UPGRADE OF THE NEUTRON DOSE MEASUREMENT SYSTEM AT BESSY *

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Abstract

Neutron radiation fields at synchrotron light sources are caused by bremsstrahlung from electron losses in accelerator components. Inside the enclosure and in transversal direction neutron and gamma radiation is of the same order of magnitude but high energy neutrons are much more penetrating. This causes outside the shielding neutron spectra with two broad maxima at about 1 MeV and 100 MeV. Standard Anderson-Braun or Leake neutron monitors measure thermalized neutrons in a proportional counter tube by nuclear reactions which limits the measurement range to neutron energies < 10 MeV. This implies two considerable systematic errors: Pulsed neutron beams causes dead-time losses due to the time structure of injections and the moderators are not sufficient to moderate high energy neutrons down to thermal energies. We determined and fixed these measurement errors by faster preamplifiers and by a more effective moderator developed by us, which expands the measurement range up to several GeV. Examples of the application at BESSY are presented.

PULSED RADIATION

Both Anderson-Braun and Leake neutron monitors measure neutrons by the detection of the products of nuclear reactions within their counting tubes. These tubes are filled with BF_3 or Helium, the educts are thermalized neutrons, the products are α particles or protons which cause a pulse in the proportional counter tube. The typical dead-time of these proportional counters is from 2 to 30 μsec. At synchrotron light sources the maximum length of the injection pulses is determined by the convolution time of the synchrotron which is in most cases < 1 μsec and 320 nsec at BESSY. The repetition rate of injection shots at BESSY is from 1/30 Hz (top-up mode) up to 10 Hz (decay mode). Because the pulse duration is shorter than the dead-time and the distance between the injection shots is much larger than the dead-time in principle only one neutron per injection shot is detectable by these neutron monitors. Because the neutrons have to be moderated down to thermal energies the neutron pulse is lengthened to several 100 μsec (but with exponential decay) so several neutrons per injection shot are detectable. But especially in situations with high electron losses during injection or even more due to stochastic beam dumps the dead-time losses can be considerable and the dose rate can be underestimated by more than one order of magnitude.

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Experiments

To investigate the dead-time losses we measured the neutron dose rate as a function of the electron beam current at the transfer lines of MLS (see Fig. 1) and BESSY [1]. We conducted also experiments at the HZB cyclotron with a pulsed proton beam hitting a spallation target. As reference we used the silver activation monitor AgRem [1,2].

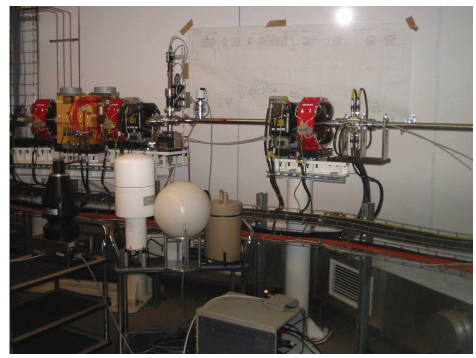

Figure 1: Measurements at MLS transfer line, 100 MeV electrons hit Al target (FOM) at 10 Hz.

In all cases we found curves that show a considerable deviation of the linear behavior already at moderate dose rates (see Fig. 2) . The measured dose rate as function of the electron beam current can be described [1] if the dose rate is not too far in the saturation range:

$$\dot{H}_m = \frac{A \cdot I}{1 + B \cdot I} \tag{1}$$

A and B are fit parameters, the true dose rate is $\dot{H}_t = A \cdot I$ which was also confirmed by the AgRem results. For the curve given in Fig. 2 we got the values A= 571 (μSv/h)/nA and B = 0.11 1/nA.

