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Study of neutron damage resistance of some scintillating crystals and associated photodetectors with the nuclear reactor ULYSSE

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Abstract

Radiation resistance is a mandatory requirement for a major part of the active or passive components of the particle detectors planned for the future high energy accelerator LHC.

Ulysse is a training reactor of the Institut National des Sciences et Techniques Nucléaires (INSTN), in Saclay, and a very suitable tool for testing materials and devices for these future large detectors. Its radiation spectrum characteristics are very similar to those expected in these detectors, in terms of spectra of fast neutrons, thermal neutrons and gamma photons, and ratios between those types of radiation.

Results are presented on the neutron resistance of two scintillating crystals, candidates for electromagnetic calorimetry, cerium fluoride (CeF_3) and lead tungstate (PbWO_4), and on the behaviour under neutron irradiation of some avalanche photodiodes, currently under development for light detection of these crystals.

Résumé

La résistance aux radiations est un impératif pour la majeure partie des composants passifs ou actifs des détecteurs de particules prévus pour le futur accélérateur à haute énergie LHC.

Ulysse est un réacteur d'enseignement de l'Institut National des Sciences et Techniques Nucléaires (INSTN), à Saclay, et un outil très commode pour le test des matériaux et dispositifs pour ces futurs grands détecteurs. Son spectre de radiation a des caractéristiques très similaires à celles qui sont attendues dans ces détecteurs, en termes de flux de neutrons rapides ou thermaux, de rayons gamma, et de ratio entre ces types de rayonnement.

Des résultats sont présentés sur la résistance aux neutrons de deux cristaux scintillants, candidats pour la calorimétrie électromagnétique : le fluorure de cérium (CeF_3) et le tungstate de plomb (PbWO_4), ainsi que sur le comportement sous irradiation neutronique de certaines diodes à avalanche actuellement en développement pour la détection de la lumière de ces cristaux.

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1. Introduction

One of the most important constraints to consider for the definition of the high energy physics experiments proposed for the Large Hadron Collider (LHC) projected at CERN is certainly the radiation environment. This is particularly important in the region of the calorimeter where the electromagnetic cascades deposit the maximum of energy, the so-called “shower-maximum”. At that place, the radiation level is of the order of 10 kGy (1 Mrad) and 10^{13} fast neutrons/cm² per year of operation, or even more in the forward regions [1-3]. Hence it is essential to test systematically the radiation resistance of all the detector's components submitted to this radiation environment : detection media, photodetectors, electronics, mechanics, etc.

Ulysse is a Uranium metal nuclear reactor of the Institut National des Sciences et Techniques Nucléaires (INSTN), in Saclay, devoted mainly to training purposes. We use it part of its running time to perform neutron irradiations. It has two great advantages for these experiments. First its running power can be easily adjusted. Thus the fast neutron flux can vary between some 10^6 and 10^{11} neutrons cm⁻² s⁻¹. Secondly, at the point where our irradiations take place, (almost in contact with the fuel elements), the fast neutron spectrum is the one of the uranium fission neutrons, characterised by a peak near 1 MeV, and so is very similar to the one foreseen at LHC, as shown in figure 1. The neutron fluxes have been measured by a thin foil activation method, and the gamma ray dose rate with an calibrated ionisation chamber. Table 1 indicates the measured values. The ratios between fast and epithermal neutron fluxes and between neutron fluxes and gamma ray rates are also close to those estimated for LHC. We now use Ulysse routinely for the study of the neutron resistance of detector components, mainly scintillating crystals and avalanche photodiodes.

Table 1. Neutron fluxes and gamma ray dose rates in the reactor Ulysse, at the position of irradiation (channel HN1).

fast neutrons ($E > 100$ keV)	epithermal neutrons ($1 \text{ eV} < E < 100 \text{ keV}$) (cm ⁻² s ⁻¹ W ⁻¹)	thermal neutrons ($E < 1 \text{ eV}$)	gamma rays (Gy s ⁻¹ W ⁻¹)
$(2.4 \pm 0.5) 10^6$	$(8. \pm 2.) 10^6$	$(7. \pm 2.) 10^6$	$(3. \pm 1.) 10^{-4}$

Figure 1. Neutron spectra in a CeF_3 calorimeter with moderator, as calculated in ref. [3] and neutron spectrum in the channel HN1 of the reactor ULYSSE. The spectra are normalised to give the same total fluence between 100 keV and 1 GeV.

2. Crystals

Two main candidates are now being considered for the electromagnetic calorimeter of the CMS experiment at LHC: cerium fluoride (CeF_3) and lead tungstate (PbWO_4) [2,4,5]. We have investigated the neutron resistance of one sample of these two scintillating crystals. Both have been irradiated in Ulysse up to 10^{14} fast neutrons cm^{-2} and 12.5 kGy (1.25 Mrad).

