Recent Activities on Neutron Standardization at the Electrotechnical Laboratory

K. Kudo, N. Takeda, S. Koshikawa and A. Uritani

Quantum Radiation Division, National Metrology Institute of Japan (NMIJ)

National Institute of Advanced Industrial Science and Technology (AIST)

1. Photon spectrometry in thermal neutron standard field

It is often necessary in neutron calibration fields to determine the dose of γ-rays produced in a neutron source and in the surroundings because some types of neutron detector are sensitive both to neutrons and γ-rays. We developed a ^{3}He-filtered GM counter to measure γ-ray dose in a standard field of thermal neutrons [1]. However, the energy spectrum of γ-rays was determined only by the MCNP calculation, but not by an experimental method.

To determine the energy spectrum of γ-rays experimentally, we used a conventional NE213 scintillation counter in a thermal neutron field located at the outside of a graphite pile (rectangular size: 190 cm x 190 cm x 230 cm). A neutron source of Am-Be (148GBq, 9.13x10^{6} n/s) was located at the center of the graphite pile. The scintillator was encapsulated in a standard BA1 cylindrical cell (inner size: 5.08 cm in diameter and 5.08 cm long). Conventional measurement of pulse shape discrimination and multi-parameter data acquisition was used to process signals from a photo-multiplier tube (R329-02, Hamamatsu) and to separate photon signals from those neutron-induced. To remove thermal neutron-induced photons in the NE213 scintillator, natural lithium fluoride (LiF) powder was used to shield the NE213 scintillation counter assembly. Natural LiF contains 7.5% of ^{6}Li that results in producing only charged particles by the reaction of ^{6}Li(n,α)T.

The γ-ray response function of the NE213 scintillation counter was measured using γ-ray reference sources of ^{88}Y, ^{60}Co, ^{22}Na, ^{54}Mn and ^{137}Cs (Amersham Buchler GmbH & Co KG). To calibrate the NE213 scintillation counter, The sources were positioned 23 cm from the center of the NE213 scintillator on the cylindrical axis. Above 3 MeV, the response function was measured using a laser-Compton-scattered (LCS) photon beam [2] to determine the nonlinear relationship between electron-deposited energy and light output from the NE213 counter assembly [3].

The γ-ray response function for the NE213 scintillation counter was calculated using EGS4 code [4] coupled with the parameter-reduced electron-step transport algorithm (PRESTA) routine developed to minimize the dependence of results on step size in electron transport simulation [5].

The response functions for reference γ-ray sources were calculated under the following assumptions: (1) the reference γ-ray source was assumed to be an isotropic point source, and (2) the calculation model and composition of the NE213 detector assembly were chosen precisely.

In the calculation of the response function matrix used for photon spectrometry in the thermal neutron field, a plane source of γ-rays was assumed to be located on the surface of the graphite pile and to have a uniform space-distribution on the surface. Energy intervals for calculating the response function were chosen as (1) 100 keV in an energy range up to 400 keV, (2) 20 keV in a range from 400 keV to 1.9 MeV, and (3) 100 keV or 200 keV from 1.9 MeV to 10 MeV. The pulse height axis was divided into 1,000 channels corresponding to an energy bin width of 10 keV/channel.

We used the HEPRO program package to unfold the measured pulse height spectra, choosing GRAVEL and MIEKE codes because of their better results [6-8]. GRAVEL unfolds using a modified SAND-II algorithm. MIEKE is a Monte Carlo unfolding code including uncertainty analysis. The pulse height distributions of photons measured for reference γ-ray sources and in the thermal neutron field were unfolded to obtain energy distributions.

Pulse height spectra measured for reference γ-ray sources of ^{88}Y, ^{60}Co, ^{22}Na, ^{54}Mn and ^{137}Cs were compared to response functions calculated by EGS4/PRESTA code. The calculated spectrum was folded with pulse-height dependent resolution assumed to be $dL/L = B/L^{1/2}$, with light output L and parameter B to be adjusted, including only the region of the Compton edge and fitted to the measured distribution [9]. By changing parameter B appropriately, a distribution best-fitted to the experimental spectrum was determined by a least square fit and precise Compton-edge positions (arrows) were determined for reference sources. An example is the result of ^{88}Y in Fig. 1-(a).

