“NSN4” Neutron Scintillation Survey Meter

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Fuji Electric has developed the “NSN4” neutron scintillation*1 survey meter that can measure the 1-cm ambient dose equivalent rate*2 at nuclear facilities, accelerator facilities and advanced medical facilities. ^{3}He*3 is currently the most widely used material for neutron detectors. Its supply is limited because it is almost non-existent in nature and is produced artificially. Furthermore, its supply is susceptible to international circumstances. In particular, the demand for ^{3}He has increased worldwide because it has been being used to test suspicious substances, such as radioactive materials, in counter-terrorism activities. This has increased its price and made it even more difficult to procure. It is against this backdrop that Fuji Electric has commercialized a neutron scintillation survey meter that does not use ^{3}He. To achieve this, the detector uses a scintillator*4, which emits light when radiation is incident. Figure 1 shows the external appearance of the meter.

1. Neutron Measurement Principles

The NSN4 uses LiF/CaF_2:Eu eutectic composites*5 (1) for the scintillator to detect neutrons. The eutectic composites have a structure that combines a LiF layer and Eu-doped CaF_2 layer in the crystal. When neutrons are incident on the eutectic composites, the ^{6}Li contained in the LiF layer produces a neutron capture reaction that generates charged particles such as alpha rays. When the charged particles pass through the Eu-doped CaF_2 layer of the scintillator, it emits the imparted energy from the charged particles as scintillation light. The LiF/CaF_2:Eu eutectic composites are nearly colorless and transparent. As shown in the conceptual diagram of Fig. 2, neutrons are measured by introducing the light generated inside the composite into the photomultiplier tube using a light guide and capturing them as an electrical signal.

Fig.1 “NSN4”

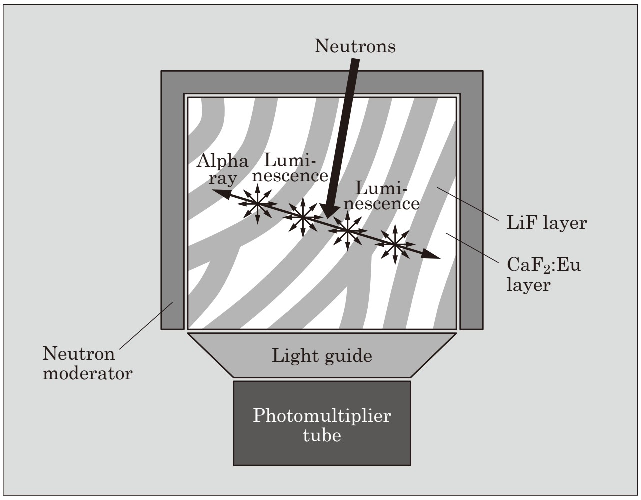

Fig.2 Conceptual diagram of the “NSN4” measurement principle

The LiF/CaF_2:Eu eutectic composites are characterized by a large amount of emission luminance per unit of imparted energy. They also exhibit an emission wavelength that is suitable for the light-receiving sensitivity of the photomultiplier tube. It is also chemically stable, which makes it easy to process and handle.

2. “NSN4” Features

2.1 Stable supply of products

The supply of the neutron detectors that use ^{3}He is also limited like ^{3}He and need to be imported from abroad. In contrast, the NSN4 uses a scintillator that can be stably produced in Japan for the detector. This solves the supply shortage problem that conventional products face.

2.2 Weight savings

The mass of conventional products that use ^{3}He is approximately 7 kg. In contrast, the NSN4 weighs

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only approximately 3.7 kg. We achieved this light weight by optimizing the eutectic composites size and ^{6}Li content, as well as the structure of the neutron moderator that surrounds the eutectic composites. The usability has thus improved, making it easier for workers to carry it around nuclear facilities.

2.3 Compatibility with international markets

We expect that the NSN4 will be in demand overseas due to the current supply instability of neutron detectors throughout the world. The NSN4 complies with the international standard IEC 61005:2014 and has obtained the CE marking, and it can be sold and used in many countries and regions outside Japan. Furthermore, we provide users with software and calibration procedures so that they can perform inspection and calibration using neutron radiation sources.

Table 1 Specifications and functionality of "NSN4"

Item	Specifications and functions
Radiation type	Neutron
Measurement energy range	0.025 eV to 15 MeV
Detector	LiF/CaF_2:Eu eutectic composites
Moderator	Polyethylene
1-cm ambient dose equivalent rate effective measurement range	0.1 μSv/h to 99.99 mSv/h
1-cm ambient dose equivalent effective measurement range	0.01 μSv to 99.99 mSv
Dose rate measurement accuracy	±20% or less (at 10 μSv/h)
Dose measurement accuracy	±20% or less (at 1 μSv)
Energy dependence	Compliance with ICRP publ.74 H*(10)/ϕ response curve
Direction dependence	±25% (0 to ±90°)
Dose rate characteristics	±20% (reference value of 10 μSv/h)
Gamma sensitivity	1% or less up to 10 mSv/h for ^{137}Cs
Display	LCD screen
Display range	Digital 5-digit display (automatic unit switching) Dose rate: 0.00 to 999.99 μSv/h 1.00 to 99.99 mSv/h Cumulative dose: 0.00 to 999.99 μSv 1.00 to 99.99 mSv
External output	USB serial communication
Power supply	○ Primary batteries (six AA alkaline batteries) ○ Secondary batteries (six AA Ni-MH batteries) ○ Commercial AC power supply (AC adapter)
Trend function	No. of records: Up to 1,200 Recording cycle: Selectable from 10 s, 20 s, 30 s, 60 s, 120 s, 300 s, and 600 s Recorded contents: Unit number, measurement date/time, dose rate, cumulative dose, trend cycle, correction count, battery voltage, high-voltage setting value
Continuous operating time	12 hours or more
Operating temperature range	−10 °C to +45 °C
Operating humidity range	35% to 90% (no condensation)
Dimensions	W150 × H250 × L300 (mm)
Mass	Approximately 3.7 kg

