PERFORMANCE TESTS OF SURVEY INSTRUMENTS USED IN RADIATION FIELDS AROUND HIGH-ENERGY ACCELERATORS

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Abstract

  Measurements of ambient dose equivalent in stray radiation fields behind the shielding of high-energy accelerators are a challenging task. Several radiation components (photons, neutrons, charged particles), spanning a wide range of energies, contribute to the total dose equivalent. Usually for measurements of the total dose equivalent, a set of radiation detectors consisting of ionisation chambers and so-called REM counters is employed. Ionisation chambers are sensitive to all radiation components, whereas REM counters are used to determine separately the neutron component. In this study measurements were carried out in a high-energy reference field at CERN to investigate the responses of the different detectors to a mixed radiation field under controlled conditions. In addition, the field and the corresponding ambient dose equivalents were simulated with FLUKA Monte Carlo calculations. The outcome of these studies determines the choice of radiation detectors for LHC and serves as a basis for a future certification of these instruments. In addition, the results will contribute to a global quality assurance system for CERN's radiation protection instrumentation.

INTRODUCTION

  Radiation dosimetry in mixed stray radiation fields behind the shielding of high-energy accelerators is a demanding task because of the complexity of the radiation field. These fields are dominated by photons and neutrons spanning an energy range from fractions of eV to several GeV. Although in most cases neutrons represent the major constituent of the ambient dose equivalent, the other components of the mixed field such as gamma radiation and charged particles have to be assessed correctly as well. The total dose equivalent strongly depends on the field composition with respect to particle types and particle energies.

  In routine-measurements, the total dose equivalent is measured by a set of radiation detectors including ionisation chambers and REM counters. Ionisation chambers are sensitive to all radiation components, whereas REM counters are designed to respond mainly to neutrons. Provided that the response of the detectors to the various particle types and energies is known, the total dose equivalent can be correctly assessed by using appropriate corrections and calibration factors. To deepen the knowledge on the detector response, measurements were carried out in a high-energy reference field at
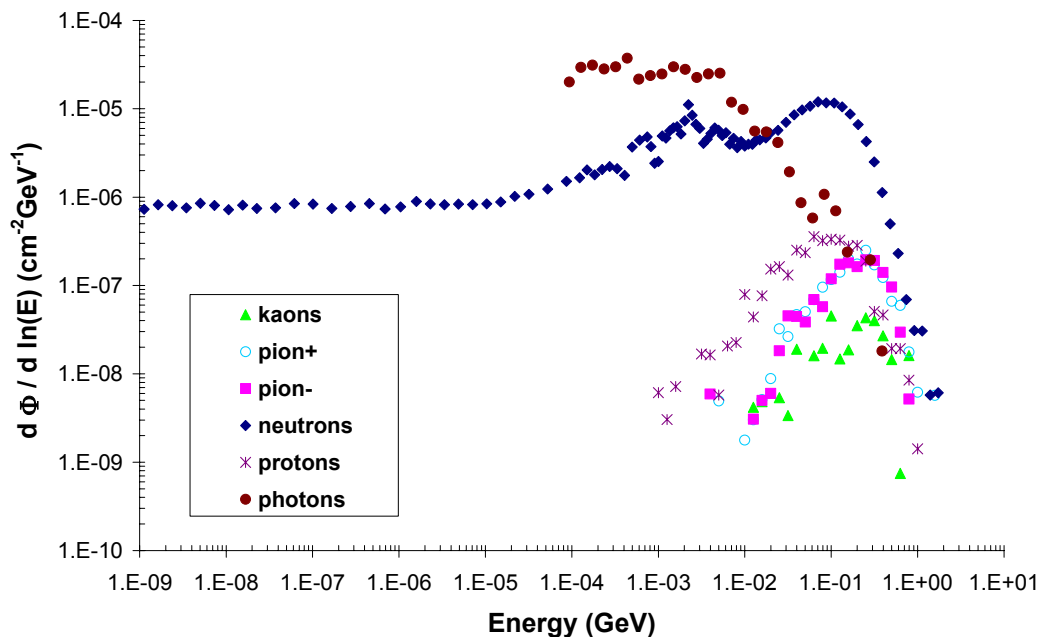

Figure 1: Fluence spectra (normalized by beam particle) for various particle types at CERF (Reference position CT6-10) [5].

