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# Experimental study on high dose rate response of cadmium zinc telluride detectors to pulsed X-ray☆

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## HIGHLIGHTS

- A measurement system for analyzing the linear response of CZT detectors is built.
- The quantity of CZT crystal can cause multiple difference on the linear parameters.
- CZT detector remains linear when the fluence rate is lower than $7 \times 10^{16}$ MeV/(cm$^2$·s).
- The maximum linear current of the CZT detectors is at the magnitude of $10^{17}$ MeV/(cm$^2$·s).

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## ABSTRACT

The linear response is the key property for a radiation detector to obtain accurate intensity of the radiation field. In this experiment, a high-intensity pulsed X-ray source, named "QiangGuang-I" is utilized to test the linear response of cadmium zinc telluride (CZT) detector. The total dose per pulse 20 cm from the pulse source is 200–3000 Gy. The full width at half maximum of each pulse is 20–30 ns, and the average energy of X-ray is approximately 1 MeV. Two detectors are placed in different intensities, and their responding curves are used to draw the Lissajous figure, analyzing the maximum energy dose rate of the CZT detector. The total dose of the pulsed X-ray into the experimental detectors is simultaneously measured by thermoluminescent dosimeter (TLD) chips. The result shows that the output of CZT detectors remains linear when the energy fluence rate is lower than $10^{17}$ MeV/(cm$^2$·s).



## 1. Introduction

In recent years, cadmium zinc telluride ($Cd_{1-x}Zn_xTe$ or CZT) has been widely used in the measurement of X- and γ-rays in national security, medical imaging, and astrophysics because of their excellent characteristics: high mean atomic number ($Z$~50), high density ($\rho = 5.78$ g/cm$^3$), and high band gap ($E_g = 1.57$ eV) combined with high resistivity (Kaye et al., 2010; Zhang et al., 2011; Fritts et al., 2014; Duvall et al., 2010; Zappettini et al., 2011; Brambilla et al., 2013). CZT detectors have also been proved as promising detectors to measure the intensity of pulsed X-ray in mixed X/neutron radiation field with high intensity on the basis of their advantages such as fast rising time and operation at room temperature (Zhao et al., 2012; Chen et al., 2016). In the high-intensity experiment, much focus is on the high dose rate response of CZT detectors to ensure that these detectors work in a linear range, thereby accurately reflecting the intensity of the pulsed X/γ ray (Guan et al., 2011; Song et al., 2004).

In this work, a pulsed power accelerator is employed, providing the pulsed X-ray beam, which is high enough to study the dose rate response of CZT detectors. A digital oscilloscope is utilized to record the response curves of the experimental detectors. The Lissajous figure is drawn to judge whether the output of the detector remains linear, acquiring the maximum linear current of CZT detectors.

## 2. Experimental methods

The pulsed power accelerator, "QiangGuang-I", at the Northwest Institute of Nuclear Technology provided a high dose rate X-ray beam. The total dose per pulse 20 cm from the pulse source is 200–3000 Gy, and the full width at half maximum (FWHM) of each pulse is 20–30 ns. The energy spectrum is shown in Fig. 1, and the average energy of X-ray is approximately 1 MeV (Kuai et al., 2005; Cong et al., 2010; Bin et al., 2005). Therefore, the conversion

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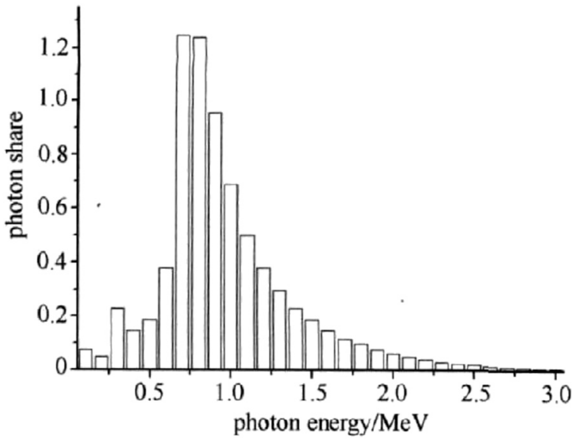


**Fig. 1.** Photo energy spectrum of “QiangGuang-I” under the short pulse X-ray mode.

formula of Gy/s and MeV/(cm$^2$·s) is given as d$\Phi$/d$t$ (MeV/(cm$^2$·s)) = d$X$/d$t$ (Gy/s) × 2.23 × 10$^{11}$ (Su, 1982). The sensitivity of the CZT detector is defined as the ratio between the volts and the combination of energy fluence rate and the resistance of the digital oscilloscope (~50 Ω). Considering the dose rate is 10$^{10}$ Gy/s and the sensitivity of the CZT detector to X-ray (energy distributed is 300 keV–1.5 MeV) is 10$^{-15}$–10$^{-16}$ A cm$^2$·s/MeV simulated by Monte Carlo N-Particle Transport code (MCNP) (Fig. 2), the output amplitude of CZT detectors can reach to 10$^6$ V. In principle, this dose rate is high enough to study high dose rate response of CZT detectors. Hence, the pulsed X-ray radiation field of “QiangGuang-I” is suitable for our experiment.

