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Response Function of a NE213 Liquid Saintillation Detector Simulated by EGS4/PRESTA Code for a Collimated γ-Ray Beam

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Abstract

For photon spectrometry in a mixed neutron-photon field, a NE213 liquid scintillation detector is one of the useful instruments which has an excellent neutron-photon discrimination capability. The γ-ray response function for a NE213 detector is required for unfolding measured pulse height spectra. The EGS4/PRESTA code was used to simulate the γ-ray response function taking into accounts the detail information on the detector assembly. Experimental data were taken in the energy range below 1.8 MeV using a collimated γ-ray beam of radioisotope reference sources. For the higher energies up to 10 MeV, a laser-Compton-scattered (LCS) photon source was used as a collimated quasi-monoenergetic photon beam. The simulated response function showed a good agreement with experimental data at different energies.

1 Introduction

It is often required 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. In the measurement of γ-rays mixed in a neutron field, conventional γ-ray detectors such as GM counter, NaI scintillator and Ge detector are influenced by neutron-induced reactions in a detector assembly, which can not be separated easily from photon detecting reactions.

Bueermann and Novotny et al. developed photon spectrometry using NE213 scintillation detectors in mixed neutron-photon fields, because of its excellent n-γ separation properties [1-3]. They calculated the response function due to photons induced by fast neutrons in NE213 scintillators using a coupled MCNP4A/EGS4 simulation, and finally obtained the photon energy distribution existing in some neutron-photon field.

In this paper as a first step to determine the γ-ray energy distribution, the gamma-ray response function of a NE213 scintillation detector will be calculated by EGS4/PRESTA code and folded properly with a resolution function. The light output function and the energy resolution will be determined by using reference γ-ray sources. The simulated results would be compared with experimental data for collimated beams of radioisotope reference sources below 1.8 MeV and a laser-Compton-scattered (LCS) photon source at higher energies up to 10 MeV.

2 Experimental Setup

In order to measure the response function of γ-rays, a NE213 scintillation counter was set as shown in Fig. 1. The NE213 scintillation detector was encapsulated in a standard BA1 cylindrical cell (inner size: 5.08 cm in diameter and 5.08 cm length) and designed to avoid any air bubble in the sensitive region with the use of an expansion reservoir of polyethylene tube around the circumference. A conventional measuring system of pulse shape discrimination and multi-parameter data acquisition was used to process the signals from a photomultiplier tube (R329-02 manufactured by HAMAMATSU) and to separate photon signals from neutron induced ones.

The γ-ray response function of the NE213 scintillation counter was measured using gamma-ray reference sources of ^{88}Y, ^{60}Co, ^{22}Na, ^{54}Mn and ^{137}Cs provided by Amersham Buchler GmbH & Co KG. In the calibration of NE213 scintillation counter, the source was located at the distance of 23cm from the center of NE213 scintillator on the cylindrical axis. The gamma-rays from the sources were collimated by a lead collimator (10 cm x 10 cm cross section and 20 cm long) to make a narrow beam of 3.85 mm diameter. In order to measure the precise response function depending on the irradiation position of gamma-ray beam, the collimated beam was irradiated to the detector in the direction of parallel or vertical to its axis, and scanned to radius or height direction, respectively.

In the experiment above 1.8 MeV, the NE213 detector was calibrated by using the LCS photon beam which is expected as a new source of quasimonoenergetic photons between 2 MeV and 22 MeV [4,5]. As shown in Fig.2, the second harmonic light emitted from a Q-switched Nd:YLF laser (maximum output: 20 W, wavelength: 527 nm, minimum pulse width: 150 ns, and pulse reputation rate: 2-50 kHz), was guided into the laser-electron interaction region through the laser polarizing controller, reflection mirror, and focusing lens. High-energy photons back-scattered by relativistic electrons (maximum energy: 800 MeV, maximum beam: 300 mA, and pulse reputation rate: 166 MHz) were collimated to a beam diameter of 2 mm using a lead block. The second lead collimator and the shielding lead surrounding a NE213 scintillation detector reduce background bremsstrahlung photons generated in the synchrotron storage ring.