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CERN. This facilitiy allows to study the response of the different detectors to mixed high-energy radiation fields under well controlled conditions. In addition, the experimental results were compared to Monte Carlo simulations.

RADIATION FIELD

The CERN-EU High Energy Reference Field (CERF) Facility provides a well-known mixed high-energy radiation field for the investigation and calibration of various instruments. It resembles very well the stray radiation fields behind thick lateral shielding at a high-energy hadron accelerator. The reference field is created by a positively charged mixed hadron beam (61% pions, 35% protons, 4% kaons) with a momentum of 120 GeV/c directed to a copper target, which is located either below an 80 cm concrete or a 40 cm iron shield [1]. The beam intensity is monitored by a Precision Ionisation Chamber (PIC). One PIC count corresponds to $(2.2 \pm 0.1) \times 10^4$ particles impinging on the target [2]. The secondary particles produced in the copper target traverse the shielding above of the beamline where several, well defined reference exposure positions are available. The particle fluences and spectra are well known from simulations with the April 2004 release of the MC program FLUKA [3, 4] at these reference positions. In Figure 1 [5] the fluence spectra for different particle types simulated for the reference position CT6-10 (concrete shield) are given as an example.

STUDIES WITH IONISATION CHAMBERS

At CERF, comprehensive studies were performed to quantify the response of ionisation chambers of type IG5 manufactured by Centronic to mixed radiation fields. The responses of the chambers with a volume of 5.2 litres and a filling-pressure of 20 bar were simulated using three different gas-fillings: hydrogen, argon and nitrogen. In Figure 2 the calculated responses for each gas-filling, are presented for the reference position CT6/10 in terms of created electrical charge per primary particle. Moreover, the relative contribution from each particle type to the total charge per primary particle is shown separately.

The simulations show that in the CERF reference field, the response of the argon- or nitrogen-filled chamber is approximately five times higher than for the hydrogen chamber. This indicates that in a CERF-like field the argon- or nitrogen-filled chamber would be the preferred instrument regarding response. However, the major contribution to the expected ambient dose equivalent outside the shielding originates from neutrons as neutrons have the highest radiation weighting factor. Therefore, it is of great importance to know the response of the detectors to neutrons to be able to choose the one which measures the corresponding dose contribution best. In Figure 2, one can see that regarding the contribution from each particle type to the total calculated electrical charge the hydrogen chamber is the most sensitive one for

neutrons. Being aware of the different responses to the particle types a qualified choice for future use of the chambers can be made.
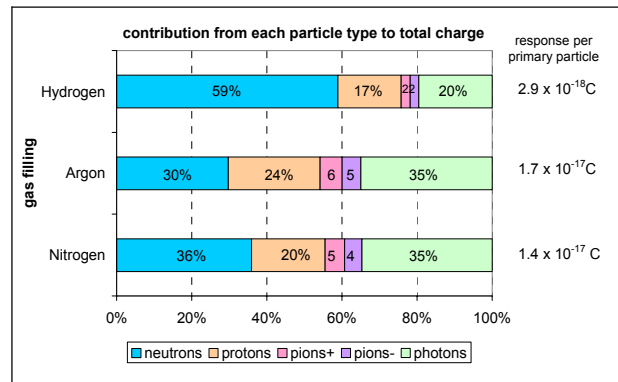

Figure 2: Relative contribution from each particle type to the total created charge (per primary particle) for a mixed radiation field encountered at the reference position CT6/10 at CERF.

Experimentally, the Monte Carlo results were verified for the argon- and hydrogen-filled chamber and are reported in [6]. The experimental investigation of the nitrogen-filled chamber is foreseen for the near future. The use of nitrogen-filled chambers instead of argon-filled chambers could be of advantage as they can be even used under recombination.

