FIRST CALIBRATION OF ALANINE AND RADIO-PHOTO-LUMINESCENCE DOSEMETERS TO A HADRONIC RADIATION ENVIROMENT

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Abstract

Alanine and Radio-Photo-Luminescence (RPL) dosemeters are used or will be used to monitor the absorbed doses occurring inside the tunnels of all CERN accelerators including the Large Hadron Collider (LHC). They are placed close to radiation sensitive machine components like cables or insulations of magnet coils to predict their remaining lifetime. At these locations the dosemeters are exposed to mixed high-energy radiation fields, but up to now both dosemeter types were only calibrated in the photon field of ^{60}Co sources. This paper presents the results of a proton calibration campaign applied to Alanine and RPL dosemeters. The dosemeters were irradiated with protons of a momentum of 24 GeV/*c* at the irradiation facility IRRAD1 at CERN-PS. The energy deposition per impinging protons seen at the location of the dosemeters is calculated with the FLUKA Monte Carlo code. By means of the measured fluence result the achieved number was translated into a finally obtained dose at the dosemeter location. Nine measurements at varying impinging proton intensities were performed. The dose results are related to the readout results obtained by the analysis procedures applied to the various detectors yielding to a proton calibration curve. This new proton based calibration curve is compared to the old one which was obtained by a ^{60}Co photon irradiation.

INTRODUCTION

At CERN the lifetime of accelerator components with respect to radiation damage is assessed by measuring the absorbed radiation dose with Alanine [1] and Radio-Photo-Luminescence [2] dosemeters. They are placed close to radiation sensitive machine components like cables or insulation of magnet coils and are exposed to a high-energy mixed radiation field with particle energies up to several hundreds of GeV. This radiation field is caused by beam losses during the operation of the machine.

Alanine is an amino acid which forms radicals when exposed to ionizing radiation. The amount of radicals created is a function of the dose seen by the dosemeter. Alanine dosemeters cover a dose range from several Gy up to several 100 kGy. The read-out system of these dosemeters is based on Electro Paramagnetic Resonance (EPR) which allows the determination of the total amount of produced radicals forming paramagnetic centers.

RPL dosemeters consist of phosphate glass. The radiation measurement procedure relies basically on the creation of radio photo luminescence centers induced by ionizing radiation. The amount of RPL centers created can be correlated to the dose seen by the dosemeters. The read-out of the amount of RPL centers is based on a UV light excitation of the dosemeter. The current CERN RPL dosemeters cover a dose range between 0.1 Gy and 1 MGy. However, the application of sophisticated measurement methods allows for an extension of the dose range to both ends.

Both dosemeter types are originally calibrated in terms of air kerma by a ^{60}Co source. In order to increase the accuracy of the lifetime prediction in a mixed radiation field a series of irradiation campaigns were successfully performed at CERN's High Energy Reference facility (CERF). The corresponding results are given in [3].

This paper describes the creation of a proton based calibration curve by the combination of FLUKA energy deposition calculations with measurement results which were achieved in the mono particle high-energy radiation field of the proton irradiation facility IRRAD1 at CERN-PS [4].

EXPERIMENTAL AND SIMULATION METHODES

Dosemeters and Readout Systems

The RPL dosemeters are composed of silver-activated phosphate glass and have a dimension of 6 mm in length and 1 mm in diameter. A Toshiba FGD-6 reader is used to analyze the irradiated dosemeters.

The Alanine dosemeters are composed of 67 % alanine and 33 % E-P rubber, which is used as binder material. Their dimensions are 30 mm in length and 4.8 mm in diameter. For the readout of the dosemeter a Varian E-3 reader is employed.

Irradiation Experiment

The dosemeters were grouped in packages consisting of 3 Alanine and 3 RPL dosemeters (see Figure 1) and irradiated by a mono energetic proton beam with a momentum of 24 GeV/c. The beam is directed towards the target by a bending magnet and passes approximately 14 m through air before impinging on the dosemeter package.

