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Progress Report on the Phoswich Neutron Detector to Measure High-Energetic Neutron Spectra Onboard an Aircraft and a Spacecraft

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The phoswich neutron detector was completed and experiments were made to measure neturon spectrum in a neutron and proton mixed radiation field. The phoswich neutron detector has been improved for high-energetic neutron measurement onboard aircrafts and spacecrafts. The detector is composed of a harmless and biodegrable liquid scintillator, a slow plastic scintillator and a short photomultiplier tube. A pulse shape is captured with data acquisition board. To confirm collected signal and define particle discrimination parameter, a pulse shape is also acquired with a digital storage oscilloscope.

KEYWORDS: neutron, proton, phoswich detector, particle discrimination, pulse shape, liquid scintillator, plastic scintillator, photomultiplier tube, aircraft, spacecraft

I. Introduction

Radiation protection inside a large human spacecraft and in an airplane is necessary for aircrews and astronauts. Particle dose equivalent at high altidude was calculated with LUIN-2000 code,[1)] as shown in **Fig.1**. Neutron indicates large part of dose equivalent with a trans-pacific aircraft crusing altitude. Calculation shows 3.45 μSv/hr at 12 km height above Tokyo for total dose equivalent and 1.3 μSv/hr for neutron dose equivalent that covers almost 40-50%. Neutron is main component in radiation exposure on these crews. Though charged particle data have been measured sufficiently, limited neutron data has been measured. Neutron energy spectra at high altitude have been measured by using the bonner ball spectrometer[2,3)] and with balloon-borne detector.[4)] Neutron spectrum outside spacecraft hitherto been measured with COMPTEL,[5)] and neutron dose equivalent in an spacecraft was measured with multispherical neutron detector during about 100 days.[6)] Neutron measurement for radiation protection has never been done sufficiently, because neutron instruments are required to discriminate neutrons from charged particles in the radiation environment that is highly complex due to the coexistence of charged and neutral particles. We developed the phoswich neutron detector for neutron measurement in these radiation environment.[7,8)] Good performance to distinguish neutron events from charged-particle events, and neutron energy spectrum in neutron and charged-particle mixed radiation fields were obtained by using our developed phoswich detector with accelerator beam experiment. It was difficult to carry this detector in an aircraft, because the detector contains harmful liquid scintillator. In this work, we have improved a neutron detector system to be able to carry the detector in aircrafts easily. We plan to measure the neutron energy spectum, thermal neutron to over 100 MeV by using two types of the neutron detectors. One is the bonner ball spectrometer for neutron measurement from thermal neutron to a few MeV, and the other is the phoswich neutron detector for neutron measurement from a few MeV to over 100 MeV.

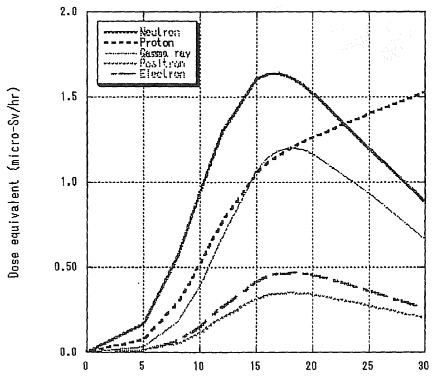

Fig. 1 Particle dose equivalent at high altitude calculated with LUIN2000[1)]

II. Detector System

The phoswich neutron detector and the data acquisition system are installed in the measurement box, as show in **Fig.2**. In **Fig.2**, the upper and lower pieces of the measurement box consist of the data acquisition unit and the neutron detector unit, respectively. The detector unit is fasten to the measurement box. The system power is supplied from an aircraft outlet or a rechargeable battery. The detector consists of two types of scintillator and a photomultiplier tube as shown in **Fig.3**. Two different decay-time scitillators are used to distin-

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guish incident neutron from incident charged-particle events by using different pulse shapes. A neutron produces short decay-time signal, and a proton produces long decay-time signal. The neutron detector measures 38 cm length by 19 cm diameter. It consists of a hollow right circular cylinder of plastic scintillator, EJ-299-13[9] with the interior filled with a liquid scintillator, EJ-399-06.[9] The plastic scintillator cylinder is 21.1 cm diameter by 21.1 cm long with a 1.5 cm wall thickness all around. The interior wall is lined with a 2 mm thick layer of clear and colorless acrylic plastic to provide an inert barrier between the liquid and the plastic scintillators. The scintillator unit is coupled to single short photomultiplier tube with wide dynamic range. Shock is absorbed by a pressure ring support. In this work, harmless scintillator and short photomultiplier tube are used for the high-energetic neutron detector.

