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RESEARCH ARTICLE

The Effect of Decreasing Aperture Diameter on Signal Transmission from the Scintillator to the Photomultiplier Tube Over a Wide Energy Range

Aleš Jančář[1,*], Zdeněk Matěj[2], Evžen Losa[3], Michal Koštál[4],
Tomáš Czakoj[4], Michal Jelínek[5], Břetislav Mikel[5], Zdeněk Kopecký[1],
Filip Mravec[1], and Jan Král[2]

ABSTRACT

In this paper, we study the effect of decreasing aperture diameter on signal transmission from the scintillator to the PMT. The apertures have been inserted directly between the scintillator and the photomultiplier. Three different aperture diameters have been used over a wide energy range. A newly developed fast digital spectrometer has been utilized for experimental measurement in the radial channel of the VR-1 research reactor. The detector signals with and without inserted apertures have been measured and evaluated. The aim of our research was to determine the effect of the apertures on the spectral quality, energy range and the evaluated physical quantities.

Keywords: Digital analyser, Gamma spectrometry, Pulse shape discrimination (PSD), VR-1 research reactor.

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[1] *VF Nuclear, Czech Republic.*
[2] *Masaryk University, Czech Republic.*
[3] *Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, Czech Republic.*
[4] *Research Centre Rez Ltd, Czech Republic.*
[5] *Institute of Scientific Instruments of the Czech Academy of Sciences, Czech Republic.*

****Corresponding Author:***
e-mail: ales.jancar@vfnuclear.com

1. INTRODUCTION

This paper can be considered an introductory study on the development of radiation detectors based on semiconductor diodes or optical fibers. In the development of these detectors, we work with a smaller detection area, i.e., a lower light output signal than conventional detectors consisting of a scintillator and PMT.

In order to assess the effect of decreasing aperture diameter on spectral quality, and energy range, and evaluate physical quantities, we provided a series of measurements with apertures of different diameters inserted between the scintillator and PMT. Our experimental arrangement of the scintillator and PMT eliminates the effect of using different types and sizes of semiconductor diodes and optical fibers.

The radial channel of research reactor VR-1 installed in Czech Technical University Prague has been used for the experimental measurements. The input analog signal from the detector has been digitized with a fast 12-bit analog-to-digital converter with a sampling frequency of 1 GHz. Digital signal processing is implemented into FPGA. Measured data from the detector have been processed into gamma spectra. The results of the development and experimental measurements are presented.

2. INSTRUMENTS AND METHODS

The cylindrical stilbene organic scintillator of (45 × 45) mm with PSD properties has been used for the measurements. The Hamamatsu photomultiplier type R329-02 has been connected with a newly developed high-voltage divider with negative voltage power. The active divider has a better ability to

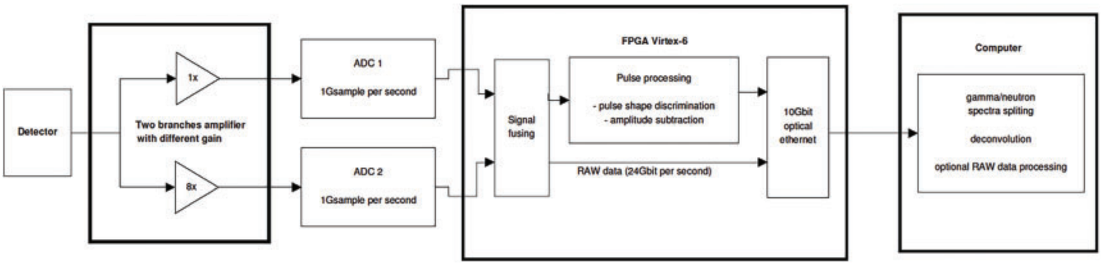

Fig. 1. The scheme of the digital analyser.

compensate for non-linearity caused by high pulse frequency and amplitude. The analog signal from the detector has been connected to a digital spectrometer.

The digital spectrometer is built as a modular system allowing the use of different types of scintillation detectors. The preamplifier splits the signal from the detector into two branches. Each branch is differently amplified and digitized by separate ADC. Different amplification increases the dynamic range of particles that the spectrometer can process.

