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Neutron Detection with Large Plastic Scintillators for RPM Applications

G. Corre, K. Boudergui, G. Sannie, V. Kondrasovs

***Abstract*— Homeland security requests the use Radiation Portal Monitor (RPM) to detect and differentiate gamma and neutron radiation. Gamma detection is required for illicit transportation of radioactive matter detection. Neutron detection is important to control nonproliferation of enriched material. Manufacturers worldwide propose sensors based on ^{3}He which give the actual state of art in term of neutron detection. The price fluctuations due to the announcement of the shortage of ^{3}He forces manufacturers to find viable alternative. From 10 years sensors providers have the challenge to replace previous ^{3}He detectors that are known to be the most commonly deployed neutron sensor. As ^{3}He detectors can only detect neutron, they must be completed with gamma detector. The proposed approach is based on pulse time correlation between adjacent sensors from signal collected by EJ200 plastic scintillators to detect gamma and neutron. Results obtained during FP7 Scintilla project test campaigns show the system relevance for replacement of today's ^{3}He detectors.**

***Index Terms*— Nuclear measurements, neutrons, gamma rays, Solid scintillation detectors, Security**

I. Introduction

THE Radiation Portal Monitors (RPMs) detect and differentiate gamma and neutron radiation. They are required to control illicit transportation of radioactive matter detection and nonproliferation of enriched material. The system is based on EJ200 plastic scintillator set and a dedicated digital signal processing. This signal processing is used for discrimination of neutron and gamma pulses, since these signals are not inherently well separated by the scintillator itself. These methods include pulse timing, pulse shape, coincidence and dual-detector subtraction algorithms. The scintillators set-up and embedded signal processing are designed to answer to the ANSI [1] and IEC [2] specifications for RPM applications. The section II describes related works based on plastic scintillators to solve the shortage of ^{3}He. The system and its digital signal processing are detailed in section III. Results obtained in laboratory and during the benchmark campaign on the Scintilla project are discussed in section IV.

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II. Related works

A wide range of materials, known to be very sensitive to neutron, were developed and tested, BF3 tubes, B lined tubes, Li Glass Fiber, Non-Scintillating Plastic Fiber [3], [4]. Since 15 years, works on gamma/neutron discrimination with non-loaded plastics scintillators appear in the literature. They allow performing simple, low cost and robust detector sets without any export restriction. A large number of technics are studied to improved detectors sensibility for example by adding Gd sandwich to enhance neutron interaction to gamma interaction [5], [6]. In [7] and [8] two possible approaches to neutron/gamma discrimination are described; one based on digital pulse processing to differentiate pulse types and the other based on low density scintillators to lengthen the time interval between multiple interactions. Results show that these techniques cannot be applied in the context of RPM applications without any improvement. Some works try to change the properties of plastic by introducing other components. In [4], the sensor contains scintillation plate with the mixture of the crystals of znS: Ag (Cu): (6) LiF of those dispersed into the optically transparent medium. The discrimination is done on the shape of pulse. In [5], a good overview of existing technologies and discrimination techniques is done. These methods include pulse timing, pulse shape, coincidence and dual-detector subtraction algorithms. Pulse shape discrimination (PSD) is the most common method to distinguish between pulses produced by gamma rays and neutrons in scintillator detectors. This technic is impractical in non-loaded plastic scintillator since these signals are not inherently well separated by the sensor material itself. The digital signal processing proposed in [8] shows that pulse shape discrimination can be performed on non-loaded scintillator if the signal is well digitized. The main limitation is the sensitivity of distortion introduced by the use of large plastic scintillators or a photomultiplier [9] which not allows its applications on RPM detection system. These limitations are bypassed with the use of multi-scintillator time amplitude analysis as shown in the following section.

