**NEUTRON SURVEY METER USING PRESCILA PROBE**

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**Abstract:**

This paper presents the design and validation of a neutron survey meter. The meter consists of a PRESCILA neutron probe (with good sensitivity, directional response, gamma rejection, and enhanced high-energy response to 20 MeV) and an electrometer developed at Non-Destructive Evaluation center. The homogeneity response of the PRESCILA neutron probe was investigated as a function of distances from the source in order to obtain the appropriate distance for accurate count-rate measurements using the neutron survey meter. A system consists of the PRESCILA neutron probe and the Ludlum Model 2326 electrometer was then used for measuring neutron dose equivalent rates in the range from 50 cm to 200 cm with the step of 25 cm. The relationship between the count-rate and neutron dose equivalent rates (in the distance ranged from 50 cm to 200 cm) were deduced to validate the proper operation of the neutron survey meter.

**Keywords:** Neutron survey meter, PRESCILA neutron probe, Ludlum electrometer.

**I. INTRODUCTION**

A neutron survey meter normally constitutes of an electrometer and a single neutron detector or multiple detectors. Conventional neutron rem meters currently in use are based on 1960s technology that relies on a large neutron moderator assembly surrounding a thermal detector to achieve a rem-like response function over a limited  
energy range [3]. Such rem meters present an ergonomic challenge, being heavy  
and bulky, and have caused injuries during radiation protection surveys.  
Another defect of traditional rem meters is a poor high-energy response  
above 10 MeV, which makes them unsuitable for applications at high-energy  
accelerator facilities [3].

Proton Recoil Scintillator – Los Alamos (PRESCILA) was developed as a low-weight (2 kg) alternative capable of extended energy response, high sensitivity, and moderate gamma rejection [3].

In this paper, a neutron survey meter consists of a PRESCILA neutron probe (with good sensitivity, directional response, gamma rejection, and enhanced high-energy response to 20 MeV) and a self-developed electrometer was manufactured by Non-Destructive Evaluation (NDE) center for the purpose of occupational radiation safety assessment. The validation of proper operation of the survey meter was also investigated.

**II. MATERIAL AND METHOD**

*II.1. PRESCILA neutron probe*

The model 42-41L PRESCILA neutron probe developed by the Health, Safety, and Radiation Protection Division at the Los Alamos National Laboratory has internal lead shield on each of the five faces of the detector. The lead shield thickness is only 0.017 inch to reduce the gamma interference of low energy photons. The probe is capable of excellent sensitivity (40 counts per minute (cpm) per μSvh-1 for 241AmBe) and extended energy response to beyond 20 MeV. Directional response is uniform (+/-15%) over a wide range of energies. Response linearity has been characterized to over 20 mSvh-1. Gamma rejection is effective in gamma fields up to 2 mSvh-1 [3].

The 3D view of the PRESCILA probe is shown in Fig.(1a) and the descriptions are seen in Fig.(1b). Where, “*11*” is a light guide; “*11a*” is the central penetration beamline; “*12-13-14*” are the top, bottom, and the side plates with 5% borated polyethylene, respectively; “*12a*” is a central aperture; “*15*” is central apertures for insertion of fast neutron scintillators (ZnS(Ag)+plastic); “*16*” is a cadmium (Cd) filter; “*17*” is a thermal neutron scintillator (ZnS(Ag)+6LiF); “*18*” is a plastic spacer; 19 is a photomultiplier tube (PMT) and “*20*” is a handle.

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| *(a): 3D outer view* | *(b): different components* |
| **Fig. 1: PRESCILA (Model 42-41L) neutron probe** | |

Principle of detection of fast scintillator:

(1)

Principle of detection of thermal scintillator:

(2)

*II.2. Commercial neutron survey meter*

A commercial gamma/neutron survey meter consists of a model 2363 Ludlum electrometer and the model 42-41L PRESCILA neutron probe was used in this paper in order to measure neutron dose equivalent rates at various distances from the source. Fig. 2 shows the gamma/neutron detection system combines Ludlum Model 2363 survey meter with the Model 42-41L PRESCILA neutron detector.

The meter has an energy-compensated GM allow gamma detection and a neutron detector using a proton recoil scintillator type. The meter is significantly lighter than other traditional REM balls [1].

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| **Fig. 2: Neutron survey meter consists of a model 2326 Ludlum electrometer and a model 42-41L PRESCILA neutron probe** |

A dual-scintillator ZnS(Ag)+6LiF and ZnS(Ag) + plastic, using both fast and thermal types, made it possible to balance the overall energy response and provide adequate response in the crossover region between the thermal and fast elements. The goal was to develop a practical low-weight (2 kg) rem meter with good sensitivity, directional response, gamma rejection, and enhanced high-energy response [3].

*II.3. Electrometer designed by NDE*

A block of analog electronic components known as an electrometer was manufactured by NDE center. The electronic diagram of the neutron meter is shown in Fig.3 with the hardware consits of the following parts: High voltage power supply, Pre-Amplier, Pusle shapper, Pusle discriminator, Counter, RS 232 interface and Graphic LCD. The dual-scintillator detector generates the pulse charge output by the backward photon. The charge is converted to voltage by the charge pre-amplifier. The longwidth signal is converted to a practical pulse signal by using a shaping amplifier, and then to logic pulse for digital counting by discriminator. Microcontroller counts thepulses from detectors to obtain the count rate [cpm], which were transmitted to the PC by serial communication RS-232 for calculation.The microprocessor-based central processing unit controls the counting, calculating, displaying of results on a graphic LCD monitor and implements the user interface through the integrated function keys. Pulse discrimination was put in block to reject gamma field. This electrometer was then connected to the model 42-41L PRESCILA neutron probe to create a neutron survey meter.