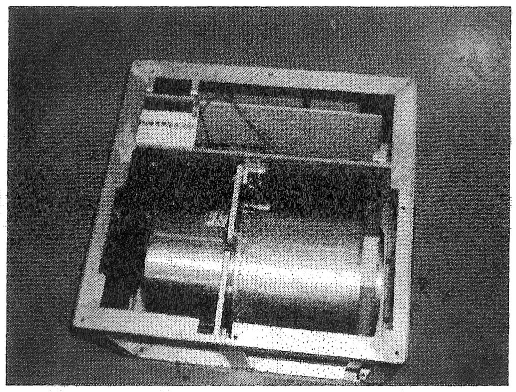

Fig. 2 Picture of the neutron measreument box, including the phoswich neutron detector and the data acquisition board.

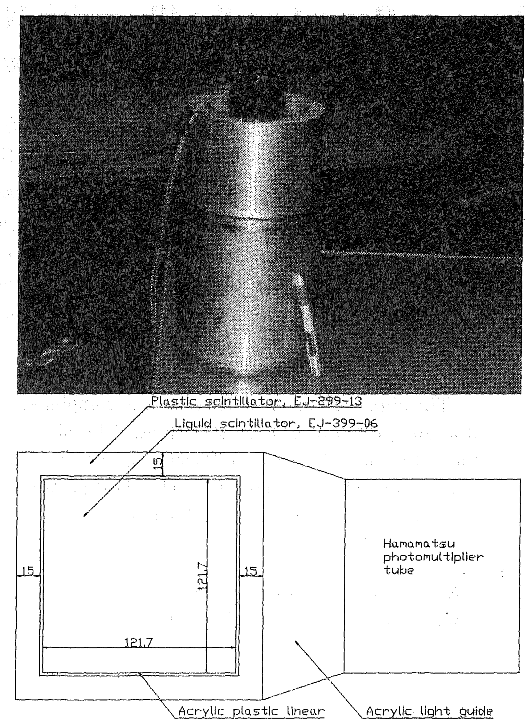

Fig. 3 Picture (upper) and configuration (lower) of the phoswich neutron detector

Table 1 Physical property of liquid scintillators, EJ-399-06 and BC501A[10]

Specifications	EJ-399-06	BC-501A
Light output (% of Antracene)	60%	78%
Wavelength of max. emission	425 nm	425 nm
Decay time of short component	3.5 nsec	3.2 nsec
Density (g/cm^3)	0.9	0.874
Flash point	138 $^\circ C$	26 $^\circ C$
H:C ratio	1.61	1.212

1. Scintillators

The neutron detector is composed of two types of scintillators with different decay time constants. One is EJ-399-06 liquid scintillator, and the others is EJ-299-13 slow plastic scintillator, produced by ELJEN Technology. TX.[9] An EJ-399-06 liquid scintillator provides excellent pulse shape discrimination properties. The basic properties show almost compatible to EJ-301, equivalent to BC501A scintillator as shown in **table 1**. This scintillator is improved with its chemical formulation to provide very low solvent action and low flammability characteristics. The improved liquid scintillator shows great advantage about low chemical toxicity and biodegradability. This scintillator is suitable to measure high-energetic neutron by carrying the detector in aircrafts.

EJ-299-13 has a principal slow scintillation decay time of approximately 280 nsec. EJ-299-13 was formulated to be resistant to the chemical activity of the liquid scintillator. EJ-399-06 and EJ-299-13 have never been attacked each other chemically for over 5 years.

2. Photomultiplier tube

The photomultiplier tube (PMT) was made short, based on 12.7 cm diameter PMT, R4144. The length of our PMT including a base, 16.5 cm is almost one half of that of R4144 PMT, 39 cm. Our PMT has wide dynamic range that 5% pulse linearity keeps up to 100 mA. But rise time, 4.4 nsec and signal width, 10.7 nsec are made worse than that of R4144 PMT as shown in **table 2**. Pulse shape discrimination is not effected large by worse timing response with our PMT.

III. Data Acquisition

By different pulse shapes, neutron and proton events are discriminated each other. Charge integration method by using two different gates, total and slow gates, has been used for particle discrimination with the phoswich detector.[12] This method shows a good performance of pulse shape discrimination. In this work, new method has been tried to capture signal

Table 2 Property of photomultiplier tube, PMT[11)]

Specifications	our PMT	R4144
Length	16.5 cm	39 cm
Rise time	1.5 nsec	4.4 nsec
Signal width	3.75 nsec	10.7 nsec
Gain	1.5×10^6	1.6×10^6
2% pulse linearity	100 mA	160 mA

directly from the neutron detector by using a digital storage osilloscope[14)] and the data acquisition board for onboard measurement where a fast ADC is installed. This method shows great advantage of taking out the maximum amount of information from the neutron detector. This increases count rate providing sucessful discrimination and has no dead time in the traditional sense because detected events can be trace during sampling period. For dead time of this method, it is considered that conversion data are sent to a storage medium. This method provides easy measurement system for signal from the scintillator, because it is unnecessary to use complicated electrical modules.