3 Calculation of Response Function by EGS4/PRESTA Code

The γ-ray response function for the NE213 scintillation counter was calculated using EGS4 code coupled with the parameter reduced electron-step transport algorithm (PRESTA) routine which was developed to minimize the dependence of results on step size in electron transport simulation [6]. The calculation of response functions for reference gamma-ray sources was made under the following conditions:

1. the reference gamma-ray source was assumed to be an isotropic point source.
2. the calculation model and the composition of NE213 detector assembly were chosen precisely as shown in Fig. 1.
3. In the simulation of the LCS facility, the geometry routine was written by taking into account the detailed system configuration, consisting of a volume source of photons produced in an electron-laser collision region, a lead collimator, and the cylindrical NE213 detector with all physical processes necessary for accurate calculations in the electron energy region from 300 MeV to 800 MeV. The 527 nm coherent light generated by the 20 W Nd-YLF laser was guided to the vacuum chamber located at the straight portion between two bending magnets of the storage ring TERAS [4] and collided head-on with high-energy electrons. Back-scattered photon energy and the emission angle corresponding to the backward direction were randomly generated by following a kinematic formula for Compton scattering, as input data for the EGS4/PRESTA calculation. The electron beam divergence and energy spread were ignored in calculation. To shorten computing time, the maximum solid angle cone to the backward emission was limited to be slightly little larger than the first collimator, positioned 503.6 cm away from the center of the volume source.
4. The NE213 detector used in the EGS4 calculation was assumed to be composed of multilayer cylinders according to factory information, as shown in Fig.3.

5. The energy intervals for the calculation of response function were chosen as:
   (a) 100keV in the energy range up to 400 keV,
   (b) 20 keV in the range from 400 keV to 1.9 MeV,
   (c) 100 keV from 1.9 MeV to 5 MeV and
   (d) 500 keV up to 10MeV.

   The pulse height axis was divided into 1000 channels corresponding to the energy bin width of 10 keV/channel.

4 Results and Discussion

The pulse height spectra measured for the reference γ-ray sources of ^{88}Y, ^{60}Co, ^{22}Na, ^{54}Mn and ^{137}Cs were compared to the response functions calculated by the EGS4/PRESTA code. The calculated spectrum was folded with the pulse height dependent resolution assuming to be $dL/L = B/L^{1/2}$, where L and B are the light output and arbitrary parameter, including only the region of the Compton edge and fitted to the measured distribution [7]. By changing the parameter B properly, a best-fitted distribution to the experimental spectrum was determined by a least square fit and then the precise position of Compton-edge could be determined for the reference sources. As an example, the comparison of simulated spectra with measured ones for the γ-ray beam from a ^{137}Cs source is shown in Fig. 4 by changing the incident position of a γ-ray beam corresponding to the bold arrows (in the left hand sketches) incident on the detector. The arrows (in the right hand figures) in the spectra indicated the precise Compton edge at different incident points perpendicular to the cylindrical detector axis.

The light output function of the NE213 scintillator resulted in linear output relationship, expressed as $L=E_e - 0.0065$, between the measured pulse height L and the corresponding equivalent electron energy E_e in the energy range below 1.6 MeV. To verify qualitative simulation by EGS4/PRESTA code, the radioactivities of the reference sources were determined by fitting simulated response functions to experimental data. The derived radioactivities agreed well within the reference uncertainty of ±5% for the different γ-ray sources.

The parameters of A, B and C in the formula of pulse height resolution dL/L described by $(A^2 + B^2/L + C^2/L^2)^{1/2}$ were determined as 0.032, 0.103 and 0.002, respectively.

In the higher energies above 1.8 MeV, the comparison of simulated spectra with experimental results were shown in Fig. 5 at energies of 3.43, 4.311, 5.151 and 5.985 MeV and in Fig. 6 at 6.816, 7.787, 8.780 and 9.869 MeV, respectively. The simulated response function showed a relatively better agreement with experimental data at different energies. The light output function of the NE213 scintillator resulted in non-linear output relation to the deposited energy as shown in Fig 7.