Correction Functions

By inserting $\dot{H}_t = A \cdot I$ in eq (1) we get a formula to calculate the true dose rate from the measured one:

$$\dot{H}_t = \frac{A \cdot \dot{H}_m}{A - \dot{H}_m \cdot B} \tag{2}$$

In Fig. 3 we show the results for Biorem A, LB6419 and Biorem B. The Biorem B has a faster preamplifier than Biorem A but is otherwise identical. The dose rates are for the repetition rate of 10 Hz. Physical relevant is the dose/burst which can be calculated by the division through the number of shots/hour. The Biorem A and B have dead-times of 10 μsec and 1.9 μsec which result in the underestimation of one order of magnitude for a measured dose

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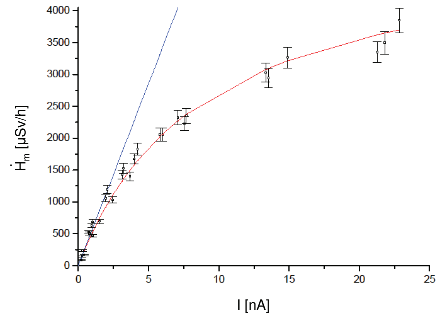

Figure 2: MLS, Biorem B Neutron dose rate H*10 in μSv/h, average electron current in nA, red: fit to eq (1), blue:$A \cdot I$.

rate of 300 μSv/h (8.3 nSv/burst) (Type A) or for the underestimation by a factor of two for a measured dose rate of 3 mSv/h(83 nSv/burst) (Type B).

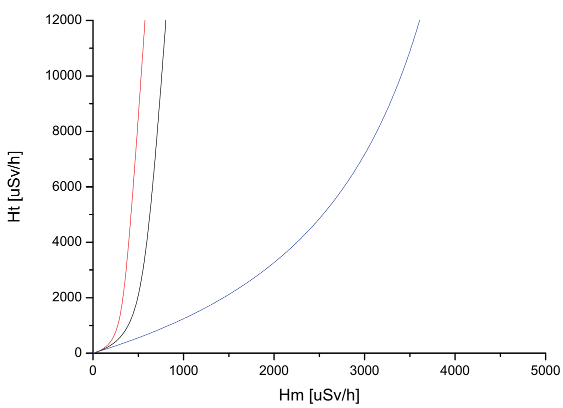

Figure 3: MLS, true does rates of Biorem A (red), B (blue) and LB6419 (black) calculated from measured neutron dose rates H*10 in μSv/h using eq. (2).

Conclusion Pulsed Radiation

We calculate the dead time correction using eq (2) with burst doses for every minute of the raw data. The number of shots/minute is recorded in the BESSY control system. We replaced all preamplifiers of the Biorems at BESSY by the faster ones. With this considerable improvement we can accurately measure the radiation through the walls even under crash conditions accurately. Exceptions are radiation flashes through the open beamshutters during top-up operation, or stochastic beam dumps which makes the dead time correction still necessary. We repeated these measurements together with the EURADOS group for almost all commercially available neutron monitors [3]. Besides the activation monitors all neutron monitors show considerable underestimation of pulses neutron radiation. Among these the Biorem B performed best.

HIGH ENERGY NEUTRONS

At electron accelerators almost all neutrons are produced by bremsstrahlung by three reaction channels. Giant resonance neutrons by (γ,n) reactions have energies with a maximum close to 1 MeV. Neutrons by quasi-deuteron fission and photo-pion productions causes a second maximum at about 100 MeV. The high energy neutrons are more penetrative and therefore the spectrum is hardened passing through the shielding wall. Neutrons detectable by Anderson-Braun or Leak monitors have to be moderated down to 25 meV, therefore the maximum neutron energy for these monitors is limited to 10 MeV. The measurement of neutron spectra is in principle possible using a set of Bonner spheres and an unfolding code. This method is limited because the thermoluminiscence detectors (TLD) within the Bonner spheres are not accurate and require more than 100 μSv for statistical reasons. Such doses would need a long measurement time in the experimental hall of a synchrotron radiation source. We therefore calculated the spectra with Fluka [4,5].

Fluka Calculations

In an earlier approach we calculated neutron spectra for different shielding thicknesses and materials and determined correction factors using the 10 MeV limit [6]. We repeated these calculation with a more accurate approach by folding the spectra with the response function of the neutron monitor and the fluence to dose values by ICRP [7] and Pelliccioni [8]. An example for 1 m ordinary concrete is shown (see Fig. 4). The resulting correction factor is 2.98 (the measured dose has to be multiplied by this factor to get the true dose) and is in agreement with our earlier result.