III. System Overview

A. System synopsis

The DAQ electronics is designed for the detection of PMT signals (pulse time duration of the order of tens of nanoseconds and total charge of tens of Pico-Coulomb). This is achieved by using multi-ways fast digitizer boards that samples the input signals at 200 MS/s. The digital samples are treated in real time to find the arrival time and amplitude of each pulse. The electronic acquisition system is controlled by an embedded CPU. The pulses induced by gamma and neutron particles in each of the four scintillators are analyzed by adjacent couple of scintillators to evaluate the gamma and neutron counting rates. The system is composed of the following elements:

- four 100x100x1000 mm² EJ 200 plastic scintillators to offer an important detection surface,
- Photomultipliers
- a cadmium slide between each scintillator
- Dedicated acquisition board
- Embedded CPU
- Remote end users PC

The scintillator geometry 100x100x1000 mm^3 offers a large detection surface. The interface between two scintillators allows placing 1x100x1000 mm^3 Cadmium. Fig. 1 describes the setting of one pillar for a vehicle configuration. The use of four pillars is needed to reach the neutron detection performance fixed in the RPM norm. In operating conditions, infrared sensors are added. The computer used for GUI can provide N42.42 file to a distant server at the end of each vehicle move.

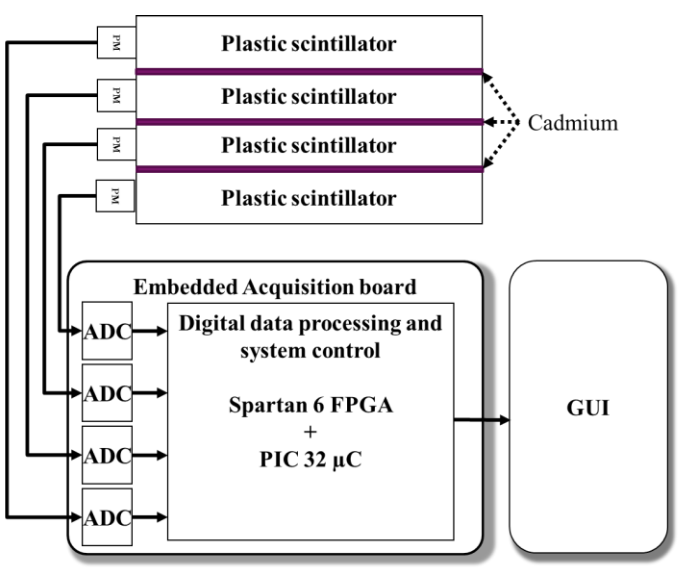

Fig. 1. Detection system synopsis (the set scintillators + embedded acquisition board in duplicated for each additional pillar used)

