Nuclear Instruments and Methods in Physics Research A 737 (2014) 203–213

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Intercomparison of radiation protection instrumentation in a pulsed neutron field

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ARTICLE INFO

Article history:
Received 7 November 2012
Received in revised form
28 October 2013
Accepted 20 November 2013
Available online 27 November 2013

Keywords:
Proton beam
Neutron detection
Pulsed neutron field
Neutron survey meter

ABSTRACT

In the framework of the EURADOS working group 11, an intercomparison of active neutron survey meters was performed in a pulsed neutron field (PNF). The aim of the exercise was to evaluate the performances of various neutron instruments, including commercially available rem-counters, personal dosemeters and instrument prototypes. The measurements took place at the cyclotron of the Helmholtz-Zentrum Berlin für Materialien und Energie GmbH. The cyclotron is routinely used for proton therapy of ocular tumours, but an experimental area is also available. For the therapy the machine accelerates protons to 68 MeV. The interaction of the proton beam with a thick tungsten target produces a neutron field with energy up to about 60 MeV. One interesting feature of the cyclotron is that the beam can be delivered in bursts, with the possibility to modify in a simple and flexible way the burst length and the ion current. Through this possibility one can obtain radiation bursts of variable duration and intensity. All instruments were placed in a reference position and irradiated with neutrons delivered in bursts of different intensity. The analysis of the instrument response as a function of the burst charge (the total electric charge of the protons in the burst shot onto the tungsten target) permitted to assess for each device the dose underestimation due to the time structure of the radiation field. The personal neutron dosemeters were exposed on a standard PMMA slab phantom and the response linearity was evaluated.

1. Nomenclature

The nomenclature has proved challenging in writing this paper. The term “pulse” is usually used to indicate both the output signal of a shaping or counting circuit and the radiation burst delivered by a particle accelerator. In the following the word “pulse” is reserved to the output of the shaping or counting circuit whereas the word “burst” is used to indicate a radiation pulse from an accelerator. There are two exceptions when dealing with pulsed radiation fields. In this case the following acronyms are used: pulsed radiation field (PRF) and pulsed neutron field (PNF).

The radiation burst is characterized by: burst duration, burst dose, burst dose rate, burst charge, burst current and burst yield. The burst dose is expressed in terms of ambient dose equivalent (nSv) that a single burst delivers at a reference distance. The burst dose rate is the burst dose divided by the burst duration. The burst charge is the total electric charge of the protons in the burst shot onto the tungsten target. The burst current is the burst charge divided by the burst duration. The burst yield is the burst dose divided by the burst charge.

2. Introduction

It is well-known that active radiation detectors operating in pulse mode can suffer severe limitations when working in PRFs.

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0168-9002/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.nima.2013.11.073

The common techniques which include dead-time corrections [1] operate properly in a steady-state radiation field, whereas it is much more difficult to cope with dead time losses in a PRF of unknown time structure and burst dose. In spite of the fact that the PRF problem is known since the forties [2], it is still an open research field. Recently some investigators [3] reported serious underestimations (up to a factor of nearly 1000) of the widely used rem-counter Berthold LB 6411 when exposed in a PNF. It is clear that all commercial rem-counters based on the same working principle share this problem. The shortage of active instruments especially designed to work in PNFs is a serious issue because it is normal to find workplace fields with bursts of radiation delivered with a defined time structure. There are plenty of practical situations with particle accelerators used for both scientific and medical applications [4] where the time structure of the stray radiation limits the use of active monitors. Usually the time duration of a single burst can range from few ns to about 1 ms with a typical repetition rate in the range 0.1–100 Hz [5,6].

In the framework of the EURADOS WG11 a task group was set up to study the problem by an experimental campaign aiming at evaluating the performance of active instruments irradiated in a PNF. The aim of the measurements was to evaluate the instrument linearity as a function of the radiation burst charge. The measurements took place at the cyclotron of the Helmholtz-Zentrum Berlin für Materialien und Energie GmbH (HZB). The intercomparison involved 29 instruments: 14 neutron area monitors and 15 active personal dosemeters (APDs).

