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Neutron-Induced Radiation Damage in LYSO and BaF_2 Crystals

Chen Hu, *Member*, *IEEE*, Fan Yang, *Member*, *IEEE*, Liyuan Zhang, *Member*, *IEEE*, Ren-Yuan Zhu, *Senior Member*, *IEEE*, Jon Kapustinsky, *Senior Member*, *IEEE*, Michael Mocko, Ron Nelson, and Zhehui Wang, *Member*, *IEEE*

***Abstract*–One crucial issue for applications of inorganic scintillators in future HEP experiments is radiation damage in a severe radiation environment, such as the HL-LHC. While radiation damage induced by ionization dose is well understood, investigations are on-going to understand radiation damage induced by hadrons, including both charged hadrons and neutrons. In this study, we report neutron induced radiation damage in BaF_2, LYSO, and PWO crystals. The results show that commercial LYSO and BaF_2 survive neutron fluence of 8.3×10^{15} n_{eq}/cm^2. LYSO crystals are expected to meet the radiation hardness specification of the CMS barrel timing layer detector.**

I. Introduction

PRECISION measurements of fundamental particles, such as photons and electrons (e/γ), enhance physics discovery potential for future high energy physics (HEP) experiments. Total absorption crystal calorimetry provides the best possible energy resolution, good position resolution, and good e/γ identification and reconstruction efficiencies. Fast inorganic crystal scintillators are needed for future HEP experiments at the energy and intensity frontiers. One crucial issue, however, is crystal's radiation damage in severe radiation environment expected by future HEP experiments. With 5×10^{34} $cm^{-2}s^{-1}$ luminosity and 3,000 fb^{-1} integrated luminosity, the HL-LHC, for example, will present up to 130 Mrad ionization dose, 3×10^{14} charged hadrons/cm^2 and 5×10^{15} neutrons/cm^2 at the endcap region [1]. In this paper, we report neutron induced damage in BaF_2, LYSO, and PWO crystals irradiated at the Los Alamos Neutron Science Center (LANSCE). Optical and scintillation properties of crystal samples were characterized at Caltech HEP crystal lab before and after irradiations. The result of this investigation is important for quality assurance of LYSO crystals for the CMS barrel timing layer (BTL) detector at the HL-LHC, and the optical-based radiation hard calorimetry.

II. Samples and Experimental Setup

Three neutron irradiation experiments 6991, 7332 and 7638 were carried out in 2015, 2016, and 2017 respectively at LANSCE. Fig. 1 shows the Target-4 experiment site at the center of LANSCE (Left) and the East Port (Right) where the neutron irradiation was carried out. Crystal samples were at about 1.2 m away from the neutron production target.

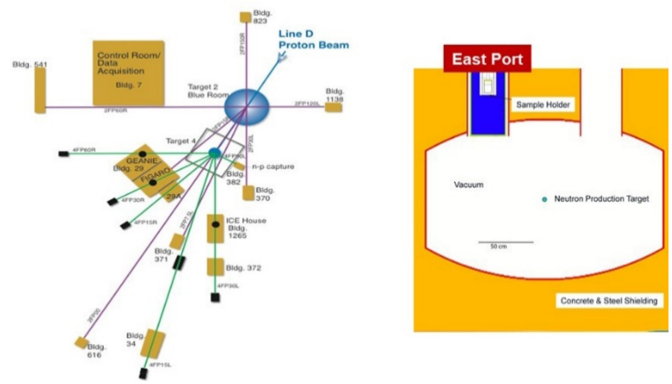

Fig. 1. Two schematics showing the neutron irradiation experiment site in the Target 4 area of LANSCE (Left), and the sample location at the East Port (Right).

In the experiment 6991, a total of 18 LFS (lutetium fine silicate identical to LYSO in performance) crystal plates of $14\times14\times1.5$ mm^3 from Zecotek Photonics Inc. were irradiated. The LFS plates were divided into three groups of six each in a holder, which was down loaded into the East Port before irradiation, and were retrieved one group at a time after 13.4, 54.5 and 118 days. In the experiment 7332, 36 LYSO, BaF_2 and PWO plates of 5 mm thickness were divided into three groups of 12 each, which were irradiated for 21.2, 46.3 and 120 days respectively. In the experiment 7638, 12 LYSO plates produced by Shanghai Institute of Ceramics (SIC) and Sichuan Tianle Photonics Co., Ltd. (Tianle) and 3 LuAG ceramic plates produced by SIC were divided into three groups of 5 each. They were irradiated for 21, 48 and 102 days respectively.