The input analog signal is digitized with fast 12-bit analog to digital converter with a sampling frequency of 1 GHz. Digital signal processing is implemented into FPGA. FPGA is able to process all data flowing from ADC (12 Gbits per second). The spectrometer is connected with a computer via an optical ethernet of 10 Gbit. The spectrometer is connected with a computer via an optical ethernet of 10 Gbit (see Fig. 1).

2.1. *Energy Calibration*

Integrated digitized pulses have been linearly calibrated in keVee units, or keV electron equivalent. The linear transformation coefficients were derived from positions of the Compton edges [1] in the spectra of two gamma-ray sources ^{137}Cs and ^{60}Co. Sources of activity 350 kBq have been placed on the center of the front face detector. Measurement time has been determined in accordance with count rates from the detectors. A negative high voltage of 1150 V has been adjusted.

2.2. *Experimental Setup*

The VR-1 research reactor is a light-water, zero-power pool-type reactor installed in the laboratories of Czech Technical University in Prague. The core consists of tubular fuel assemblies of IRT-4 M type enriched to 19.75 wt. % of ^{235}U and can contain several dry vertical channels with different diameters up to 90 mm intended for experimental measurements. Fuel assemblies are formed by combinations of 4 to 8 concentric tubes according to the fuel element type. Fissile material in each fuel tube has a form of uranium dioxide dispersion in aluminium and is cladded by aluminium alloy from both sides.

Up to two horizontal channels, tangential and radial, can be utilized for extracting larger neutron beam out of the core. The measurements have been carried out in the radial channel of the VR-1 research reactor with the C16 core, which layout is displayed in Fig. 2. The speciality of the C16 core is the installation of three pieces of assemblies with stainless steel pins (see Fig. 2, positions D7, E7, and F7) placed in the opposite direction to the radial channel.

The experimental arrangement in the reactor hall is shown in Figs. 3 and 4. The radial channel's inner diameter is 251 mm and the total length of the channel is 1925 mm. Measurements have been carried out in the centred position of 1400 mm from the front end of the channel. The nuclear reactions in the core of the reactor produced characteristic gamma lines with energies from 7 to 9 MeV.

Three apertures made of matt steel have been used for the measurement. The outer diameter of the apertures is 53 mm and the thickness 0.1 mm. The inner diameters of the apertures are 5, 12 and 25 mm and hole are filled with air. The apertures have been inserted directly in contact geometry between the radiation detector and the PMT.

2.3. *MCNP Calculations*

The flux density in the radial channel as well as the detector light output response have been calculated in the Monte-Carlo MCNP6.2 code using ENDF/B-VII.0 nuclear data libraries. The gamma spectrum in the radial channel has been calculated in the critical mode of calculation including neutron and photon transport. 2 million neutrons have been preset for the calculations in one generation and more than 20.000 active generations were simulated. The result is acceptable statistics in energy lines appearing between 7 and 10 MeV.