The results on CeF_3 have been recently reported [6]. The sample does not show a significant modification of its photoluminescence properties (figure 4 in [4]). Its transparency is only slightly affected. As shown in figure 2, the irradiation induced absorption coefficient is proportional to the fluence and equal to $0.27 \pm 0.08 \text{ m}^{-1}$ per 10^{13} fast neutrons cm^{-2} . This is equivalent to an attenuation length of roughly 4 m at 10^{13} neutrons cm^{-2} , or 0.4 m at 10^{14} neutrons cm^{-2} .

Figure 2. Radiation-induced absorption coefficients in the CeF_3 (left) and PbWO_4 (right) samples, at the emission peaks (respectively 303 and 490 nm), as function of the neutron fluence.

The sample of PbWO_4 was given to us by K. Korzhik and J.-P. Peigneux. It is a piece (dimension $2 \times 2 \times 2 \text{ cm}^3$) cut at the end of one of the 20 cm long crystals studied in test beams at IHEP Protvino and CERN Geneva [5]. For radiation safety reasons, the optical measurements were done at least one week after the irradiations, (2 weeks for the last step). During that time, the sample was kept out of light. Compared to CeF_3 , PbWO_4 is much more activated by thermal neutrons, the dominant isotope being ^{186}W , activated in ^{187}W with a thermal neutron capture cross section of $37 \pm 2 \text{ b}$. The decay of ^{186}W is nevertheless faster, with a half life of 24 h.

The sample studied exhibits after irradiation a behaviour similar to CeF_3 , if not better. Its photoluminescence spectrum is not significantly affected (figure 3). A very slight diminution of its transparency is observed. The radiation induced absorption coefficient is very low, and equal to $0.086 \pm 0.05 \text{ m}^{-1}$ per 10^{13} fast neutrons cm^{-2} (figure 2). This is equivalent to an attenuation length of approximately 1.2 m at 10^{14} neutrons cm^{-2} .

Figure 3. PbWO_4 : Photoluminescence spectra, (thick solid line : before irradiation, thin solid line : after $10^{14} \text{ n cm}^{-2}$; left : excitation for a 490 nm emission, right : emission for a 306 nm excitation) and optical transmission before irradiation (dashed line), as function of the wavelength.

3. Avalanche photodiodes

Avalanche photodiodes (APDs) are fast compact photodetectors with good quantum efficiency which are much less sensitive to high magnetic fields than photomultipliers. They may be very useful in future high energy physic experiments for the detection of the light emitted by scintillating devices like scintillating crystals. High gains (> 100) are currently achieved and available photosensitive areas vary from 1 mm^2 to 2 cm^2 .

We have started a program to measure the behaviour of APDs irradiated by fast neutrons. Here we report on the measurement done with an APD from EGG (type 30902, diameter 1 mm). During the irradiations the diode was biased at a voltage corresponding to a gain $M = 100$. The measurements were done a few days after the irradiations so that most of the annealing effects have already taken place.

Figure 4 shows the noise and the dark current for a gain of 100 as a function of the total neutron fluence. The measurements were done at room temperature and at 0°C ; the noise was measured using a shaping time (RC) of 100 ns. At high fluence, the dark current is dominated by the bulk current induced by the damage, and the noise and the dark current are approximately proportional to the gain. Figure 4 shows also a rough calculation of the expected noise based on the data of [7]. This shows that the diodes behave as expected. These results are very encouraging and we have started to test APDs having larger areas. The amount of damage is proportional to the thickness of the diodes, thus for high levels of radiation, thin diodes will be preferred over those which have a thick multiplication or drift region.

Figure 4. Noise (in equivalent electrons) and dark current of irradiated APD EGG type 30902 as a function of the fast neutron fluence.

4. Conclusion

With Ulysse we have at our disposal a very suitable tool to simulate the radiation environment of the future high energy physics experiments. The results reported here are encouraging as to the possibility to employ in a large high energy physics experiment, cerium fluoride or lead tungstate as dense scintillators and avalanche photodiodes as light read-out.

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References

- [1] G. Stevenson, in : *Proc. Large Hadron Collider Workshop*, vol.3, eds G. Jarlskog and D. Rein, CERN/90-10, ECFA/90-133 (1990) 566-583.
- [2] CMS collaboration, *CMS Letter of Intent*, CERN-LHCC/92-3 (1992).
- [3] P.A. Aarnio and M. Huhtinen, Nucl. Inst. and Meth. A336 (1993) 98-105.
- [4] Crystal Clear Collaboration, Nucl. Inst. and Meth. A322 (1993) 373-394.
- [5] O.V. Buyanov et al, *A first electromagnetic calorimeter prototype of PbWO₄ crystals*, LAPP-EXP/94-06, submitted to Nucl. Inst. and Meth. A.
- [6] R. Chipaux, J.-L. Faure, P. Rebougeard, G. Dauphin and J. Safieh, *Behaviour of CeF₃ scintillator in a LHC-like environment*, DAPNIA/94-01, to be published in Nucl. Inst. and Meth. A.
- [7] R. Wunstorf et al., in : *Proc. Large Hadron Collider Workshop*, vol.3, eds G. Jarlskog and D. Rein, CERN/90-10, ECFA/90-133 (1990) 706-720.