The cyclotron used for the intercomparison is routinely employed for proton therapy of ocular tumors. The intercomparison was performed in an experimental area located beside the treatment room. The 68 MeV protons accelerated by the machine impinged on a 20 mm thick tungsten target. The neutron spectrum emerging from the target was evaluated with Monte Carlo (MC) simulations, which also provided the value of the ambient dose equivalent $H^*(10)$ expected at the reference distance of 50 cm from the target.

3. Experimental facility

The HZB is at present the only facility in Germany for the treatment of ocular tumours with protons [7,8]. It started operation in 1998 as a cooperation between the Ionenstrahllabor (ISL) at the former Hahn-Meitner-Institute and the Benjamin Franklin University Hospital Berlin, now Charité. Almost 1800 patients were treated so far. After the termination of basic and applied research at the ISL at the end of 2006, the accelerator complex has been optimized for the requirements of the therapy to deliver a 68 MeV proton beam with high reliability. Since 2007, the cyclotron is operating chiefly for medical purposes. In addition to therapy, a small number of experiments for radiation hardness tests, detector tests and dosimetry are performed. The beam line directed towards the treatment room is equipped with a switching magnet that supplies the ion beam to the experimental room used for the measurements. The 68 MeV proton beam impinges on a tungsten target sketched in Fig. 1.

For treatment purposes the accelerator works in quasi-dc mode. For this measurement campaign the accelerator delivered the proton beam in bursts by using a burst suppressor between the Van-der-Graaf injector and the cyclotron. The burst suppressor deflects the beam and sends it to the target only for the desired time. This technique permits to generate radiation bursts with time duration ranging from 50 ns to 1 ms with 100 kHz as a maximum repetition rate. The beam current can vary in the range from 0.5 pA to 300 nA. The possibility to vary all these parameters permits to generate radiation bursts whose intensity spans over about five orders of magnitude. A complete list of the machine settings used for the measurements can be found in Section 6.

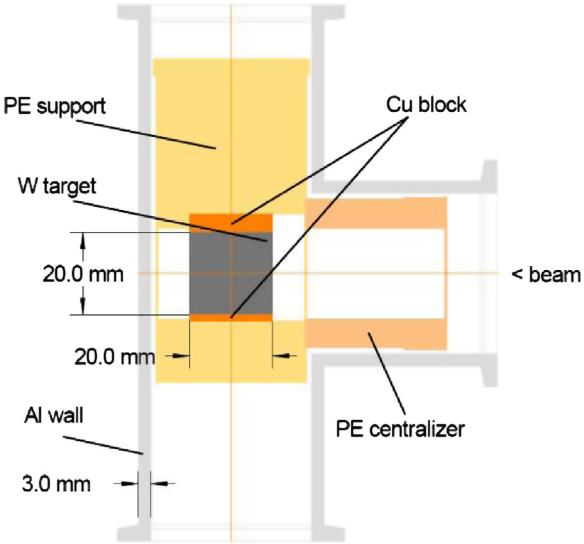

Fig. 1. Drawing of the tungsten target used as proton to neutron converter.

Fig. 2. Picture of the optical bench. The instruments are placed on a shifting trolley (off-axis in the picture) equipped with mechanical locks to ease the positioning reproducibility.

The ion current is monitored off line with a Faraday cup, and on-line by measuring the signal of a transmission ion chamber placed on axis upstream of the target and by measuring the target current. The first two current signals are used for beam set-up and diagnostic. The current measured on the tungsten target, in the following referred as ion current, is the reference quantity used to measure the total proton charge impinging on the target. The three current signals are stored together with a time stamp in a logfile that permits reconstruction of the irradiation profile.

The experimental area (see Fig. 2) is equipped with a laser pointer assisted optical bench that permits a precise and reproducible positioning of the instrumentation. The instruments are placed on a trolley that can move perpendicular to the optical bench axis (in Fig. 2 the trolley is off-axis). The target, the monitor chamber and the target cooling system are placed a few centimetres upstream of the trolley on-beam position. Signal cables between the experimental area and the measurement room are available and a video camera permits to read instruments not equipped with a data transmission system.