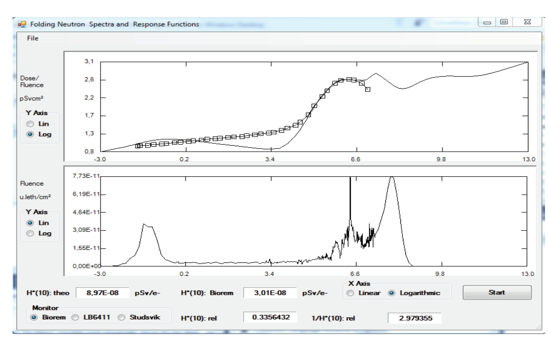

Figure 4: Correction factor from folding neutron spectrum. Squares: Biorem response function. Upper curve: Fluence to dose conversion function [7,8]. Lower curve: Neutron spectrum transversal behind 1 m concrete in lethargy units.

Expanding the Measurement Range

The introduction of top-up operation at BESSY made it possible that also neutrons coming through the opened front-ends during the injection shots are detected by our neutron monitors. Those neutrons have the same energy distribution like inside the shielding enclosure where their maximum at 1 MeV is an order of magnitude higher than the second maxim at 100 MeV. The usage of the concrete correction factor would therefore overestimate the dose. Birattari et al [9] used high Z materials for a shell around the counting tube of an AB counter to expand the measurement range to high energy values. We modified this approach and developed a high energy neutron moderator that encloses the complete monitor to expand the measurement range of our existing measurement system. We made FLUKA calculations for different materials and thicknesses until we reached an increase of the fluence of thermalized neutrons at the location of the detector tube by a factor of three for our neutron spectrum (see Fig. 4). The resulting high energy moderation consists of lead with the thickness of 10 mm (see Fig. 5).

Figure 5: Biorem with lead moderator.

We tested our lead moderator at the CERN reference field CERF with very good result [10] (see Fig. 6).

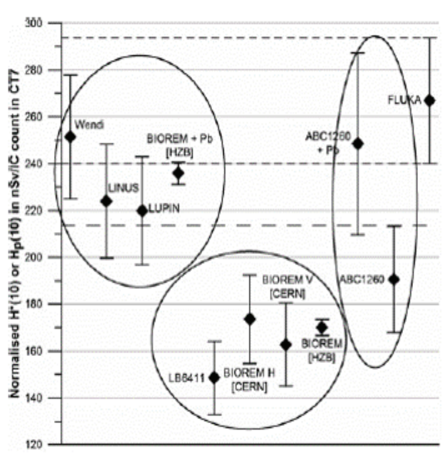

Figure 6: CERF results for our Biorem (HZB) among others [10], left: extended range counters, center: conventional counters, right: ABC 1260 detector

Conclusion High Energy Neutrons

We calculated high energy correction factors by folding neutron spectra with the response function of the Biorem and the fluence to dose conversion factors of ICRP and Pelliccioni and found 2.98 for 1 m ordinary concrete in transversal direction at BESSY. Top-up operation makes it possible that also neutrons reach the experimental hall whose spectrum is not hardened by the concrete. We developed with FLUKA calculations a lead moderator that expands the measurement range from 10 MeV to several GeV and tested it successfully at the CERN reference field CERF. Since January 2015 these moderators are used in the experimental hall at BESSY. The resulting increase of the measured annual neutron dose of a factor 2.5 (sum2015/sum2014 (from Fig. 7)) is in agreement with the calculated correction factor.

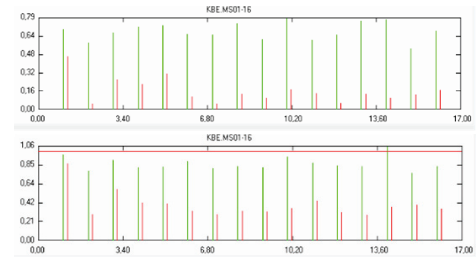

Figure 7: Annual dose results in mSv 2014 and 2015 in experimental hall, sections 1 to 16 (injection at section 1), green γ, red neutrons.

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