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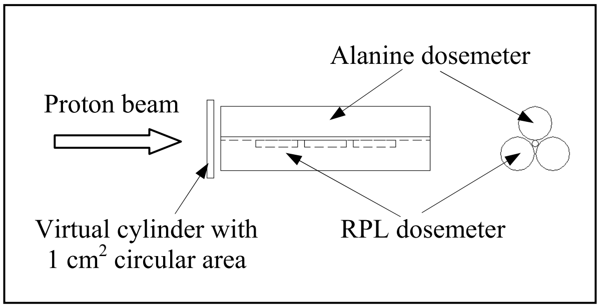

Figure 1: The dosemeter package consists of 3 Alanine and 3 RPL dosemeters. The arrow indicates the direction of the incident 24 GeV/*c* protons. Furthermore, the virtual cylinder with the circular area of 1 cm^2 is used in the simulations to score the fluence similar to the measured fluence by aluminium activation in the experiment.

The beam shape measured at the dosemeter front position can be approximated by a two dimensional gauss distribution with a horizontal standard deviation of 0.72 cm and a vertical standard deviation of 1.2 cm [5]. The integral fluence reaching up to 10^{16} protons per cm^2 was measured via activation of aluminium foils covering the front face of the dosemeter package.

The dosemeters were analysed after the irradiation. The position of the RPL dosemeters coincided with the peak of the Gaussian beam profile. However, the orientation of the Alanine dosemeters in the asymmetric beam profile is unknown. Therefore, the reading values of the dosemeters as given in Figure 2 and 3 are averaged over three dosemeters resulting in an increased uncertainty of the measurement.

Monte Carlo Simulation

All simulations were performed with the Monte Carlo particle transport code FLUKA [6, 7] (Fluka 2003).

The simulations were carried out to calculate the total absorbed dose deposited by the primary proton beam and to assess the influence of secondary particles on the absorbed dose seen by the dosemeters. The energy cut-offs of the calculations were set to 0.1 MeV for photons, muons and hadrons except for antineutrons (50 MeV) and neutrons which where followed down to thermal energies. Electrons and positrons were tracked down to 100 keV. Positrons reaching that energy are forced to annihilate with an electron resulting in the production of two 511 keV photons.

In a first step the influence on the measured dose caused by secondary particles produced in the surroundings of the single dosemeters were investigated. In order to assess this contribution all details of the experimental set-up (14 m of air upstream the dosemeters, a massive marble plate 20 cm downstream the dosemeters and the dosemeters with their real material composition) were taken into account to calculate secondary particle yields. It was found that the influence of secondary particles produced in hadronic showers is negligible compared to the dose deposited by the primary proton beam in the dosemeters.

Moreover, the modification of the beam shape and the beam intensity caused by multiple scattering of the protons in the upstream located air were investigated. The results showed that the proton beam is attenuated uniformly within a circle of 0.5 cm radius around the beam axis. The total decrease of intensity within this circle is about 4%. Therefore, the same beam shape parameters as measured at the target were applied to the proton source at the exit of the bending magnet (starting point of simulation).

In order to calculate the energy deposition in air (reference value for the calibration) by incoming protons the beam was started in air 14 m upstream the dosemeter positions. Because of the minor influence of the secondary particles produced in the surroundings, all materials except for air could be omitted in the simulation. In front of the dosemeter positions a simulation detector (denoted as fluence detector) was placed (see Figure 1) in order to count the percentage of started protons crossing the measurement positions. This detector had approximately the same dimension as the aluminium foil used to count the incoming protons during the experiment.