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| **Fig. 3: Neutron survey meter consists of a commercial model 42-41L PRESCILA neutron probe and an electrometer designed at NDE (the component inside the dashed line)** |

The design goal was to balance the under response in the range  
from about 0.1 MeV to 2 MeV by an over response below 0.1 MeV that  
would give the most accurate results for a range of practical field spectra, with the applied radiation weighting factor (WR =10), so when the calibration dose is much simpler (usually using the energy of the neutron emitted by ). The detail is shown in Fig. 4.

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| **Fig. 4: Neutron detection efficiency and balance energies.** |

**III. RESULT AND DISCUSSION**

*III.1. Investigation of the effective distance*

The use of both fast and thermal scintllator allows the energy response function to be optimized for a wide range of operational spectra. Therefore, investigation of appropriate effective distance is necessary*.*

The self-developed neutron survey meter was used to measure the count rate caused by 02 a bare neutron sources strengths of 80 mCi and 40 mCi. is an anpha neutron source with average neutron energy 4.2 MeV. In this experimental 02 source were placed parallel to the detector surface. The experimental setup can be seen in Fig.5.

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| sơ đồ bố trí.png |
| **Fig. 5: Experimental setup for investigating the effective distance** |

#### The total count rates were measured in the distance range from 0 cm to 75 cm with a step of 15 cm (at each distance, measurements were performed 25 times with each side 5 times). The average count rate at each distance was calculated as shown in Table 1. Where, “*D*” is distance from source to detector; “*Side ABC*” is one of four sides fast scintillator of probe; “*SD*” is standard deviation; “*A*” is the count rates averaged over all of five sides; “*P*” is the detection probability which is a function of distance from the source (“P” is Confidence intervals of value average with each distance ). The “P” values are shown in the Table 1. The effective distance for the measurements using the self-developed neutron survey meter was chosen at the distances greater than ones those have the “*P*” value greater than 95% (i.e. 0.95).

**Table 1: The count rates (cpm) caused by 02 neutron sources were measured by the self-developed neutron survey meter as a function of distances**

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| ***D (cm)*** | ***Thermal*** | ***Side I*** | ***Side II*** | ***Side III*** | ***Side IV*** | ***A*** | ***SD*** | ***P (%)*** |
| ***Count  rate  (cpm)*** | ***Count  rate (cpm)*** | ***Count  rate (cpm)*** | ***Count  rate (cpm)*** | ***Count  rate (cpm)*** |
| 0 | 1106.2 | 1512.0 | 1447.4 | 1473.6 | 1616.0 | 1431.0 | 180.9 | 60.0 |
| 15 | 342.8 | 399.0 | 394.8 | 413.8 | 416.8 | 393.4 | 31.5 | 70.0 |
| 30 | 188.2 | 197.0 | 202.6 | 209.6 | 217.0 | 202.9 | 14.9 | 85.0 |
| 45 | 117.8 | 131.2 | 121.8 | 130.4 | 135.8 | 127.4 | 14.5 | 95.0 |
| 60 | 83.8 | 87.6 | 86.0 | 88.8 | 88.8 | 87.0 | 6.6 | 99.0 |
| 75 | 61.8 | 64.0 | 62.4 | 63.8 | 62.8 | 63.0 | 5.4 | 99.5 |
| P: probability as Confidence intervals of value average with each distance. | | | | | | | | |

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| **Fig. 6: Detection probability of self-developed neutron survey meter** |

*III.2. Investigation of angular dependence of the self-developed neutron survey meter.*

The angular dependence of the PRESCILA probe was investigated at 5 sides consist 4 thermal sides and one fast side at three reference point 50, 75cm and 100cm distances from source to probe. Data were collected for both X-Y and X-Z planes of rotation (Z-axis being defined along the handle of the probe). The results are presented in Fig 7. The maximum deviation, about 23% over response, was measured at 50cm distances for the bottom facet of the probe.

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| **Fig. 7: The homogeneity response of the self-developed neutron survey meter** |

*III.3. Validation of the self-developed neutron survey meter*

Once the effective distance from the source to the detector was obtained for the self-developed neutron survey meter, the neutron dose equivalent rates were measured using the commercial neutron survey meter in the distance range from 50 cm to 200 cm with a step of 25 cm. The total count rates were also measured using the self-developed neutron survey meter in the same distance range from 50 cm to 200 cm with the same step of 25 cm. The total count rates were then fitted as a function of the neutron dose equivalent rates whose relationship is shown in Fig. 8.

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| **Fig. 8: Neutron dose equivalent rate (μSv/h, measured by a commercial neutron survey meter) as a function of the total count rate (cpm, measured by the self-developed neutron survey meter)** |

The results in this section illustrate that the proposed fitting function can be practically applied to calculate the conventional value of the ambient dose equivalent rate for the purpose of radiation safety assessment. The discrepancy between the calculated and [measured values](https://www.sciencedirect.com/topics/engineering/measured-value) is found to be about 10%.

**IV. CONCLUSION**

In this paper, the neutron survey meter was designed based on the commercial neutron probe (model 42-41L PRESCILA neutron detector) and a self-developed electrometer. The effective distance for the measurements using the meter was investigated. The other characteristics of the neutron survey meter were also evaluated, such as the homogeneity response, the dose equivalent rate response. The neutron survey meter will be completed and calibrated at the secondary standard dosimetry laboratory at the Institute for Nuclear Science and Technology to improve accuracy of the device. Moreover the device will have to undergo testing in the laboratory to assess the capabilities, features of equipment, including technical characteristics of the equipment: sensitivity, energy range, gamma noise, dose rate range. In the future, to evaluate adaptability of the device, the survey must be performed on the variety of source radiation as the sources from equipment in the industry, in instrumentation, radiation secondary accelerator energy 10MeV and reactors.

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