The light output function of the NE213 scintillator resulted in linear output relationship, expressed as $L=E_e$ - 0.0065 between measured pulse height L and corresponding equivalent electron energy E_e in an energy range below 1.6 MeV. In an energy range above 1.6 MeV, we adopted a nonlinear relationship derived from LCS photon measurement. The nonlinearity of this counter above 3 MeV was caused by the photomultiplier tube assembly [3].

To verify qualitative EGS4/PRESTA code simulation, the radioactivity of reference sources was determined by fitting simulated response functions to experimental data. The derived radioactivity agreed well within a reference uncertainty of ±5% for the different γ-ray sources.

The response matrix calculated by EGS4/PRESTA code coupled with light output and the resolution function was applied to unfold pulse height spectra measured for reference γ-ray sources. Energy distributions unfolded by GRAVEL (thick line) and MIEKE (thin line) codes for the ^{88}Y source experiment were compared as shown in Fig. 1-(b). Both showed similar spectra with full energy peaks corresponding to reference energies of 0.898 and 1.836 MeV of ^{88}Y γ-rays. The energy resolution obtained by MIEKE code was generally better than that of GRAVEL. Minor photon contributions in the lower energy region were less than 1%, perhaps due to scattering in the surroundings, since a shadow cone was not used in this experiment.

The pulse height spectrum measured in the thermal neutron field was unfolded by GRAVEL and the MIEKE codes as described above. The measured pulse height spectrum and unfolded energy distributions are shown in Fig. 2-(a) and 2-(b). Photon spectra showed a very similar shape over the entire energy range. To confirm unfolding procedures, unfolded spectra were refolded to obtain a pulse height spectrum and compared to the experimental pulse height spectrum as shown in Fig. 2-(a). They agreed well with the measured pulse height spectrum. Fluence uncertainties of each energy bin obtained by MIEKE analysis ranged from ±1% to ±5% and up to ±40% above 5 MeV. A 2.2 MeV peak mainly caused by the H(n,γ) reaction in the NE213 scintillator was still observed among other peaks. By comparing total counts measured by the NE213 scintillator with LiF and without LiF, it was reduced to 30%, however could not be removed perfectly. One reason is that intermediate and fast neutrons contaminated in the thermal neutron field produce 2.2 MeV photons interacting with the scintillator.

To obtain the effective dose equivalent, the energy distribution was multiplied by the corresponding conversion coefficient from fluence to dose [10] and integrated over the entire energy range. The effective dose equivalent under the irradiation geometries of anteroposterior (AP) and LAT (irradiation from either side of the body) were determined as (0.47 ±0.05) μSv/h and (0.35 ±0.05) μSv/h, compared to the dose of (0.57 ±0.1) μSv/h measured by the ^{3}He-filtered GM counter.

We will continue to improve the nonlinearity of the photomultiplier tube assembly and measure the response function of photons above 1.6 MeV up to 20 MeV using the LCS photon beam.