3. Specification and Functionality

Table 1 shows the specifications and functionality of the NSN4. The NSN4 complies with JIS Z 4341:2006 (Neutron ambient dose equivalent (rate) meters) and IEC 61005:2014 (Radiation protection instrumentation-Neutron ambient dose equivalent (rate) meters). Figure 3 shows the ambient dose equivalent response*[6] to continuous-energy neutrons, and Fig. 4 shows the fluence*[7] response to monoenergetic neutrons. As shown in Fig. 3, the favorable responses (the ambient dose equivalent responses of 0.5 or higher) were obtained over a wide energy range, including low-energy regions where graphite-moderated thermal neutrons are located. Figure 4 shows the calculation results of the particle and heavy ion transport code system (PHITS)*[8] [(2)] in addition to the actual ir-

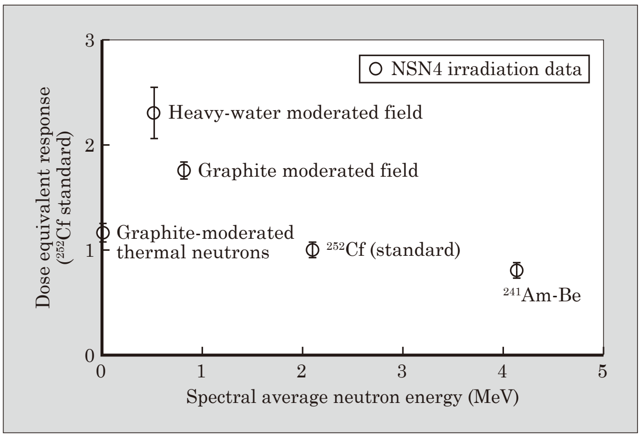

Fig.3 Ambient dose equivalent response to continuous-energy neutrons

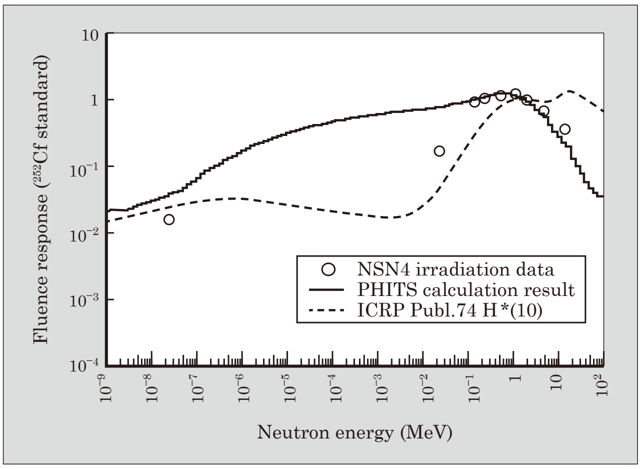

Fig.4 Fluence response to monochromatic energetic neutrons

radiation data because the monoenergetic neutron fields that can be used for irradiation tests are limited. We achieved responses close to the response curve of ICRP74 over a wide energy range of 8 orders of magnitude or more.

Acknowledgment

We developed the NSN4 with the help of Associate Professor Kenichi Watanabe of the Graduate School of Engineering, Nagoya University and in collaboration with Tokuyama Corporation. We would like to express our gratitude to all those involved in the development.

*1 Scintillation: A phenomenon in which radiation excites atoms or molecules in a substance, causing this excitation energy to be emitted as light. It also refers to the emitted light.

*2 1-cm ambient dose equivalent (rate): The ambient dose equivalent (rate) at a depth of 1 cm above the main axis from the incident surface along the direction of incidence when the ICRU sphere is irradiated with a unidirectional plane-parallel beam of neutrons or photons. The 1-cm ambient dose equivalent rate of neutrons is obtained by multiplying the fluence by the conversion coefficient.

*3 ^{3}He: One of the isotopes of He. The abundance ratio in the atmosphere is approximately one millionth of that of ^{4}He. ^{3}He is produced by beta decay (half-life of 12.3 years) of tritium (^{3}H) obtained by irradiating lithium (^{6}Li) with a proton beam.

*4 Scintillator: A general term for a substance that causes scintillation. It is widely used as a radiation detector.

*5 Eutectic composite: A compound of two or more crystals that simultaneously precipitate from a liquid containing two or more components.

*6 Response: the value obtained by dividing the measured value by the reference value.

*7 Fluence: the value obtained by dividing dN by da when dN corresponds to the number of neutrons incident on a sphere with cross section da.

*8 PHITS: a Monte Carlo particle transport simulation code that can be used in the simulation of various radiation behaviors in all kinds of substances using nuclear reaction models and nuclear data. The Japan Atomic Energy Agency (JAEA) is the primary developer of PHITS.

References

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(2) Sato, T. et al. "Features of Particle and Heavy Ion Transport code System (PHITS) version 3.02", J. Nucl. Sci. Technol. 55(5-6), 2018, p.684-690.

Launch Date

January 2020

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