A Neutron Dose Rate Monitor For High Energies

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Abstract. Neutron dose rate monitoring at neutron energies of several hundreds of MeV requires special instrumentation. Berthold Technologies has developed a new version of the widely used LB6411neutron dose rate monitor for high energies, the LB6411-Pb. A prototype was calibrated at the CERF at CERN in Geneva/Switzerland with neutron energies ranging up to 1 GeV. For comparison simultaneous measurements were made with a conventional LB 6411. The conventional neutron dose rate meter shows a underestimation, reporting only 68.9% of the reference dose. However, the results of the new version LB 6411-Pb with an additional lead layer of 10 mm thickness agree with the reference values by 98.8%. This shows that the new version is a promising candidate for neutron dose rate monitoring at high energy accelerators.

INTRODUCTION

Radiation protection environments encountered, for instance at synchrotron radiation sources, require neutron dose rate monitoring at high energies. The primary beam energies are ranging up to several GeV and the neutrons that are produced in these facilities have typical energies of several hundred MeV. Conventional neutron dose rate monitors were designed to cover only neutron energies within the range of classical nuclear physics below 20 MeV. It is well known that these instruments show considerable underestimation of the dose equivalent at higher neutron energies. Consequently neutron monitoring in such radiation fields requires the development of new instrumentation and appropriate calibration facilities. In 1992 CERN installed a reference neutron field with a high energy neutron spectrum, which was called CERF (CERN-EU high energy reference field). This facility is commonly used for aircraft dosimetry measurements and testing active and passive instrumentation for radiation fields encountered in the environment of a high-energy accelerator.

THE NEUTRON DOSE RATE MONITOR LB 6411

In the publication ICRP60 the International Commission on Radiological Protection (ICRP) recommended new quantities for radiation protection [1] which are now used in many countries. These quantities have been widely discussed for a couple of years and were adopted in the European Directive 96/29/EURATOM [2] in 1996. The new operational quantity for the measurement of area doses of penetrating radiation is the ambient dose equivalent $H^*(10)$. Appropriate conversion factors from fluence to $H^*(10)$ were published in ICRP74 [3].

For neutrons the new ambient dose equivalent $H^*(10)$ differs significantly from the formerly used quantity H_{MADE} [4] depending on neutron energy. Therefore, Berthold Technologies decided to develop a new and modern dose rate monitor for neutrons which should be perfectly tuned to $H^*(10)$. The neutron dose rate monitor LB 6411 was designed in cooperation with the research center Karlsruhe/Germany in the nineties. For thermal neutron detection the probe utilizes a cylindrical ^{3}He proportional counter tube centered in a moderating polyethylene sphere with 25 cm diameter. The geometrical arrangement of the detector, the moderator and the internal absorbers provides high sensitivity of approximately 3 counts/nSv together with an excellent energy dependent response of ±30% between 50 keV and 10 MeV. The respective design was patented in 1997 [5]. The instrument is calibrated to bare ^{252}Cf. For this spectrum it shows a fluence response of 1.09 cm² and a calibration factor of 1.27 µSv/h per cps.

The response function over the whole energy range from thermal energies up to 20 MeV was carefully calculated with MCNP. For several energies these results were cross-checked with monoenergetic neutron measurements performed at the PTB in Braunschweig [6], [7]. These data are extremely useful for investigations, where spectral calculations have to be done.

THE MODIFIED NEUTRON DOSE RATE MONITOR LB 6411 WITH LEAD

It is well known, that the response of neutron dose rate monitors to high-energy neutrons can be increased by using layers of lead in addition to the standard moderator. High-energy neutrons produce spallation neutrons in collisions with the lead nuclei. These secondary neutrons have lower energies and can therefore be sufficiently moderated in the polyethylene layer to be detected by the ^{3}He proportional counter. Consequently, the response of the instrument to high-energy neutrons is enhanced.