References

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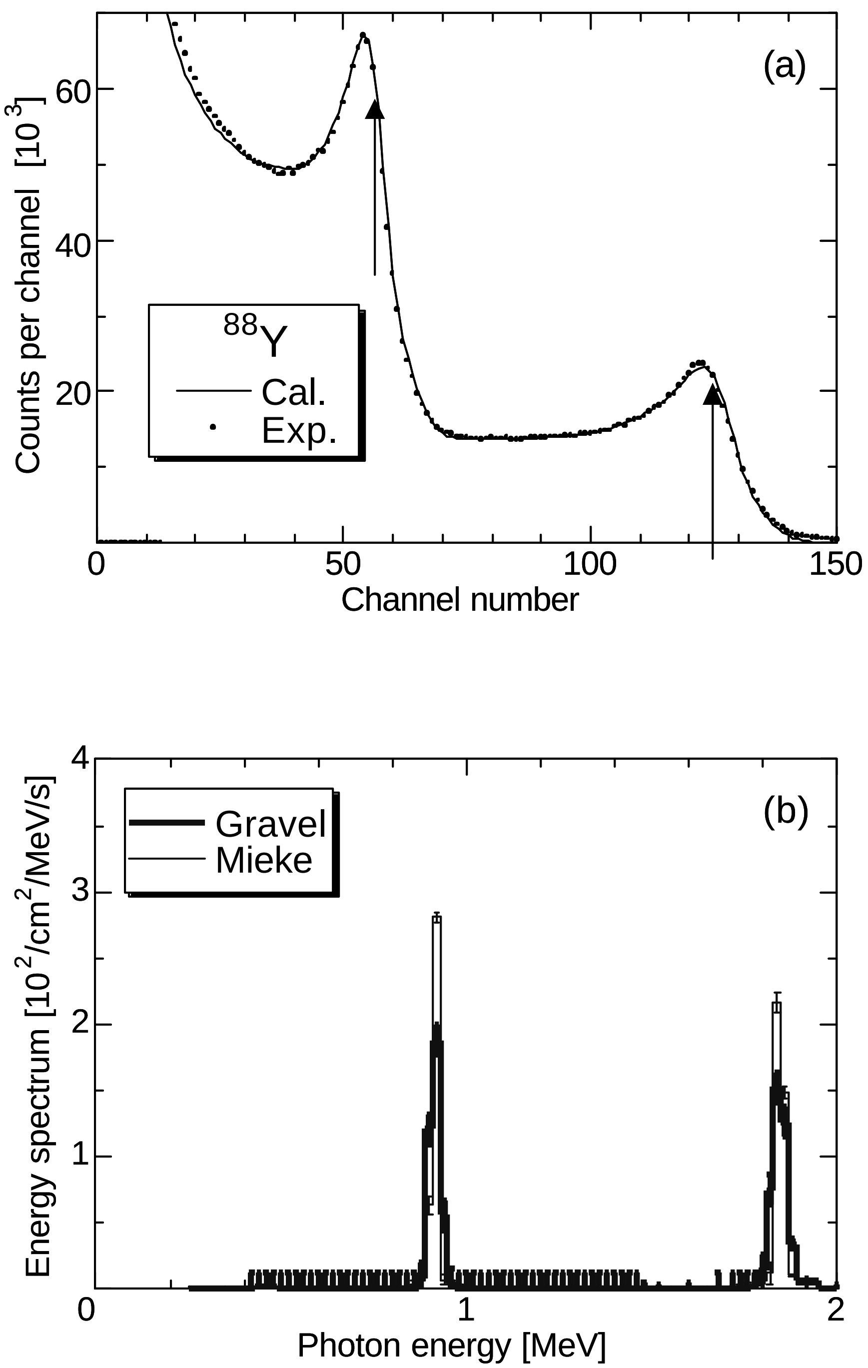
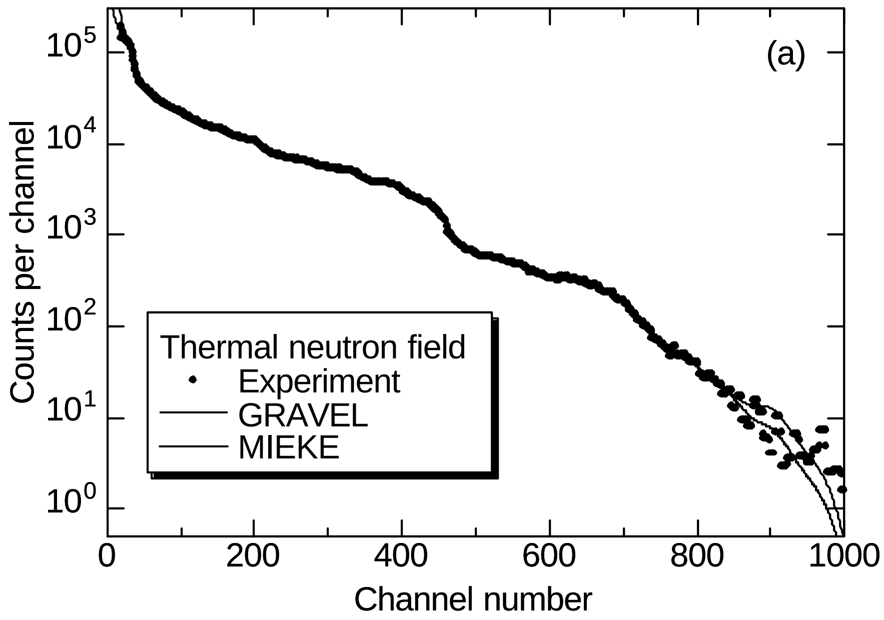