5 Conclusion

The EGS4/PRESTA code was used to simulate the γ-ray response function taking into accounts the detail information on the detector assembly. Experimental data were taken in the energy range below 1.8 MeV using a collimated γ-ray beam of radioisotope reference sources. For the higher energies up to 10 MeV, a LCS photon source was used as a collimated quasi-monoenergetic photon beam. The simulated response function showed a good agreement with experimental data at different energies. The response matrix calculated by the EGS4/PRESTA code coupled with the light output and the resolution function would be applied for unfolding pulse height spectra measured for the reference γ-ray sources by using unfolding codes of the GRAVEL and the MIEKE [8].

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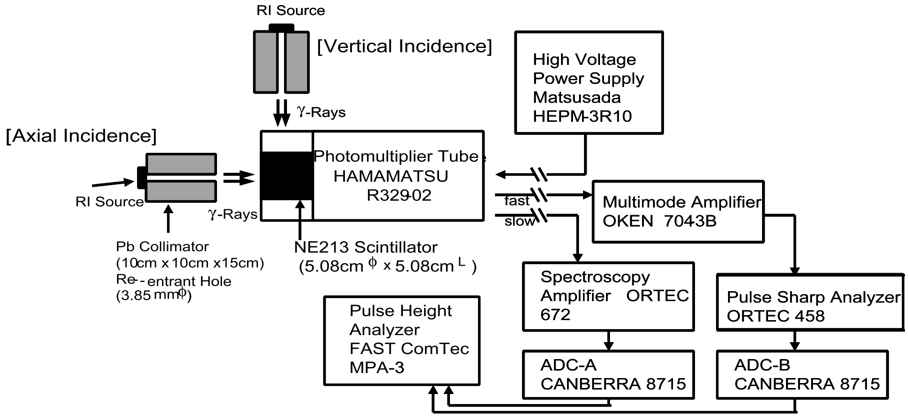

Figure 1: Fig. 1 Experimental setup for a collimated beam of radioisotope reference source.

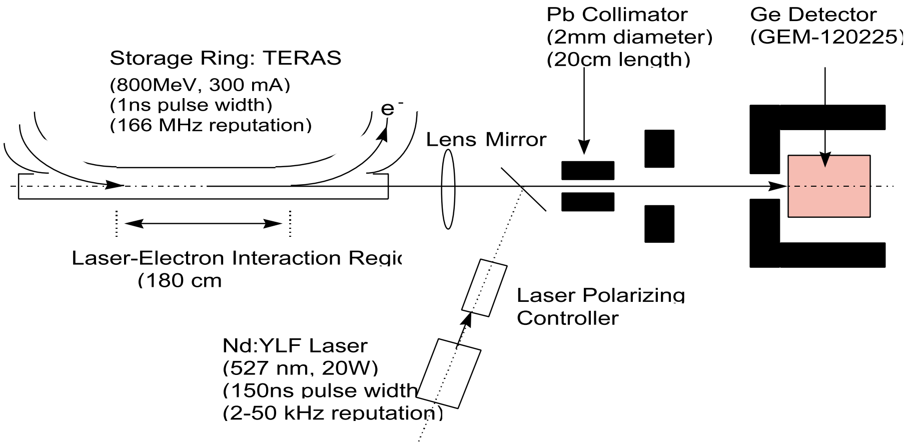

Figure 2: Experimental setup for a collimated beam of LCS photon source.