1. Digital oscilloscope

The digital oscilloscope (DSO), DS4374[13)] with bandwidth 500 MHz was used to identify detected signals with our acquisition system and make PSD better. This DSO includes an analog-to-digital conversion (ADC) system that samples waveform in a read time mode at rates of 2G sample per second, equivalent to 0.5 nsec/pt, to 8 bit code. The waveform traces with 1000 segments each were stored to PC ATA card. Signal from the neutron detector is divided to three different gain amplifiers (10, 50, and 200 mV/div.) to measure signals of wide dynamic range with good pulse height resolution. Three divided signals are combined to obtain an original signal.

2. Acquisition board

On neutron measurement on board aircrafts, signals are acquired with a data acquistion board that sample rate is 10 nsec/pt with 8 bit code. Data acquistion starts with trigger level -0.1 V, and pulse shape is captured every 10 nsec during 200 nsec with 20 points. For total energy pulse height, signal charge is intergrated during 100 nsec. Pulse height and pulse shape data are stored in a memory, labelled with a trigger time stamp. One event needs to be measured during only 1 μsec, that includes simple pulse discrimination and data store into a memory. Count rate can increase over 100 kHz, and counter in the system can measure high rate event about 10 MHz. After measurement, pulse data is analyzed off line. This sysytem has been improved to obtain clear pulse shape and shows better PSD.

IV. Pulse Shape

We demonstrate to discrimination neutron events from proton events. Pulse shapes were captured by using the DSO. The detector was supplied at the voltage, -1050 V. Neutron and proton pulse shapes were measured at the NIRS-cyclotron[15)] and HIMAC[16)] in the National Institute of Radiological Sciences (NIRS), Chiba, Japan. Neutrons were produced by the bombarding of 70 and 160 MeV protons on a full-stopping length graphite target, 4 cm and 13 cm, at the NIRS-cyclotron and the HIMAC, respectively. As HIMAC experiment, the detector was placed at 2.3 m downstream from a target and proton beam intensity was measured to be 1.2×10^8 (protons/sec). Proton beam intensity was decreased to about 1×10^3 (proton/sec) in order to irradiate proton beam to the detector directly. Proton energies were decelerated with an aluminium plate, from 50 to 150 MeV. On proton measurements, a 3 mm thick plastic scintillator is placed at the upstream of the phoswich detector to trigger proton event. After neutron and proton pulse shapes were captured with different pulse heights and different incident proton energis, respetively, these signals were normalized at peak pulse height, as shown in **Fig.4**. The threshold levels for neutron signal were set to be -1.2, -1.8, -2.4 and -2.7 V. Incident proton energies were decelerated to be 74, 92, 107, 121, 134 and 139 MeV. Trigger time of these signals is adjusted to show same time at a signal voltage, -0.2 V.

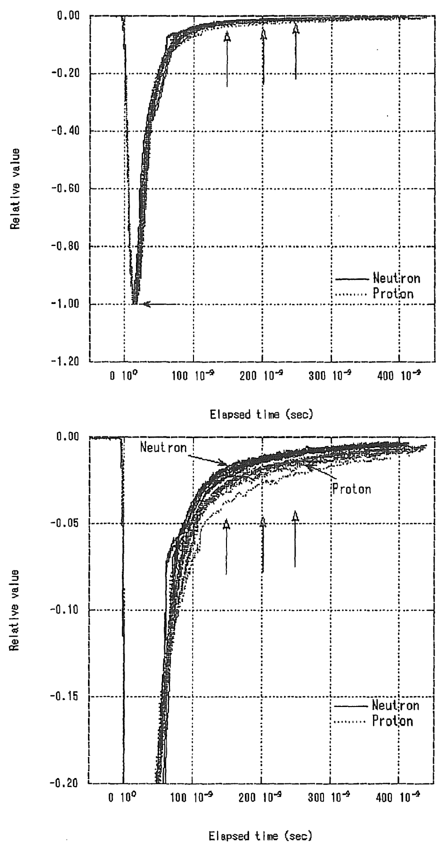

Fig. 4 Neutron and proton pulse shapes normalized at peak value (top), and magnified signal tails from 0 to -0.2 V (bottom)

Difference between neutron and proton pulse shapes shown in the top of **Fig.4** cannot be found. But by pointing signal tail, as shown in the bottom of **Fig.4**, the difference between neutron and proton pulse shapes is observed clearly at the time, 100 to 300 nsec elapsed after trigger time. By using these different pulse heights, neutron and proton signals can be identified each other.

As pulse shape discrimination, three methods are considered in this work. The first is charge integration by using two different gates, the second is pulse height level at any particular time elapsed after trigger time, and the last is considered to fit signal to a sum of three exponential formulas. We need to study particle discrimination more.

V. Conclusion

The harmless and compact neutron detector system to measure neutron energy spectrum on board aircrafts has been completed. Neutron and proton pulse shapes captured with a digital storage oscilloscope were demonstrated to show different signal tails. This difference is important to discriminate neutrons from charged particles. We will measure neutron spectrum at high altitude next year.

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