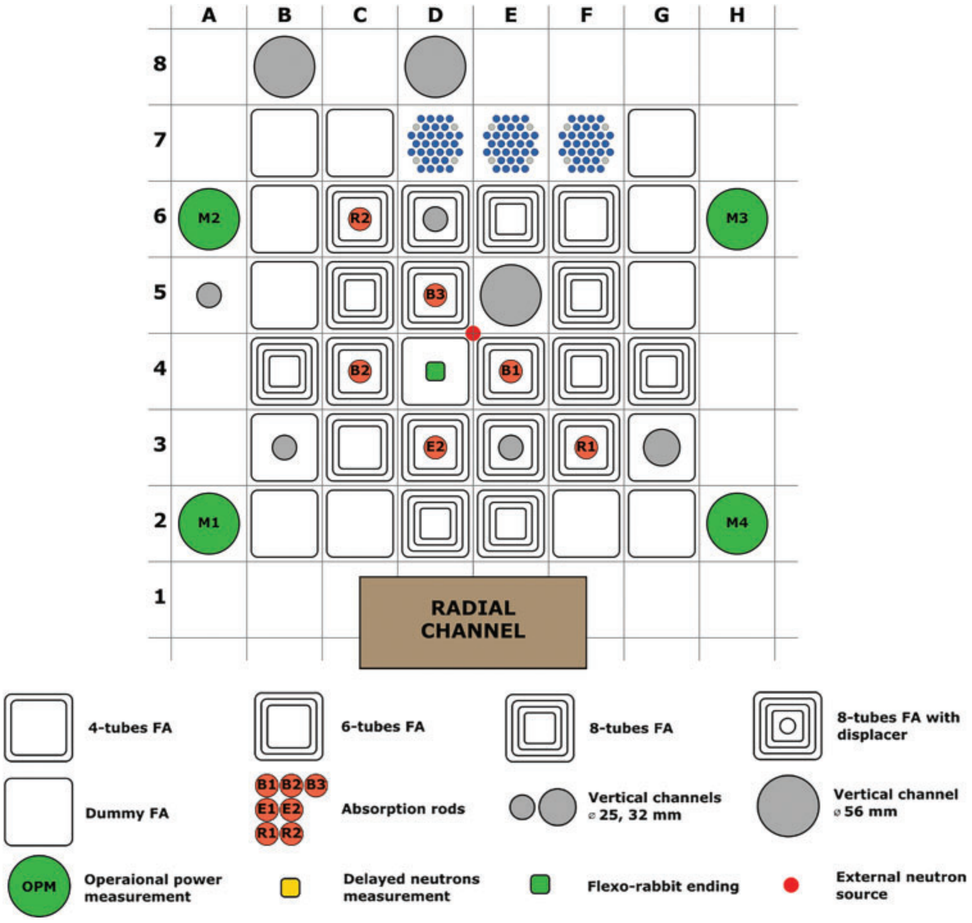

Fig. 2. The layout of the C16 core of the research reactor VR-1.

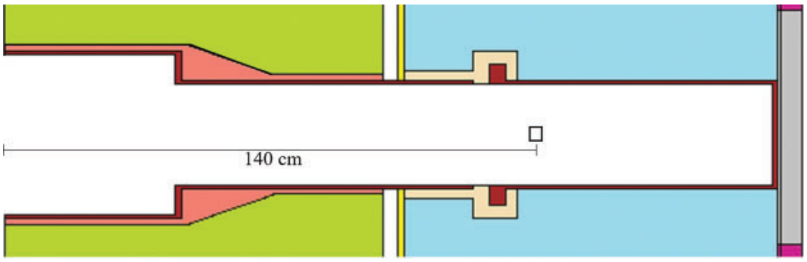

Fig. 3. The detector arrangement in the radial channel of the VR-1 experimental reactor.

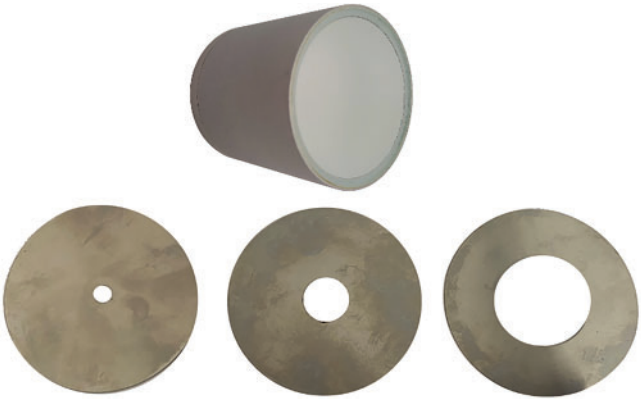

Fig. 4. The radiation detector and apertures used for the measurement in the radial channel of the VR-1 experimental reactor.

