$PbWO_4$ Crystal Irradiation in the High Energy Hadrons Field of IHEP Accelerator

V. Katchanov, V. Lukanin, O. Lyashenko, V. Pikalov, A. Uzunian
Instiyite for High Energy Physics, Protvino, Russia

Introduction

The lead tungstate crystals $PbWO_4$ were chosen as the baseline for the electromagnetic calorimeter of the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collaider (LHC) in CERN [1]. The one of the main requirements for the $PbWO_4$ is the relative conservation of the optical properties in the conditions of high radiation levels. The expected value of the maximum absorbed dose in the crystal will be of 30 kGy/year for the full luminosity of the LHC operation.

The present paper is a first stage of the radiation hardness research of the full-scale $PbWO_4$ crystals in hadronic fields of the IHEP accelerator. The secondary from the Be target by 70 GeV proton beam interaction were used for $PbWO_4$ irradiation. The integrated absorbed dose of 28 KGy was observed. The results of the mesurements of the induced radioactivity and radionuclide concentration for the crystal samples are given.

1. First run of irradiation

1.1. Conditions of irradiation

The sample of $PbWO_4$ was irradiated within 150 hours near to the internal target of 70-GeV IHEP accelerator. The sample was installed in a plane of an accelerating protons orbit on a line making about 10 degrees with a tangent to an orbit, on distance about 3 meters from a target forward on a course of a proton beam.

The structure of radiation field in an irradiation place is characterised by a wide set of secondary particles (neutrons, pions, protons, photons etc.). The mean energy of the secondary hadrons is equal to a few GeV.

The hadrons fluence value on ^{22}Na activity, generated in the aluminium activation detector, irradiated together with a sample, is estimated.
Using the cross-section value of 15 mb for $Al(h, spall)^{22}Na$ reaction ($E_h \geq 20\ MeV$), the hadrons fluence equal to $5 \cdot 10^{13} h/cm^2$ is received.

1.2. Induced radioactivity attenuation

Seven measurements of gamma-radiation spectra of the sample were carried out with the help of the Germanium detector. The summary of the absorbed dose (Gy/hour) in Germanium detector (at 60 cm from $PbWO_4$-sample) as a function of the cooling time (the run out time from the end of an irradiation) of the sample is given on a Fig. 1.

With by a good accuracy this dependence by the sum of four exponents is approximated

$$D(t) = A_1 e^{-t/\tau_1} + A_2 e^{-t/\tau_2} + A_3 e^{-t/\tau_3} + A_4 e^{-t/\tau_4},$$

where t — cooling time, A_i — exponents meaning at $t = 0$, τ_i — constant time of exponents, connected with half-life ($T_{1/2}$) by a ratio: $\tau = T_{1/2}/ln2$, $A_1 = 2.7 \cdot 10^{-6}$; $A_2 = 1.1 \cdot 10^{-6}$; $A_3 = 3.4 \cdot 10^{-7}$; $A_4 = 1.8 \cdot 10^{-7}$.

It, certainly, does not mean, that in a sample three gamma-active radionuclides were formed only. Nevertheless, it is obvious, that the gamma-radiation of a sample is formed, on the whole, by three groups of radionuclides with the Half-life about 15, 53, 63 and 379 hours respectively.