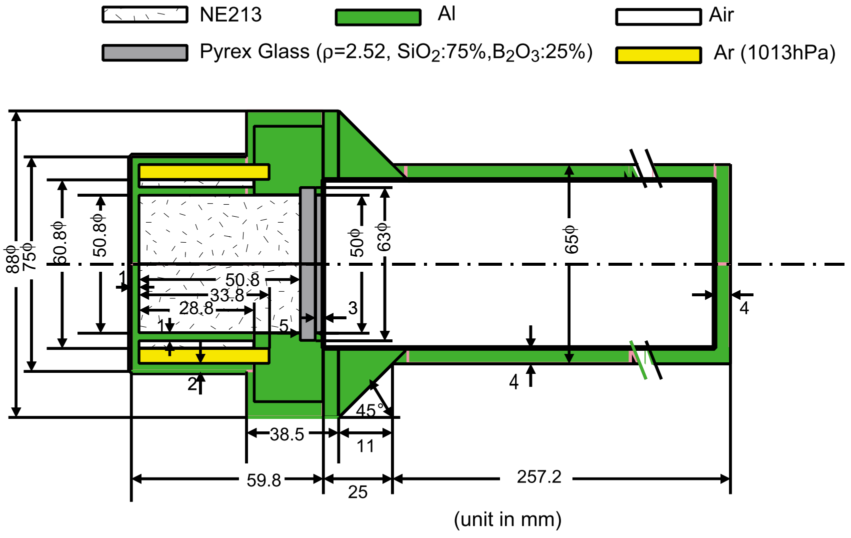

Figure 3: Calculation model of NE213 Scintillator.

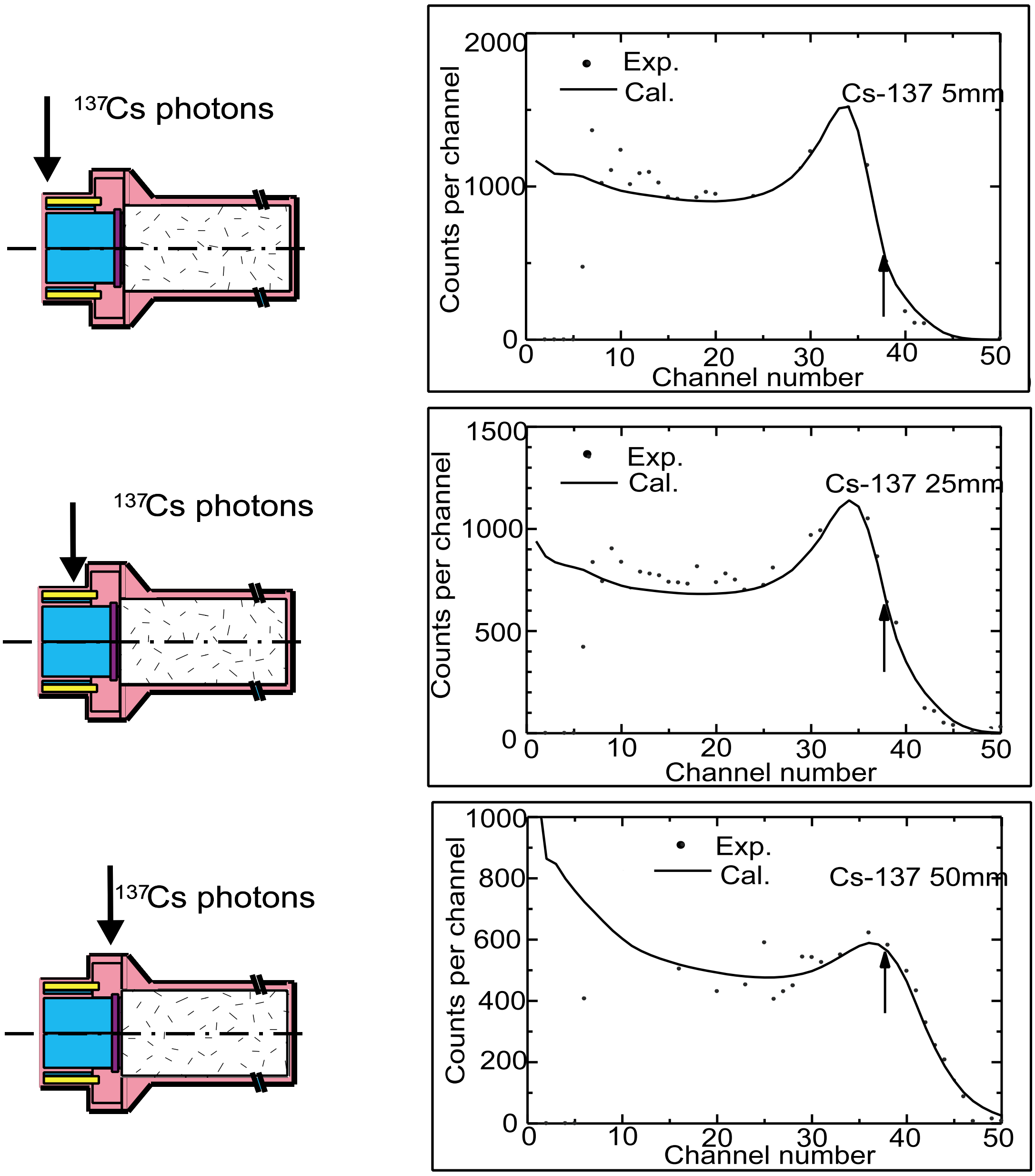

Figure 4: Position dependent pulse height spectra for a photon beam of ^{137}Cs source.