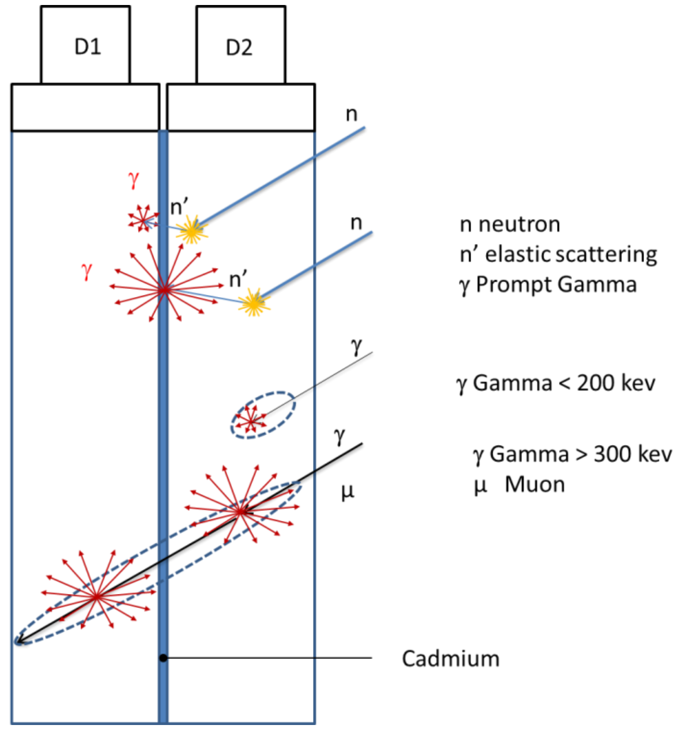

Fig. 2. Particles interactions with Detectors

B. General principle

Our digital signal processing can distinguish the different kind of interaction when they occur in two adjacent scintillators. The process can discriminate gamma, neutron and muon. The detection is based on interaction described in Fig. 2. The neutron interaction can be detected with the recoil proton which ionized atomic layers of plastic atoms and create light. The mean energy of recoil proton is around from 100 Kev to 400 KeV. Neutrons can also generate gamma flash due to high cross section of material such as Cadmium or Gadolinium. The time between a neutron interaction with plastic and a gamma generated by Cadmium is around 20 nanoseconds. The energy level of these two interactions is very different. Detect gamma flash improves the detection of neutrons. A gamma with energy less than 200KeV creates an interaction in only one plastic scintillator. A gamma with higher energy and a muon can interact with two or more scintillators. The time detection between two interaction caused by gamma (or muon) are very close, generally, less than 2 nanoseconds.

C. Neutron/gamma discrimination implementation

The neutron/gamma discrimination is performed into the FPGA. The discrimination is done pulse by pulse in real time and reduces the dead time of the system according to the duration of a pulse. The dead time falls down to 30 nanoseconds. The process discrimination provides real time neutron count rate. Laboratory and ISPRA's test bench show that neutron answer is still full operating, even if the total count rate reaches 2 million counts per second. The algorithm is shown in Fig. 3. The algorithm is described for a pair of scintillator and is duplicated for each pair used in the detection setting. When two pulses arrive in the defined time window, the discrimination process is performed.

```
if  (T(j) – T(i)) < Time_window then
    if A(i) or A(j) > Amp_threshold then
        DeltaA=abs(A(j)-A(i))
        if A(i) < A(j) then
            if (DeltaA>=low_threshold) and (DeltaA<=high_threshold)
                NEUTRON_COUNT_100ms ++
            end if;
        end if:
    end if;
end if;
```

Fig. 3. Neutron gamma discrimination pseudo code for two adjacent detectors

with

- T(i) T(j) : time of arrival of the pulse in neighboring plastic scintillators i and j.
- Time_window: arrival time window coincidence
- A(i) A(j) : amplitude of pulse of neighboring scintillator i and j
- Amp_threshold : if amplitude of a pulse is higher than this threshold, algorithm to detect neutron is applied
- Low_threshold : value must be higher than low_threshold to count neutron
- High_threshold : value must be lower than high_threshold to count neutron
- DeltaA : absolute value of A(i) – A(j)

Consider that a pulse P(i) of amplitude A(i) is created at T(i) in a detector and a pulse P(j) of amplitude A(j) is created at T(j) in its adjacent detector. P(i) is arrived before P(j). If all conditions are met, the number of neutrons is incremented. The neutron counting is read each 100 ms and a moving average is performed to provide the neutron count rate in cps/s.

This treatment is realized on each pair of detectors. In the vehicle configuration, there are 3 adjacent pairs of detectors. The overall neutron count rate is the sum of the results of the three treatments.

IV. Results

A. Preliminary results

The detector system neutron counting rate background is compare to theoretical counting. The study of influence of gamma and muon is performed to verify the neutron counting rate background. The gamma impact on neutron counting rate is realized with a cobalt 60 which generates 1.2 Mcps on four scintillators. There are around 1200 gamma per scintillator that appear in the timing window used to performed neutron gamma discrimination. This high rate does not disturb neutron counting. The muons particles impact is also tested by vary the position of the detection set. The time/amplitude analysis rejects muons and limits their effect on neutron counting rate. In a second step, a mobile source carrier test performed in the laboratory uses a Californium 252 of 10 000 c/s/4π. Two pillars are positioned on each side of the transit source, face to face. The laboratory tests objectives were to find the fine tuning for background threshold to satisfied 1/10 000 rates of alarm or 1 alarm in 2 hours (IEC standards) or 1 in 8 hours as required by ANSI standard. Results of laboratory tests are summarized in Table I.