Considering that the output dose of “QiangGuang- I” accelerator cannot be adjusted arbitrarily and the absolute dose rate of X-ray is difficult to determine in the present experiment, the Lissajous figure is utilized to study the high dose rate response of the CZT detector to X-ray, which is widely used to analyze the linear response of pulsed radiation detectors (Zhang et al., 2014; Jiang et al., 2013; Li et al., 2008). The principle involved is that two detectors are designed with the same shape and crystal dimension. In the experiment, one detector is closer to the target and is termed the front detector, while the other is relatively farther from the target and is termed the latter detector. This position distribution ensures that the latter detector always works in linear response, while the front one works over its linearity. A digital oscilloscope is used to record the response curves of the two detectors. After deducting the time discrimination caused by the length of the cable and the position difference between the detectors and the target, the amplitudes of the latter and front detectors are taken as the X-axis and Y-axis, respectively. Accordingly, we can draw the Lissajous figure and adjust the distance of the front detector to the target, ensuring that the output of the front detector reaches its maximum linear current.

The dose into the CZT detectors in each pulse is monitored by two LiF(Mg)-M thermoluminescent dosimeter (TLD) chips placed on the front surface of detectors, and the pulse width is monitored by a scintillator detector (Song et al., 2003). Because the linearity of the TLD chips is 5 × 10$^{-5}$~500 Gy (the energy distributed is 30 keV–3 MeV), the TLD chips work in linearity in this specific experiment (Cong et al., 2010). The uncertainty of the dose measurement is about 25.1% (Cong et al., 2010). The scintillator detector consists of ST401 crystal (with a decaying time of several nanoseconds) and a phototube, and is fixed 4–8 m from the target. The uncertainty of dose rate is 50.8% (Cong et al., 2010).

In radiation measurement radiation interference is often accompanied with pulsed X-ray that cannot be ignored, especially in the high-intensity X-ray field. To reduce the influence of the interference to the experiment result, CZT detectors are packed with a copper net and placed in a lead chamber to lower the influence of the scattering X-ray. The illustration of the pulsed X-ray experiment for determining the fluence rate response of the CZT detector is shown in Fig. 3.

## 3. Experimental procedure

A set of $Cd_{0.9}Zn_{0.1}Te$ single crystals with the same dimension of 10 × 10 × 2 mm$^3$ are grown with the Vertical Bridgman (VB) method by the Northwestern Polytechnic University. Electrodes were deposited on the 10 × 10 mm$^2$ surfaces by gold deposition after chemical polishing. The serial numbers of experimental CZT detectors are 001#, 002#, 003#, 004#, and 005#.

Because the output of CZT detectors under high dose rates are too large to bung the oscilloscope, the amplitudes are shrunk with attenuations and power dividers before they are imported into the oscilloscope in this experiment. Both the attenuating components and the oscilloscope are placed in the monitoring room, which implies that the radiation interference have no effects on these instruments. All the parameters of the attenuations and the power dividers are listed in Table 1. The multiples reflect the relationship between the actual outputs of CZT detectors and the amplitudes of

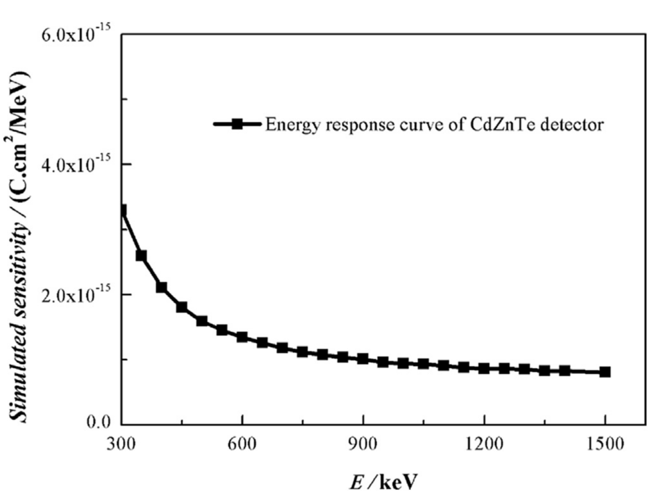


**Fig. 2.** Energy responding curve of CZT detectors simulated by MCNP.

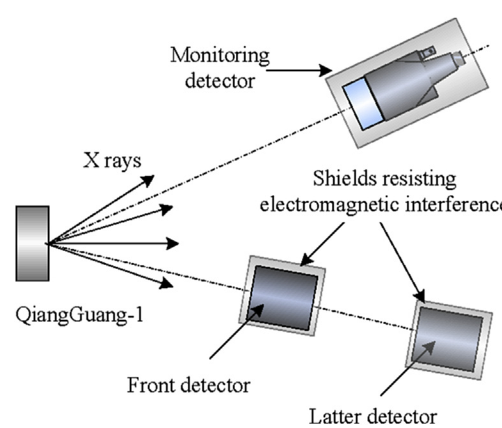


**Fig. 3.** Illustration of pulsed X-ray experiment for determining the fluence rate response of the CZT detector.