Fig. 1-(a) Measured (dots) and calculated (solid line) pulse height spectra to ^{88}Y γ-rays.

Fig. 1-(b) Comparison of energy distribution of ^{88}Y γ-rays unfolded by MIEKE (thin line) and GRAVEL (thick line) codes



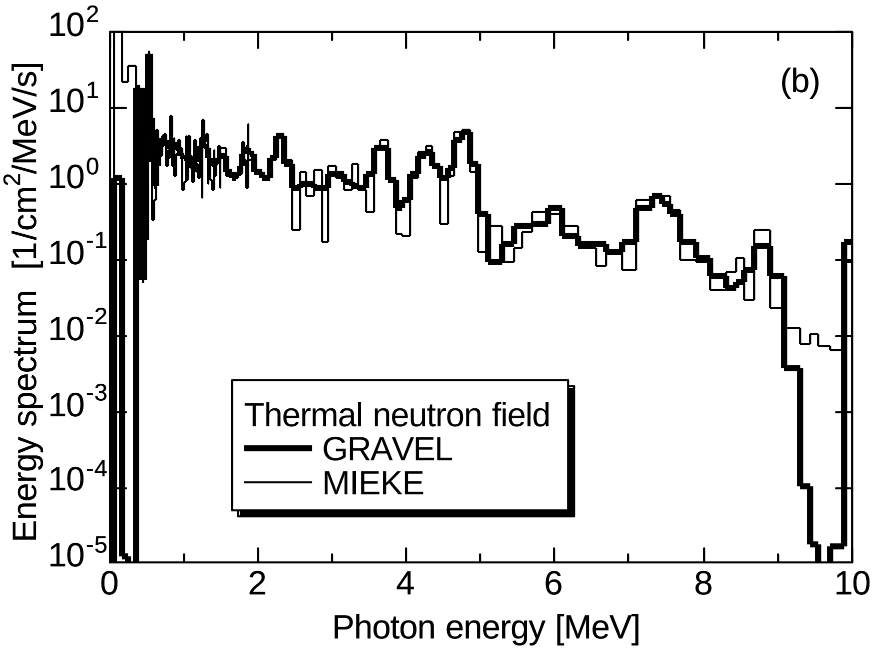


Fig. 2-(a) Measured pulse height spectrum (dots) and refolded spectra by MIEKE (thin line) and GRAVEL (thick line) code

Fig. 2-(b) Comparison of photon energy distribution in a thermal neutron field

unfolded by MIEKE (thin line) and GRAVEL (thick line) code

2. Key Intercomparison of Neutron Fluence Measurements held at PTB

ETL participated in the key intercomparison of neutron fluence of monoenergetic neutrons at 144keV, 1.2MeV, 5.0MeV and 14.8 MeV, together with other six national metrology institutes organized by CCRI-III. We used the Bonner sphere detectors (3.5 and 9.5 inch diameter) as a transfer device to determine the neutron fluence at some fixed distances from the neutron producing target. The results would be reported at the end of October.

3.Reorganization of Agency of Industrial Science and Technology (AIST)

AIST was reorganized at the 1st of April 2001. The new AIST stands for National Institute of Advanced Industrial Science and Technology in which the National Metrology Institute of Japan (NMIJ: 15 divisions) manages for both the physical and chemical standards. The Quantum Radiation Division is responsible for standardization of optical radiation, X & γ-rays, neutron and radioactivity standards.