To obtain the final reference dose values in air ($D_{real,air}$) for the various irradiations and dosemeters, Formula 1 has to be applied to the data sets consisting of the simulated absorbed dose in air ($D_{pp,air}$) per primary proton started in the simulation, the simulated fluence (F_{pp}) per primary proton and the integrated fluence measured by the aluminium foil (F_{meas}).

$$D_{real,air} = D_{pp,air} \times \frac{F_{meas}}{F_{pp}} \qquad (1)$$

In order to obtain a proton calibration curve for Alanine and RPL dosemeters, the derived dose value has to be related to a read-out value obtained by the EPR and RPL analysis machines.

PROTON CALIBRATION CURVES FOR RPL AND ALANINE DOSEMETERS

Figure 2 presents the RPL proton calibration curve together with the calibration curve obtained by a ^{60}Co dosemeter irradiation. Both curves show the RPL reading value as function of the energy deposition in air. The behaviour of the two curves is similar however, it can be clearly seen that the proton calibration curve is shifted towards lower absorbed dose values. Although the absorbed dose in air is the same for both types of particles, the response of the RPL and Alanine is higher to protons than for photons.

Figure 3 shows the comparison between the proton and the ^{60}Co calibration curve for Alanine dosemeters. Also here a clear shift of the proton curve to lower absorbed doses can be observed. Only for dose values close to the saturation region similar reading values for both particle types can be observed.

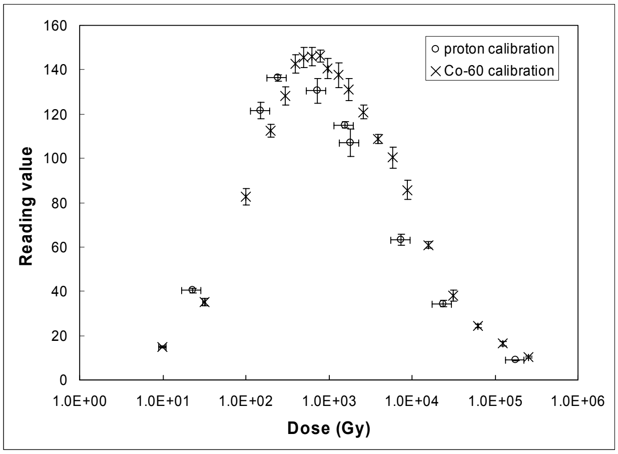

Figure 2: RPL reading values as a function of dose in air caused by 24 GeV/*c* protons and ^{60}Co photons, respectively.

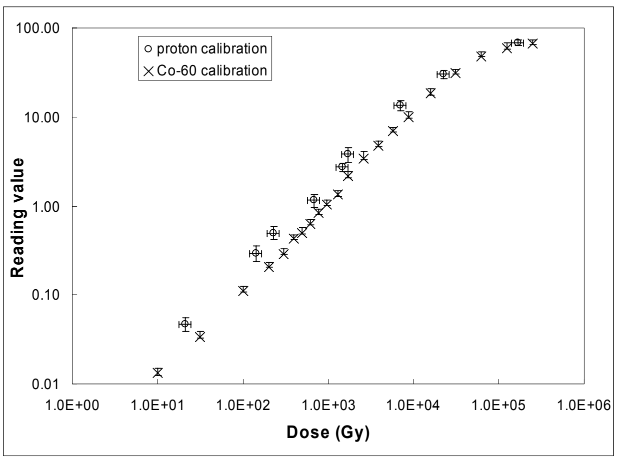

Figure 3: Alanine (EPR) reading values as a function of dose in air caused by 24 GeV/c protons and ^{60}Co photons, respectively.

CONCLUSION

This paper presents calibration curves for RPL and Alanine dosemeter measured in a 24 GeV/*c* proton field up to a dose range of 300 kGy. The calibration curves of both dosemeter types are compared to their photon counterparts. Compared to the photon curve a shift to lower absorbed doses of the proton curve can be observed for both dosemeter types. This campaign shows clearly that different particle types cause different effects in the Alanine and RPL dosemeters. Therefore, beside the measured reading value of a dosemeter also the particle types has to be taken into account to obtain a correct measured dose value.

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