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Experimental study on fluence rate response of $LaBr_3$ to pulsed X-rays

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ABSTRACT

The linear response is the key property employed by a radiation detector to determine the accurate intensity of a pulse radiation field. In this study, we investigated the high fluence rate response behavior of a $LaBr_3$ scintillator. We used a high-intensity pulsed X-ray source called "QiangGuang-I" which could produce an X-ray pulse with a total dose of 100 Gy, full width at half maximum of 20 ± 5 ns, and an average energy of 1 MeV, to test the linear response of the $LaBr_3$ scintillator. The Lissajous figure method was used in this experiment. The results showed that the fluence rate linear response limit was more than 1.8×10^{20} MeV/(cm^2·s).

1. Introduction

Lanthanum bromide mixed with Ce^{3+} ($LaBr_3$:Ce^{3+}) scintillators discovered at Delft University of Technology and the University of Bern have been studied extensively in recent years. $LaBr_3$ scintillators have superior properties such as high energy resolution (2.9% for 662 keV gamma rays), fast response time (typically ~22 ns), small non-proportionality (< 6% for 30 keV-1000 keV gamma rays), and high scintillation yield (~60,000 ph/MeV for Φ50 mm × 50 mm $LaBr_3$ scintillator) (Van Loef et al., 2001, 2002; Krämer et al., 2006; Glodo et al., 2005). $LaBr_3$ detectors are also promising for measuring the intensity of pulsed X-rays in a mixed X/neutron field because of their fast rising time and high gamma/neutron discrimination (Lu et al., 2014).

In this study, we evaluated the high fluence rate response behavior of a $LaBr_3$ scintillator. The mechanism of this nonlinear response is complex and the fluence rate linear response limit cannot be derived by simulation. This parameter can only be acquired using experimental methods.

2. Experimental conditions and method

The pulsed power accelerator called "QiangGuang-1" was used to provide a high fluence rate pulsed X-ray radiation field. The X-ray generation process was introduced below. High voltage pulse was produced by a linear transformer driver. After twice pulse compression, great electrical current pulse was collected on the load. The discharge process of electrical currents was controlled by a plasma opening switch. High energy electron beam was produced then. The bremsstrahlung X-ray was generated by the collision of high energy electron beam and tantalum targets.

The full width at half maximum (FWHM) of the pulsed X-ray was about 15–25 ns and the maximum dose near the target was higher than 100 Gy. The pulsed X-ray emission spectroscopy of "QiangGuang-1" accelerator was shown in Fig. 1. The average X-ray energy was approximately 1 MeV (Cong et al., 2010). This pulsed radiation facility is ideal for studying the high fluence rate response behavior of radiation detectors (Song et al., 2004).

The experimental layout is shown in Fig. 2. The detector placed near the target is called the former detector. The detector located further from the target is called the latter detector, which is always operated in the linear response mode in this study. Each detector comprised one $LaBr_3$ scintillator measuring 50 mm × 10 mm (produced by Saint-Gobain in 2015) and one photoelectric tube (GD40).

In order to avoid the GD40 tube in the former detector being directly irradiated, the former detector was set as shown in Fig. 3. Lead bricks with a thickness of 20 cm were placed in a position between the target and the former detector. The latter detector was set at a certain distance (> 3 m) where the noise caused by direct X rays can be neglected.

The linear current of the GD40 in the former detector was tested by a pulse xenon lamp. The results were shown in Fig. 4. Fig. 4 (b) showed the linear output upper of the GD40 is nearly 9.5 V. The attenuation of the GD40 is 40 dB. The channel resistance of the oscilloscope was 50 Ω. The linear current $I_{\max}$ of the GD40 is

$$I_{\max} = \frac{V_{\max} \times 100}{R_{channel}} = \frac{9.5\ \text{V} \times 100}{50\ \Omega} = 19\ \text{A}$$

A digital oscilloscope was used to record the output curves from the

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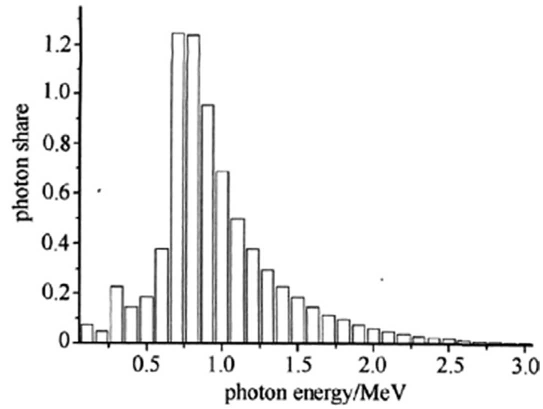

Fig. 1. X-ray emission spectroscopy of "QiangGuang-1" accelerator (Cong et al., 2010).

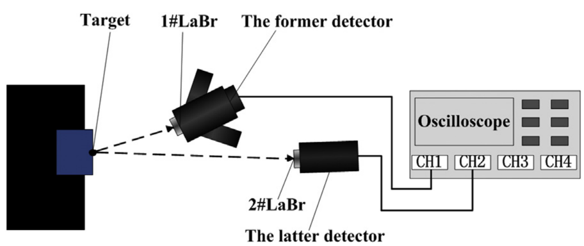

Fig. 2. Experimental layout.