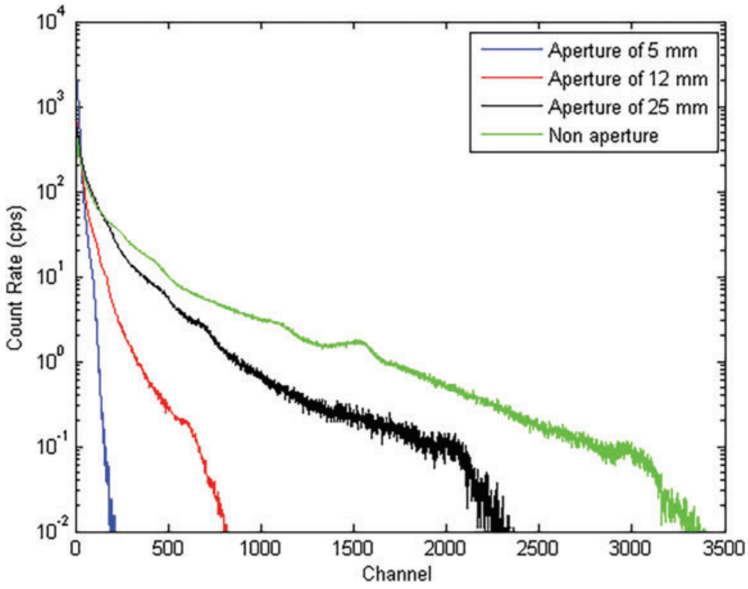

Fig. 5. The apparatus gamma spectra in various apertures.

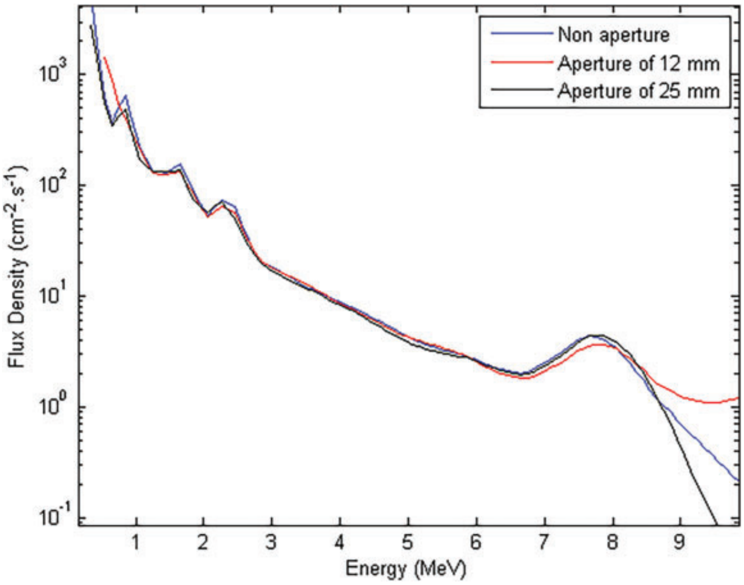

Fig. 6. The gamma spectrum in the radial channel of reactor VR-1.

3. Results and Discussion

We carried out a measurement of the gamma spectrum in the radial channel of nuclear reactor VR-1. Three different diameters of apertures have been used in experimental measurements in the energy range from 1 to 7 MeV, see Fig. 5.

The analyser stores the measured data in the form of a pulse shape discrimination matrix, which preserves information about the energy of the particle and particle type. This matrix can be downloaded onto a PC for further processing.

The apparatus spectra have been unfolded into the energy spectrum using calibration information and detector response function. The pulse-shape discrimination capabilities of the stilbene detector have been evaluated and the results are presented in Fig. 6.

The MC simulations of the light output response matrix of the stilbene detector have been performed using MCNP code 6.2. An MC model was set up to calculate the absolute energy response to photons. Fig. 7 shows the calculated light output response of the stilbene detector as a function of photon energy.

