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Investigation of the $LaBr_3$ scintillator response to heavy ions

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ABSTRACT

Lanthanum Halide scintillators such as lanthanum bromide ($LaBr_3$:Ce) and lanthanum chloride ($LaCl_3$:Ce) have been studied extensively in gamma radiation fields and have shown to be excellent gamma ray detectors. Measurements with these detectors in complex radiation fields that include neutrons, protons and heavy ions may produce some information about the radiation field. For example fast neutron (n,γ), (n,p), and (n,α) reactions produce scintillations in the crystal from the energy deposited by the resulting secondary particles. Also high energy radiation environments such as those encountered in spacecraft and high energy charged particle facilities contain protons and heavy ions with enough energy to penetrate typical scintillation detectors. The light produced in the crystal by these heavy ions is proportional to the energy deposited along the ion track. To investigate the response of $LaBr_3$ detectors to heavy ions, a series of experiments have been carried out at the Heavy Ion Medical Accelerator in Chiba, Japan (HIMAC). Measurements with He and Si ions with various incident energies have been performed and the light output of the scintillator has been measured. The experimentally measured spectra have been compared to simulations using the particle and heavy ion transport system (PHITS) code and quenching effects have been observed in the measured spectra. The quenching of the Si ion experiments is greater than the quenching observed in the He ion experiments. The results from both simulation and experiment are presented and discussed.

1. Introduction

Lanthanum halide detectors are now widely used as gamma ray spectrometers and are noted for their high efficiency, good energy resolution, high light output, faster decay and better timing properties than conventional crystals such as NaI (Oberstedt et al., 2012). Recently, these detectors have been incorporated in space missions as gamma ray spectrometers. However, their response is influenced by other radiation particles such as neutrons, protons and heavy ions that are abundant in such complex environments (Owens, 2008). Radiation effects in $LaBr_3$ crystals from protons and heavy ions as well as neutron activation effects have been studied (Owens, 2008) (Quaratiet al, 2011). The energy deposited in these detectors by heavy charged particles can produce significant scintillation events with large light output. In our previous work, fast neutron reactions (n,p) and (n,α) have been studied in CLYC detectors and have shown to produce measurable light pulses that are proportional to the incident neutron energy (Machrafi et al., 2015) (D'Olympia et al., 2014). The same reactions are expected to occur in $LaCl_3$ detectors because of the ^{35}Cl isotope presence in the crystal. To evaluate the response of lanthanum halide detectors in complex mixed space radiation fields, it is required to characterize their responses to heavy charged particles. In this work we have used a BrilLanCe™ 380 $LaBr_3$:Ce detector to study the response to high energy heavy charged particle irradiation (BrilLanCe Scintillators Performance Summary). Measurements were carried out at the Heavy Ion Medical Accelerator in Chiba, Japan (HIMAC). Monte-Carlo simulations of the experiments using the particle and heavy ion transport system (PHITS) code were also performed. This paper outlines the results of different experiments with He and Si heavy ion beams, discusses the resulting scintillation light output of the crystal and compares the experimental data with the simulations.

2. Methodology

2.1. Detector description

The detector used in this study was a cylindrical 1.5 × 1.5 inch brilliance™380 $LaBr_3$:Ce crystal from Saint- Gobain Crystals attached to a 2 inch Hamamatsu R6231 photomultiplier tube (PMT) encased in a standard aluminum housing assembly (BrilLanCe Scintillators Performance Summary). The $LaBr_3$ crystal has a density of 5.08 g/cm^3. The detector was attached to an Osprey universal digital multi-channel analyzer (MCA) manufactured by Canberra for scintillation spectrometry (Osprey). The Osprey unit allows for control of the High voltage

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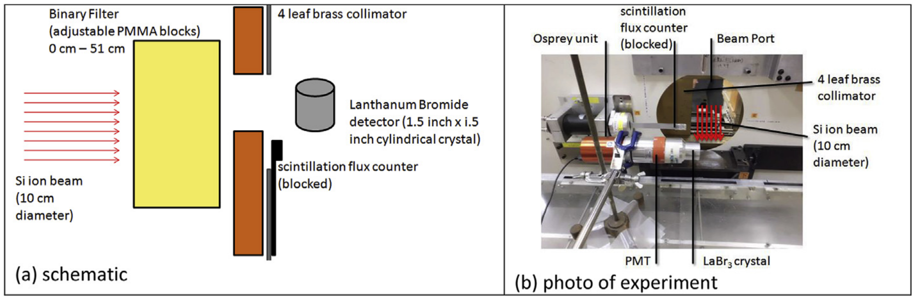

Fig. 1. Experimental setup at the HIMAC BIO room for 490 MeV/nucleon Si beam.