III. Results and Discussion

Fig. 2 shows the radiation induced absorption coefficient (RIAC) values at the emission peak as a function of 1 MeV equivalent neutron fluence for six each of LYSO (circles), BaF_2 (squares) and PWO (triangles) crystals with (open) and without (solid) 5 mm lead shielding irradiated in the experiment 7332, and the corresponding fits. While the average RIAC values after neutron fluence of 8.3×10^{15} n_{eq}/cm^2 are 14, 50 and 97 m^{-1} respectively for LYSO, BaF_2 and PWO without 5 mm Pb shielding, they are 7.3, 44 and 111 m^{-1} with Pb shielding. The Pb shielding appears does not reduce the damage level in crystal samples, indicating that the damage caused by the γ-ray dose at

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Chen Hu, Fan Yang, Liyuan Zhang, and Ren-Yuan Zhu are with the HEP, California Institute of Technology, Pasadena, CA 91125, USA (e-mail: zhu@hep.caltech.edu).

Jon Kapustinsky, Michael Mocko, Ron Nelson, and Zhehui Wang are with the Los Alamos National Lab, Los Alamos, NM 87545, USA.

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the East Port is much less than the damage induced by neutrons. This is also confirmed by an independent calculation of damage caused by the accompany ionization dose

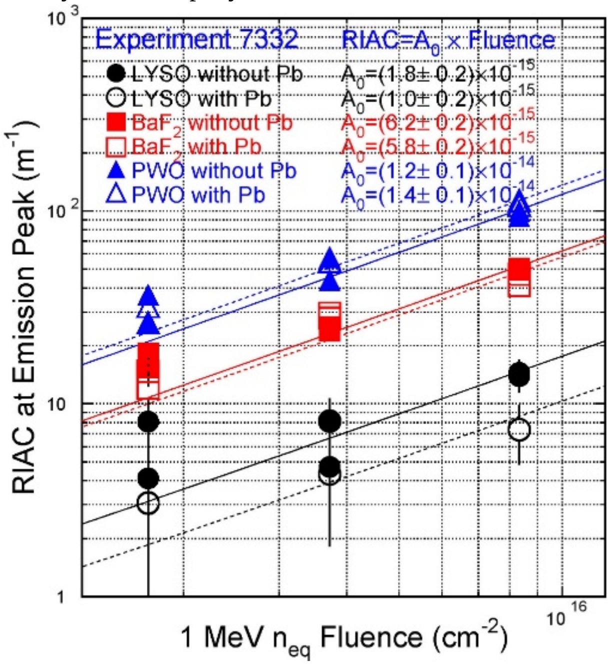

Fig. 2. RIAC values are shown as a function of 1 MeV equivalent neutron fluence for LYSO, BaF_2 and PWO plates.

Fig. 3 shows the normalized light output (LO) as a function of 1 MeV equivalent neutron fluence for LYSO, BaF_2 and PWO. Each LO value is an average of two samples irradiated under the same condition. The normalized LO values after a neutron fluence of 8.3×10^{15} n_{eq}/cm^2 are 77% and 76% respectively for LYSO and BaF_2 crystals without Pb shielding, and 80% and 80% with Pb shielding. It is clear that LYSO and BaF_2 plates survive neutron fluence of 8.3×10^{15} n_{eq}/cm^2 well, and are much more radiation hard than PWO against neutrons.

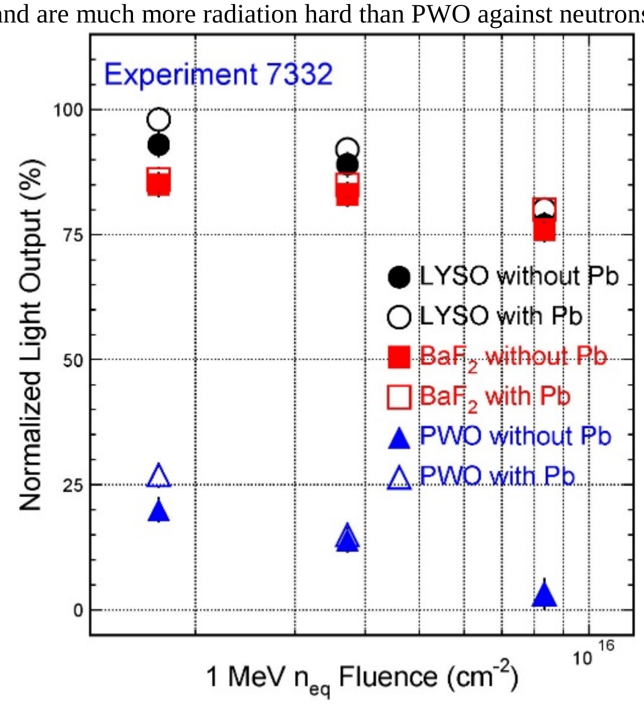

Fig. 3. Normalized LO is shown as a function of 1 MeV equivalent neutron fluence for LYSO, BaF_2 and PWO plates.

