, conformable and less sensitive to vibration that optimizes the source-to-detector geometry and provides robust performance in field applications. The glass-fibers are sensitive to both gamma rays and neutrons. However the coincidence electronics are optimized for neutron to gamma ray discrimination allowing very sensitive measurements with a low false-alarm rate. Applications include SNM surveillance, material control and accountability (MC&A), safeguard inspections, Pu health physics / bioassay and environmental characterization.

1. Background

The concept of scintillating-glass-fiber neutron sensors have been proposed in the literature since the 1960's [1-4], but have not been commercially available because of technical difficulties in producing fibers with good optical qualities that also provided high efficiencies for thermal neutron capture. Oxford Instruments has acquired innovative neutron sensitive glass fiber technology under license

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from Pacific Northwest National Laboratory (PNNL) and the U.S. DOE and is designing and manufacturing a variety of commercial products. During the last decade PNNL has fabricated cerium-activated lithium silicate scintillating fibers with an operational transmission length (e^{-1}) of over 2m.

2. Technology

The basic nuclear and optical principles have been described in detail [5]. Thermalized neutrons incident on the glass fibers induce a $^6Li(n,\alpha)^3H$ reaction with 4.7 MeV of exothermic energy mostly carried by the ^3H. The alpha particle and triton interact with the glass matrix to produce ionization. When the ionization transfer energy to a Ce^{3+} ion, the emission of optical photons (400nm) occurs during the return to ground state. Fluorescence *lifetime* is about 40-60 ns, therefore high-speed electronics can be used to advantage with shorter deadtimes and correspondingly higher throughputs (>10 Mcps) than possible with ^3He tubes (deadtime $\approx$ 1 μs).

The Ce / ^6Li bearing silicate glass composition is reported to be the best candidate for these waveguides [6]. A hot-downdraw process in an anoxic environment is employed to manufacture the fibers. Fibers, from 1cm to 2m in length are bound with RTV in bi-layer ribbons and layered with a hydrogenous moderator. The ends of the fiber bundles are optically coupled to two or more PMTs and their outputs are processed to determine both the pulse-height of the event and whether the event results in signals at two or more of the PMTs within a set time domain.

Neutrons deposit all of their energy in a single fiber resulting in light output at both ends of the fiber. The glass is sensitive to gamma rays that interact by photoelectric absorption, Compton interactions and pair production due to the higher effective Z of the silicate glass relative to gas tubes. This sensitivity can be both an advantage or disadvantage depending on the application. For neutron assay applications including passive, active and multiplicity, the glass sensors may not provide either technical nor price advantage over conventional ^3He or BF_3 tubes. Even with the excellent neutron to gamma discrimination, the spillover from the neutron to gamma channel adds unwanted variance and hence greater inaccuracy for assay applications. The cost of the additional PMTs adds to the overall price of such systems. On the other hand, for surveillance or detection applications where total neutron counting provides enhanced sensitivity, the glass performs better and at lower cost than comparable gas sensors. Furthermore, the gamma sensitivity is useful because a shielded source of Pu will result in the hydrogenous material may partially shield the neutrons, but they also interact to yield H capture gamma rays of 2.2MeV. Hence, a lower neutron count in conjunction with a gamma count is an indication of a shielded Pu source.

Gamma-rays interacting in the glass that create photoelectrons and Compton electrons produce a much smaller pulse than neutrons because the electron's range is greater than the 120-mm diameter of the fibers. The resulting energy is deposited in multiple fibers compared to neutrons that deposit their energy in a single fiber. The light output of both the neutrons and gamma rays is small and must also be discriminated against any dark noise in the individual PMTs. Through pulse-height discrimination, neutron to gamma discrimination ratios from 1000:1 to over 8500:1 have been achieved. These discrimination ratios minimize the problem of gamma sensitivity for neutron assay. For surveillance applications, this sensitivity can benefit the measurement objective. The PMTs used in past applications have shown both temporal and temperature insensitivity. The scintillating fiber sensors have performed well in field applications and have been space qualified. Their principle technical advantage over ^{3}He tubes is the added active area that provides improved sensitivity.

3. Applications

Panels from 0.5m^2 to 5m^2 can be fabricated for stationary and portable applications. Examples include panels for portal monitors, soil monitors, freight monitors, truck and railway car monitors. A 2m^2 roadbed monitor can measure 10g of weapons grade Pu in 10 seconds at a source to detector distance of 1m. A Pu storage container monitor has been constructed consisting of eight 3.5cm-wide bi-layer ribbons that encircle the container. Encircling the container with ^{3}He tubes would cost many times more than the glass fiber sensor. An extended duration measurement resulted in less than a 3% increase in the neutron channel when 1.8mCi ^{60}Co or 9.5mCi ^{137}Cs source was added to the PuO_2 in the container [7]. Using the criteria $\check{S} = 1 - S/S_{avg}$ provided five identified alarms over a 45 day period. Each alarm was correlated with human activity near the container or other factors. Low-power electronics allow small concealable devices and sensors such as vests for weapons verification. The conformable ribbons are perfectly suited for Pu lung measurements using direct neutron observation rather than relying on the low-intensity gamma rays or low-energy L X-rays. Although the sensors can be flexible, the conformable packaging can be constructed in a fixed geometry to provide a reproducible source to detector geometry. Current product development also includes hand-held devices for lower sensitivity but highly portable customs applications.

The electronics package for these products include the complete analog and coincidence circuits coupled to a microprocessor with local readout and remote data transmission capability. Data taken over present intervals are stored in a 64k non-volatile buffer until transmitted to a central PC or local data logger. Background and efficiency data are stored for both neutrons and gammas to provide output in units of net counts per second or mass of Pu. Alarm set points trigger the unit to provide local or remote visible, audible or tactile alarms.

4. Conclusions

These sensors are better suited and provide superior performance to ^{3}He gas detectors for certain safeguards monitoring and surveillance applications requiring lightweight, large-area sensors. They are also well-suited for small concealable sensors and field applications that are rugged or require unusual form factors.

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