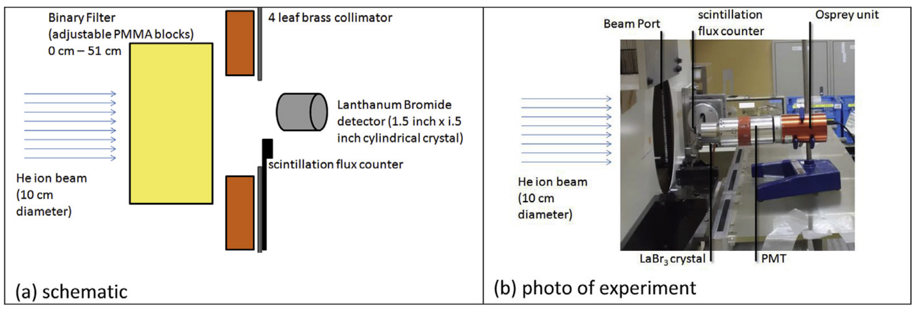

Fig. 2. Experimental setup at the HIMAC BIO room for 150 MeV/nucleon He beam.

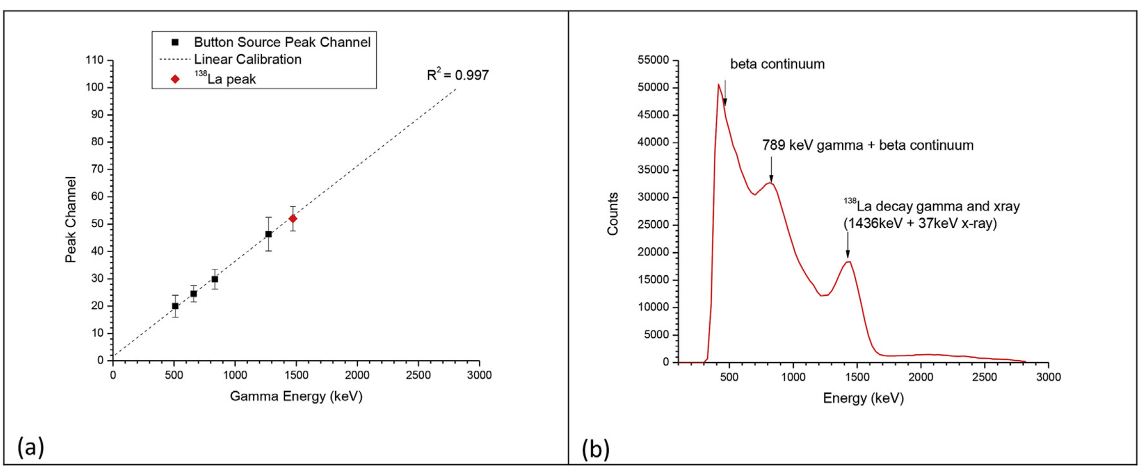

Fig. 3. (a) $LaBr_3$ gamma calibration and (b) 12 h $LaBr_3$ background measurement before HIMAC experiments.

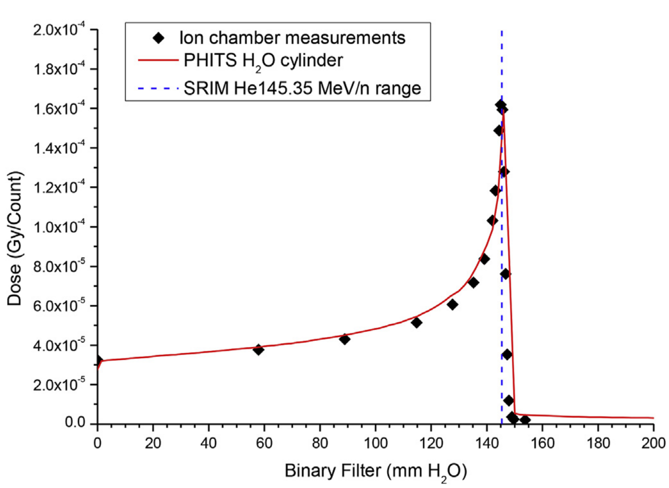

Fig. 4. Measured and simulated Bragg curve for He ion beam.

applied to the PMT and acquisition of energy spectra with adjustable gain, channel and timing characteristics. The high voltage for these experiments has been significantly reduced from typical operation (750–1000 V) down to 250 V in order to reduce the peak anode current and PMT saturation as prescribed in similar previous experiments (Quaratiet al, 2011). The system was calibrated with standard calibration gamma sources from Spectrum Techniques including 37,000 Bq ^{22}Na, ^{137}Cs, and ^{54}Mn.

2.2. Facility description and experimental setup

Measurements of 150 MeV/nucleon ^{4}He ions and 490 MeV/nucleon ^{28}Si ions were performed at the HIMAC facility Biological Room. The facility provides a 10 cm diameter mono-energetic heavy ion beam. To reduce the ion energy in different experiments, polymethylmetacrylate (PMMA) 'Binary Filters' of varying thickness were placed between the beam collimator and the $LaBr_3$ detector (Ploc et al., 2017). The beam dose depth curve was measured with a Radiation Products Design Inc. PTW 23343 Markus Ion Chamber for various thicknesses of Binary