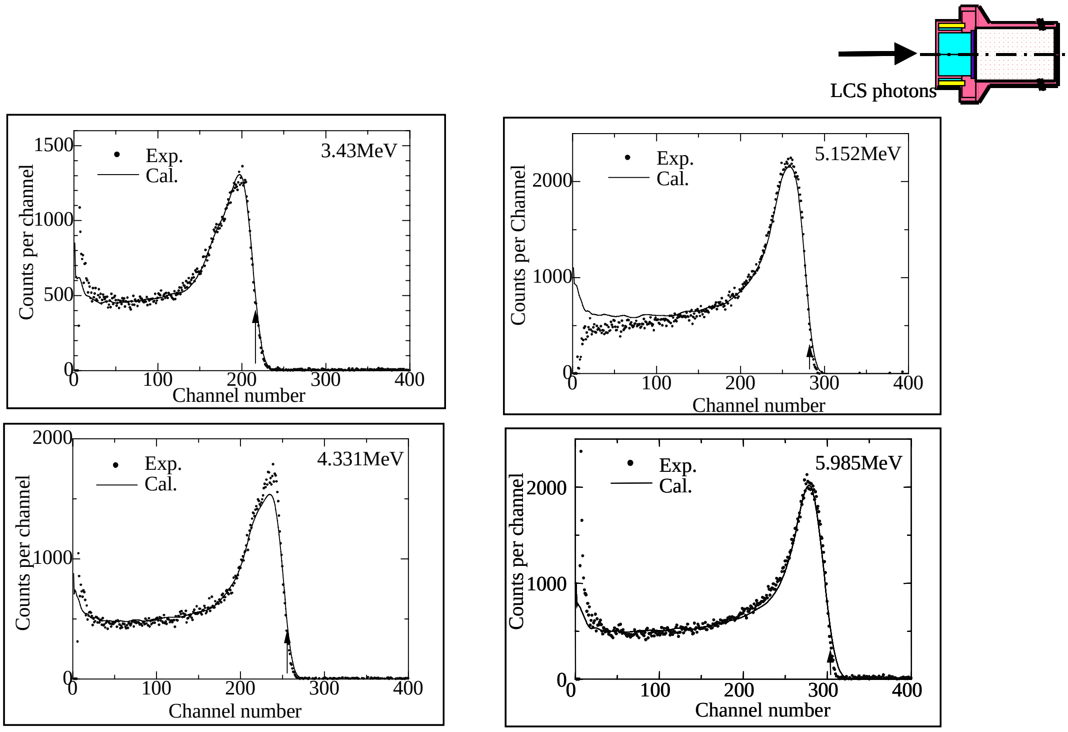

Fig. 5 Position dependent pulse height spectra for a LCS photon beam at energies of 3-6 MeV