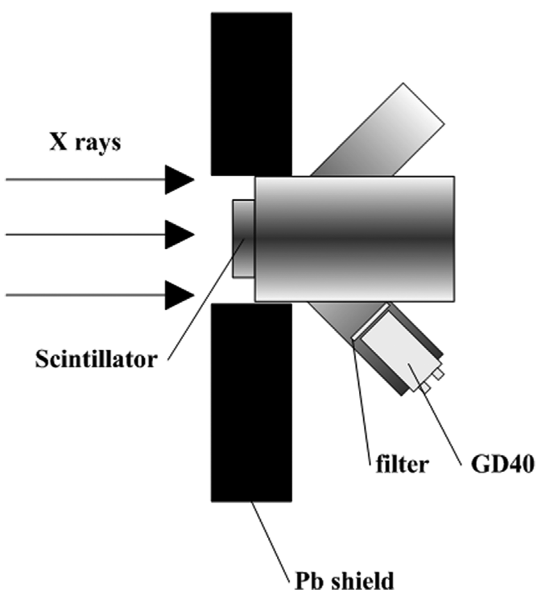

Fig. 3. The former detector.

two detectors. The channel resistance of the oscilloscope was 50 Ω. Considering the outputs of the detectors could exceed the range of the oscilloscope at high dose rates, the signals were attenuated and subjected to power dividers before they were imported into the oscilloscope (as shown in Table 1).

The dose that entered the $LaBr_3$ detector in each pulse was monitored using three LiF(Mg)-M thermo luminescent dosimeter (TLD) chips placed on the front surfaces of the detectors. The linearity range of the TLD chips is 5×10^{-5} Gy to 500 Gy. The uncertainty of the dose measurement was 25.1% (Cong et al., 2010). The pulse width was monitored by a Si-PIN detector (Kuckuck RW, 1971; Kun-Sik Park., 2006; Guo et al., 2014). The parameters of the detector were shown in Table 2.

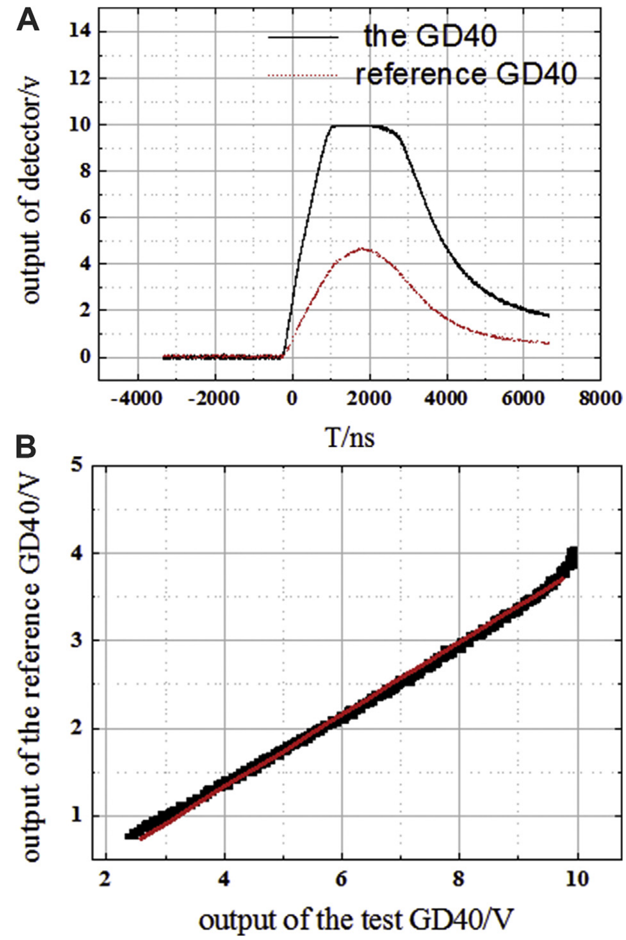

Fig. 4. Measurement of the maximum pulse linear current of the GD40.

Table 1
Attenuation and power dividers properties of detectors.

	The former detector				The latter detector			
Filter	10%				50%			
Divided factor	4				4			
attenuation	None	6 dB	20 dB	30 dB	None	10 dB	20 dB	30 dB
V/div	1 V	1 V	1 V	1 V	1 V	1 V	500 mV	500 mV

Table 2
The parameters of the Si-PIN detector.

Size/mm	Energy response range/MeV	Working voltage/V	Rise time/ns	FWHM/ns
Φ12*0.3	0.8–8.0	−800 ± 15	1.15	2.39

3. Results and discussion

3.1. Results

Fig. 5(a) shows the output waveforms for the detectors in the first X-ray shot. The amplitudes of the waveforms obtained by the former detector are shown on the X-axis and that for the latter detector on the Y-axis in the Lissajous figure in Fig. 5(b). There was a linear relationship between the amplitudes of the former and the latter detectors, which indicated that the 1#$LaBr_3$ scintillator exhibited a linear response. The dose that entered the front detector was 21.06 Gy and the