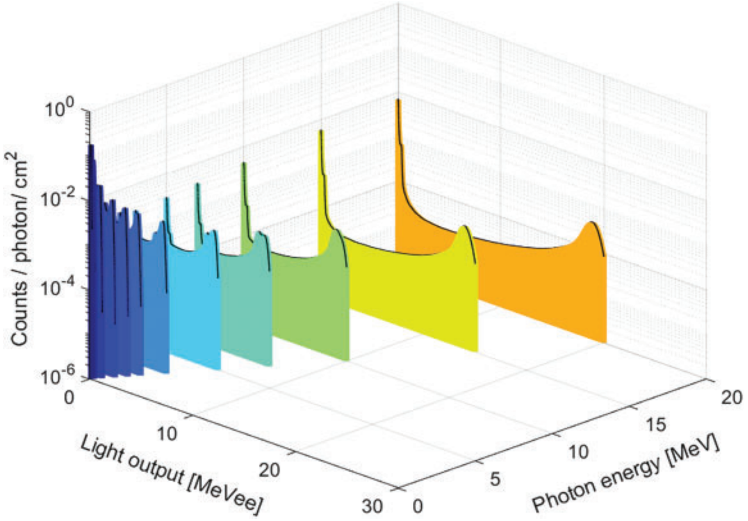

Fig. 7. The stilbene detector light output response for gamma radiation.

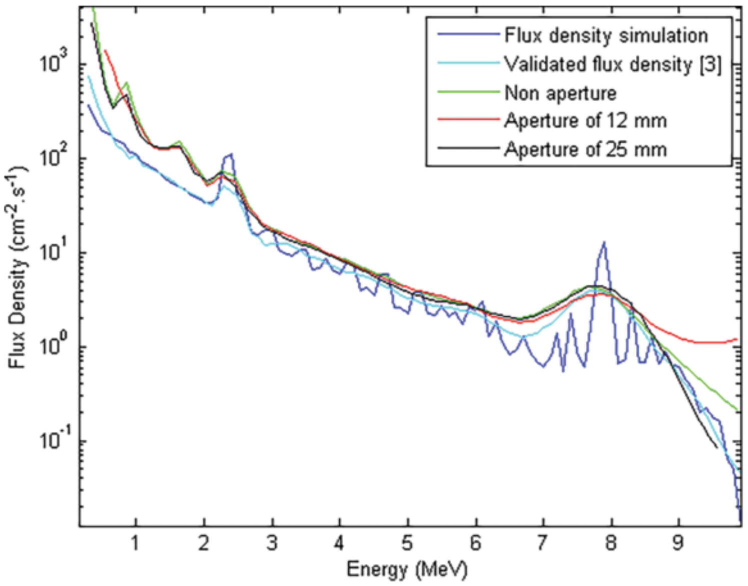

Fig. 8. The comparison of gamma spectra in the radial channel of reactor VR-1.

4. Conclusions

In this paper, the effect of decreasing aperture diameter on signal transmission from the scintillator to the photomultiplier has been performed. A wide gamma energy range was ensured by using experimental reactor VR-1.

We compared evaluated gamma spectra, see Fig. 8 with published spectra [2] and simulated spectra. The flux density in the range of low energies is higher than the published spectra. The reason is a high level of fission products namely ^{140}La, ^{95}Zr and ^{95}Nb. The ^{95}Zr and ^{95}Nb peaks are also observed in previously measured spectra. The amplitude of these peaks is lower due to the long decay time.

Simulated gamma flux density, see Fig. 8, in the radial channel of reactor VR-1 corresponds with a measurement provided during a Mock-Up experiment for the benchmarking of high-power reactors [3] and [4].

The energy of the particle detected by the stilbene detector corresponds to a certain level of the output voltage pulse. If we insert an aperture between the PMT and the detector, due to the lower light intensity detected by the PMT, the level of the output voltage pulse will decrease and the spectrum will shift towards the lower channels (see Fig. 4). Shading the effective area between the scintillator and the PMT by 50% shortens the spectrum by about 1000 channels compared to the total unshielded effective area. In the case of 75% shading, we observe a shortening of the spectrum by about 2500 channels. In both cases, it is still possible to perform the unfolding of the apparatus spectrum, see Fig. 6. At 90% shading, the spectrum shortens by 3200 channels and steeply decreases, see Fig. 5. No Compton edges are identified in the spectrum and such an apparatus spectrum can no longer be evaluated. Aperture diameters of 12 and 25 mm correspond to commonly available semiconductor diodes or optical fibre bundles. Due to their small diameter, a similar spectral shortening effect can be expected with respect to their near-quantum efficiency.

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CONFLICIT OF INTEREST

Authors declare that they do not have any conflict of interest.

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