Table I. Blind Test Results

Speed (m/s)	Number of passages	Number of Neutron detections	% of neutron detections
1,2	294	260	88
1,7	168	122	73
1,95	90	65	72
2,16	60	44	73

B. Blind test at ITRAP+10 Facility, JRC

All tests are based on the ANSI and IEC standards for RPM. The General testing conditions are the following. Dynamic test are performed at a source speed of 8 km/h for vehicle. The portal configuration (distance from source) is full-size double-sided vehicular portals with 5 m distance between pillars.The responses to neutron radiation for RPM-type of equipment is generally performed in dynamic conditions.

1) Neutron detection test

When a testing neutron source passes through a portal at the constant reference speed (as stated above), it should trigger an alarm in 59 cases out of 60 trials. The reference neutron testing source is a Cf-252 source with emission of 20’000 n/s (±20%) shielded with 1 cm steel and 0.5 cm lead. The source effectively used (NC5549) had an emission of 21000 n/s at the date of the tests. The test has been executed also in non-standard conditions, in particular, for lower neutron emission 13’000 n/s and 7’000 n/s, with a 8cm HDPE moderator, and for different source heights, 2.1 m and 2.7 m.

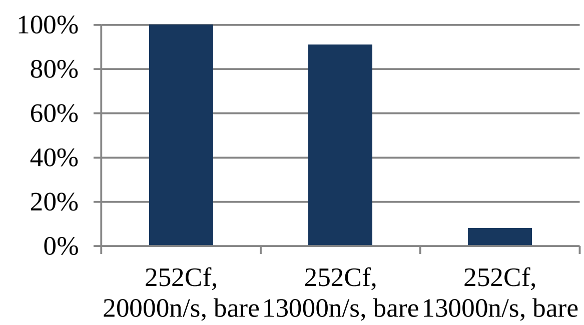

Fig. 4. Detection success rate in function of 252Cf activity

The benchmark results show that the RPM detection system reaches the requirement of ANSI for vehicle. The low counting rate of the system limits their performance because of statistical distribution. The system is 3 times less efficient with the HDPE moderator.

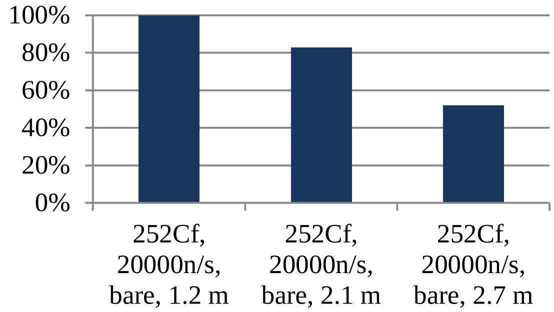

Fig. 5. Detection success rate in function the 252Cf height

The height increase shows that the system has to adapt the pillars detector position to match to another kind of application such as container scanning.

2) False alarm

The false alarm rate in a background measurement condition is relatively close to the rate defined in [1] and [2]. Tests are carried out to verify if strong gamma source do not create false alarm in absence of neutron and do not disturb neutron detection in presence of neutron. A 137Cs source is used and do not create neutron detection disturbing until 2 million cps.

V. Conclusion

This work shows that it is possible to use standard plastic scintillators for RPM applications. The proposed approach based on a multi-scintillators EJ-200 and its dedicated time-amplitude analysis provides good results compared to RPM requirement. Some additional works on identification are currently done. This system would then become a real and complete alternative to the ^{3}He. It is also less expensive than boron lined systems, and safer than BF_3 system. This kind of systems can be used in a wide range of security applications.

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