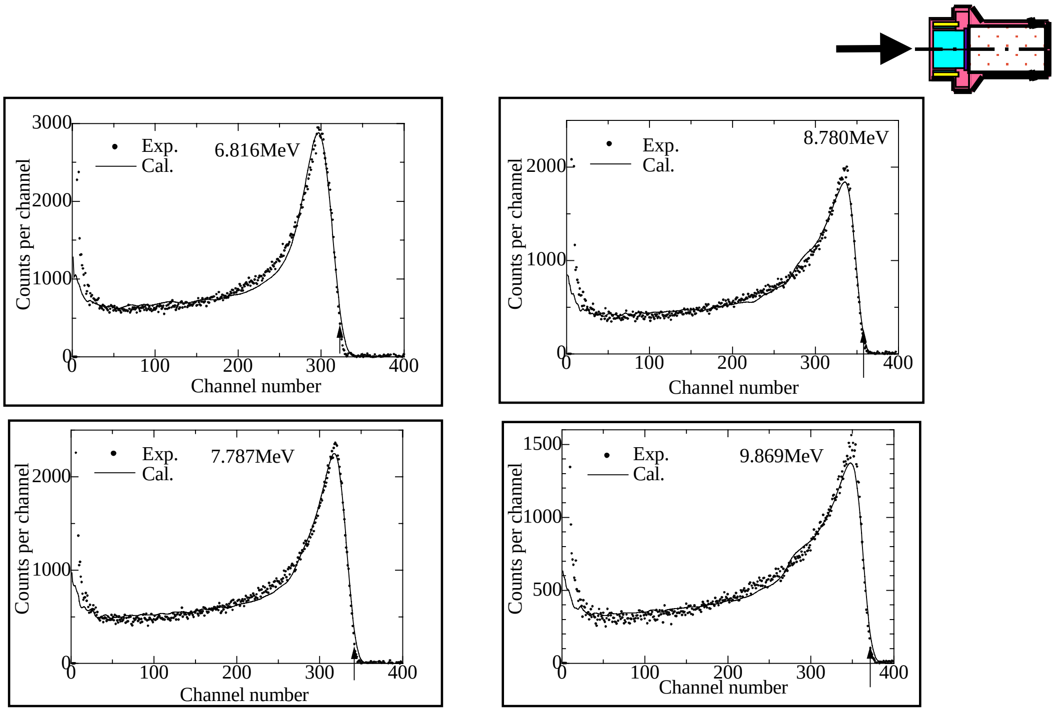

Fig. 6 Position dependent pulse height spectra for a LCS photon beam at energies of 7-10 MeV

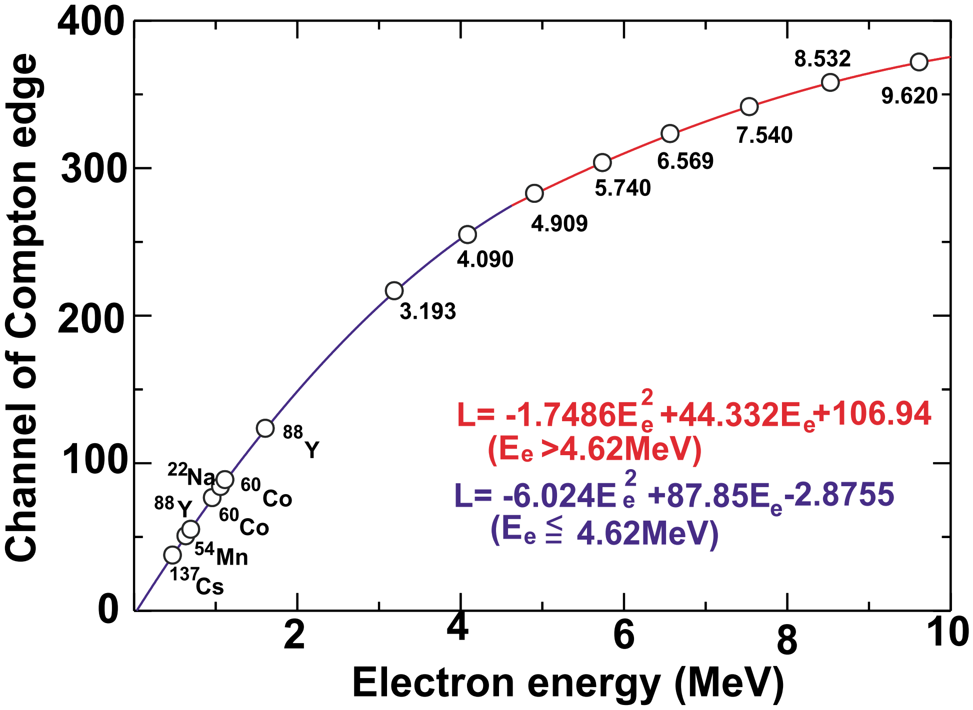

Figure 7: Light output function for the NE213 scintillator (PM tube: R329-02)