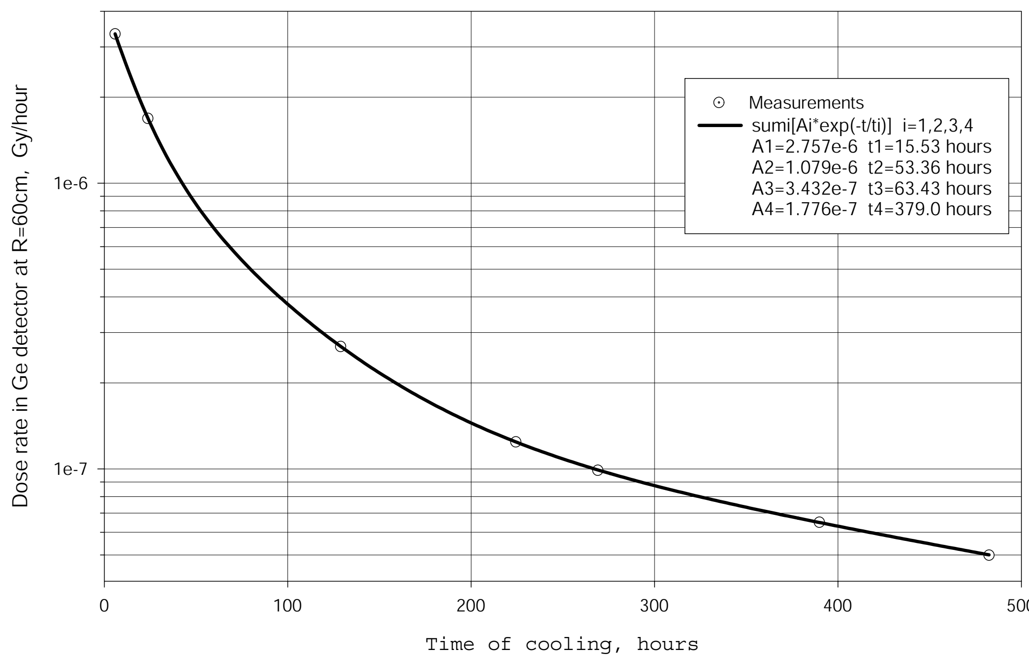

Figure 1: The absorbed dose rate in Germanium detector from irradiated $PbWO_4$-sample as a function of the cooling time.

1.3. Analysis of gamma-spectra

For an estimation the gamma-activity rate and concentration, of formed gamma-active radionuclides two gamma-spectra were analysed:

- Spectrum Sp277 (Fig. 2) with 1 day of cooling time for short lived radionuclides selection. This spectrum corresponds to the 2-nd point on the plot of a Fig. 1;
- Spectrum Sp297 (Fig. 3) with 20 days of cooling time for long lived radionuclides selection. This spectrum corresponds to the last point on the plot of a Fig. 1.

The preliminary results of the analysis of spectra Sp277 and Sp297 are given in tables 1 and 2 accordingly.

2. Second run of irradiation

2.1. Irradiation of samples and detectors

Three pairs of $PbWO_4$ samples together with by activation detectors were irradiated in a field of secondary particles from an internal target of the IHEP U-70 accelerator. The assembly of samples with detectors settled down on tangent to the orbit of the accelerated protons in a direction "directly - forward" on distance 8 m from an internal target (between magnetic blocks 27 and 28).

The irradiated assembly of situated one after another three sample pairs was consisted. The sample pairs as “10k”, “100k” and “300k” were marked. Together with each pairs the activation detectors were installed. The irradiation time 2 hours 10 minutes is continued for “10k” sample, 21.5 hours — for “100k” sample and 195 hours — for “300k” sample.

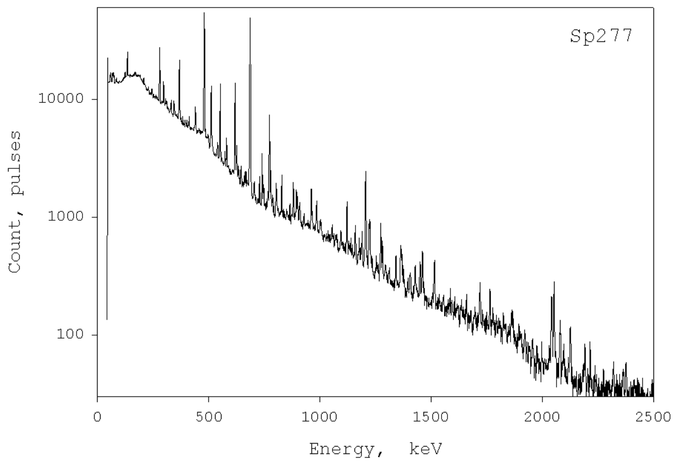

Figure 2: The hardware gamma spectrum of $PbWO_4$ (1 day cooling time).

Radionuclide	Activity, Bq/cm^3	Nuclear concent., $nuc./cm^3$	Half-life, *hours*
Ba-131	3.74e+03	5.50e+09	282.8
Eu-152m	2.10e+05	1.02e+10	10.0
Hf-181	2.62e+04	1.38e+11	1018.1
W-187	1.02e+06	1.26e+11	23.3
Hg-197m	1.96e+05	2.42e+10	23.3
Ta-183*	9.78e+04	6.22e+10	123.1
Pb-203	7.49e+04	2.02e+10	51.6
Tl-200	7.32e+04	9.92e+09	26.6
Au-198	5.23e+03	1.76e+09	64.9
Nd-147	6.42e+05	8.79e+11	262.8
Ir-194	7.32e+05	7.28e+10	20.0
Ce-143	4.63e+04	7.93e+09	33.3
Na-24	3.45e+03	2.68e+08	15.0

Table 1: Activity and concentration of short lived gamma-active radionuclides (1 day of cooling time).