Fig. 4 shows the RIAC values as a function of 1 MeV equivalent neutron fluence for LFS plates used in 6991 (black), LYSO plates used in 7332 (red), LYSO plates used in 7638 (black), and the corresponding fits. It is clear that LYSO crystals from three different vendors show consistent damage as a function of 1 MeV equivalent neutron fluence: RIAC @ 430 nm = 1.4×10^{-15} F_n, which is a factor of ten less than protons [2]. This is attributed to contributions from ionization energy loss from protons, in addition to hadron induced displacement damage and nuclear breakup.

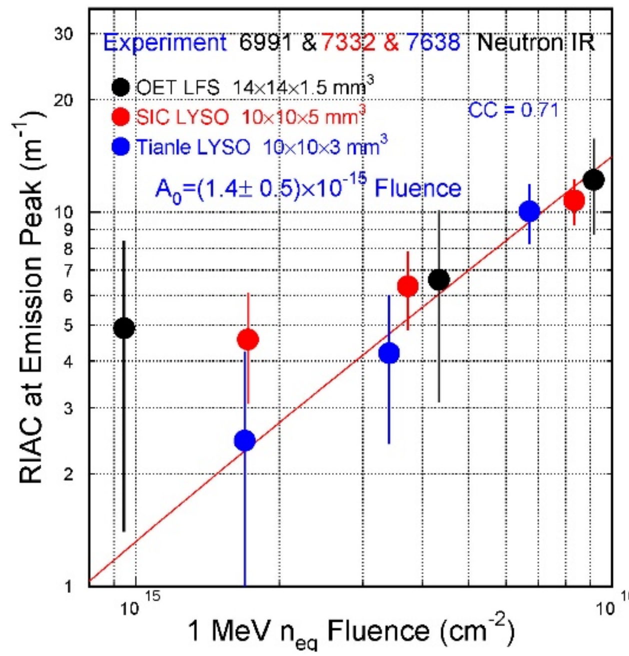

Fig. 4. RIAC values are shown as a function of 1 MeV equivalent neutron fluence for LYSO plates used in three experiments from three vendors.

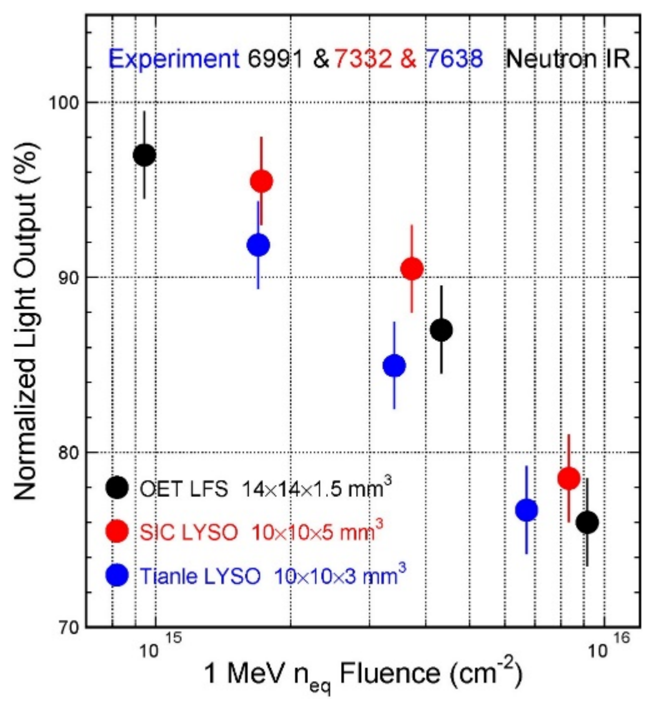

Fig. 5. Normalized LO is shown as a function of 1 MeV equivalent neutron fluence for LYSO plates used in three experiments from three vendors.

Fig. 5 compares the normalized light output (LO) as a function of 1 MeV equivalent neutron fluence for LFS samples in 6991 (black), LYSO samples in 7332 (red), and LYSO samples in 7638 (black). The results show consistent damage level for LYSO crystals from three vendors. It is clear that LYSO crystals survive 1 MeV equivalent neutron fluence up to 8×10^{15} n_{eq}/cm^2.

IV. Summary

We investigated neutron induced radiation damage for BaF_2, LYSO, and PWO crystals. LYSO crystals show the best radiation hardness among all tested crystals. About 20% light output loss is found in 14×14×1.5 mm plates after 8×10^{15} n_{eq}/cm^2. Commercial LYSO crystals are expected to meet CMS BTL radiation hardness specification: induced absorption <3 m^{-1} for 1 MeV equivalent neutron fluence of 3×10^{14} n/cm^2.

BaF_2 shows a radiation damage large than LYSO at low neutron fluence and compatible to LYSO at high fluence. Investigation will continue on BaF_2:Y crystals, and to compare damage in various inorganic crystal scintillators induced by ionization dose, protons and neutrons.

While both protons and neutrons cause damage in inorganic scintillators, damage induced by protons is an order of magnitude larger than that from neutrons, which is attributed to ionization energy loss by protons, in addition to displacement and nuclear breakup damages by hadrons.

References

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