STUDIES WITH REM COUNTERS

REM (Roentgen Equivalent Man) counters are used to measure the ambient dose equivalent due to neutrons over a wide range of neutron energies. They generally rely on capture reactions for neutrons, e.g. $^{10}B(n, \alpha)^7Li$ or $^3He(n, p)^3H$, in an inner detector which is surrounded by a polyethylene moderator. The instruments investigated in this study were the Thermo WENDI-2, the Thermo Biorem, the EG&G Berthold LB6411, the Studsvik 2202D and the Centronic REM Ionisation Chamber (RIC). With exception of the WENDI-2 which is specified to measure neutrons up to several GeV all detectors belong to the category of conventional neutron dose rate monitors which usually cover neutron energies up to 20 MeV.

Measurements were performed with the instruments for different beam intensities at various reference positions behind the concrete shielding. In addition, measurements were carried out with a different type of detector, the HANDI-TEPC (tissue equivalent proportional counter), which is able to measure microdosimetric spectra. This device is usually taken as reference device at CERF because of its proven reliability for measuring the total (neutron) dose equivalent in radiation fields with a dominant dose equivalent component due to high-energy particles [7]. In Figure 3 the measurement results together with the simulation are plotted exemplarily for the reference position CT6/10.

The study at the CERF facility (Figure 3) showed that the simulation results agree with the measurement results of the HANDI-TEPC and the WENDI-2 within the respective uncertainties [8]. As expected, the conventional types of REM counters, which were designed for neutron energies up to 20 MeV and which are calibrated in radiation fields of reference sources, underestimate the neutron dose equivalent by a factor of two. As a result of these studies a field calibration factor for each detector can now be deduced. This field calibration factor provides a better estimate of the neutron dose equivalent in a presumably similar, but unknown high-energy field around an accelerator, than a calibration factor determined in a radiation field of a standard reference neutron source like ^{252}Cf of Am-Be. In addition, the experimental results provide an input for setting standards for ambient dose equivalent measurements in mixed high-energy radiation fields. Existing standards for portable neutron dose equivalent ratemeters cover only an energy range up to 16 MeV.
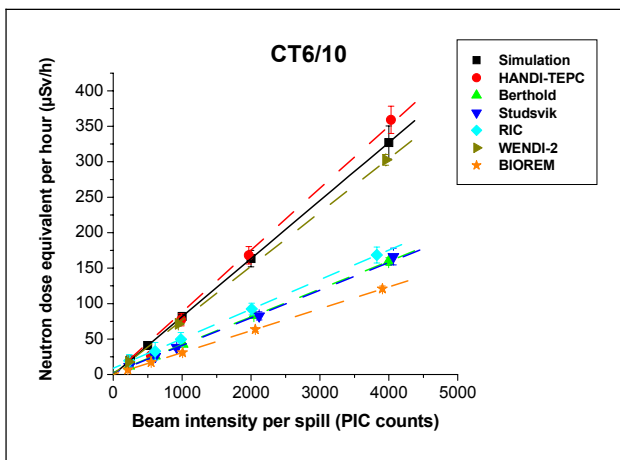

Figure 3: Neutron dose equivalent measured with various types of REM counters and the HANDI-TEPC behind concrete shielding at CERF [8]. For comparison results of Monte Carlo simulations are shown.

CONCLUSION

With the objective to equip the LHC with state of the art radiation detectors and CERN with a general quality assurance system for its radiation protection instrumentation, measurement campaigns were performed in the high-energy reference CERF-field. Various detectors were studied, including those that are presently in use, as well as potential candidates for future use around the LHC. Ionisation chambers measuring the total dose equivalent as well as REM counters measuring neutron dose equivalents were intercompared. In addition,

the experimental results were compared to FLUKA Monte Carlo simulations.

The results of these studies confirmed that the adequate detectors had been chosen for the LHC (ionisation chambers and WENDI-2). Field calibration factors for REM counters could be derived for measurements in unknown high-energy radiation fields behind the shielding around a high-energy accelerator. Simple calibration of these detectors in the field of reference sources tends to underestimate the actual dose equivalent, since a typical source spectrum covers only neutron energies up to 11 MeV. Furthermore, the studies form a solid basis for quality assurance and possible future certification of the instruments in high-energy radiation fields.

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