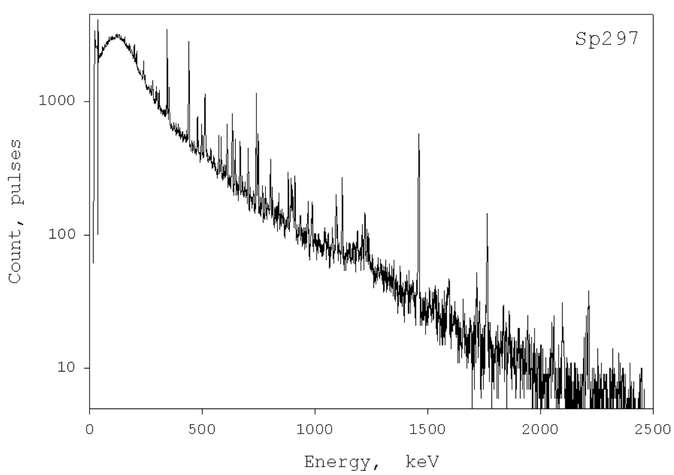

Figure 3: The hardware gamma spectrum of $PbWO_4$ (20 days cooling time).

Radionuclide	Activity, Bq/cm^3	Nuclear concent., $nuc./cm^3$	Half-life, *hours*
Yb-169	3.14e+03	1.25e+10	768.6
Ta-182	8.37e+02	1.19e+10	2746.5
Hg-203	6.71e+02	3.89e+09	1117.9
Hf-175	3.72e+03	3.25e+10	1680.2
Tl-202	3.23e+03	4.92e+09	292.8
Be-7	3.37e+03	2.23e+10	1277.6
Ru-103*	2.93e+02	1.43e+09	941.6
Te-121	4.77e+02	9.97e+08	402.6
Os-185	5.40e+02	6.29e+09	2245.8
Lu-171*	2.61e+03	2.67e+09	198.0
Zr-95*	2.27e+02	1.81e+09	1535.5
Re-184	1.30e+03	6.16e+09	911.6

Table 2: Activity and concentration of long lived gamma-active radionuclides (20 days of cooling time).

2.2. Characteristic of the radiation field and $PbWO_4$ absorbed doses

The structure of a particles field composition is not correctly investigated. But the draft estimations is shown the contribution of high energy neutrons (E$\geq$20 MeV) with the average energy in limits of 30–50 GeV is not less than 60 percents and fluence of the thermal neutrons is equal to 2 percents from the fluence of high energy neutrons.

The particle fluences by Aluminium and Cobalt activation detectors were measured. The cross-section of the $Al \Rightarrow^7 Be$ 8 mb was taken, $Al \Rightarrow^{22} Na$ — 15 mb, $Al \Rightarrow^{24} Na$ — 20 mb. The capture cross-section of thermal neutrons by cobalt as 37.18 barn was taken.

The analysis of the activation detectors was made using the Gamma-spectrometer with by the germanium semi-conductor detector. The calibration of the spectrometer was provided by the certificated set of Exemplary Spectrometric gamma-sources. The absorbed dose was defined by multiplication received fluences on a conversion factor equal $6 \cdot 10^{-10} Gy \cdot cm^2$. The results of measurements are given in table 3. Errors of fluence value as 20–25% and absorbed doses — about 40%.

Marked $PbWO_4$ sample	**Hadron fluence, h/cm^2**	**Absorbed dose, Gy**
"10k"	$6 \cdot 10^{11}$	$3.6 \cdot 10^2$
"100k"	$6 \cdot 10^{12}$	$3.6 \cdot 10^3$
"300k"	$5 \cdot 10^{13}$	$2.8 \cdot 10^4$

Table 3: Fluences and absorbed doses, received by the $PbWO_4$ samples at an irradiation in April 14-21, 1999.

References

[1] CMS Collaboration. *The Electromagnetic Calorimeter Project. Technical Design Report.* CERN/LHCC 97-33, CMS TDR 4 (1997).