For high-energy neutron dose rate monitoring Berthold Technologies designed and built a modified version LB 6411-Pb with an additional external spherical lead layer of 10 mm thickness, which consist of 4 spherical segments covering the whole sphere. The overall weight of the lead segments is 25 kg, while the conventional neutron dose rate monitor already weighs about 10 kg. With a total weight of 35 kg it would be still transportable, however a permanent installation is recommended.

THE MEASUREMENTS IN THE CERF-FIELD AT CERN

In August 2004 a prototype of the new detector type LB 6411-Pb version and a conventional neutron dose rate monitor LB 6411 were simultaneously calibrated for comparison: the measurements were done at the CERN-EU high-energy reference neutron field facility (CERF) in Geneva/Switzerland [8]. This is one of the few sites providing the capability for a high-energy neutron dose calibration. CERF is using one of the secondary beamlines of the Super Proton Synchrotron (SPS) facility. This beam consists of positively charged particles (35% protons, 61% pions and 4% kaons) with a momentum of 120 GeV/c. When impacting on a copper target of 50 cm length the beam produces a mixed high-energy radiation field.. The reference measurement positions are located above the copper target behind 80 cm of concrete or 40 cm of iron at approximately 90° relative to the beam direction. For the measurements reported here, we used only the test field on the concrete roof with an area of 2 m x 2 m. This area is divided into 16 segments giving the reference locations CT1 to CT16. Designation CT6/10 denotes a position centered between CT6 and CT10. The neutron energy spectrum ranges from thermal up to about 1 GeV with a mean energy of 70 MeV. The intensity of the beam was monitored by an air-filled precision ionisation chamber (PIC) placed upstream of the copper target. For the reference positions the latest available values for ambient dose equivalent *H*(10)* of the neutron field per PIC count were taken from [8] . Currently new studies of the radiation environment present at the CERF facility are under way but not yet published.

TABLE 1. Measurements LB 6411 S/N 1038 without Lead.

Run	Position	Dose equivalent per PIC count [nSv/PIC]	Average PIC count rate [s^{-1}]	Measured dose equivalent rate [µSv/h]	Reference dose equivalent rate [µSv/h]	Response/ required response
1	CT4	185	16,1	6,3	10,7	59,1%
2	CT4	185	40,5	16,3	27,0	60,5%
3	CT4	185	73,7	27,5	49,1	56,0%
4	CT4	185	138,5	54,0	92,3	58,5%
5	CT4	185	234,6	111,0	156,2	71,1%
6	CT6/10	270	227,4	154,3	221,0	69,8%
7	CT6/10	270	145,1	95,3	141,0	67,6%
8	CT6/10	270	72,3	47,6	70,3	67,8%
9	CT6/10	270	44,1	29,7	42,9	69,4%
10	CT6/10	270	31,4	20,8	30,5	68,2%
11	CT6/10	270	16,0	11,2	15,5	71,9%
12	CT16	182	18,0	8,6	11,8	73,2%
13	CT16	182	34,0	15,7	22,3	70,5%
14	CT16	182	60,5	29,5	39,7	74,3%
15	CT16	182	116,6	58,6	76,4	76,7%

TABLE 2. Measurements LB 6411-Pb S/N 1481 with a 10 mm Lead-layer.

Run	Position	Dose equivalent per PIC count [nSv/PIC]	Average PIC count rate [s^{-1}]	Measured dose equivalent rate [µSv/h]	Reference dose equivalent rate [µSv/h]	Response/ required response
1	CT6/10	270	16,4	15,0	16,0	94,1%
2	CT6/10	270	40,2	36,7	39,1	93,8%
3	CT6/10	270	71,5	61,7	69,5	88,8%
4	CT6/10	270	133,9	122,6	130,2	94,2%
5	CT6/10	270	256,9	252,5	249,7	101,1%
6	CT16	182	237,2	148,5	155,4	95,6%
7	CT16	182	144,0	91,5	94,4	97,0%
8	CT16	182	72,0	46,4	47,2	98,3%
9	CT16	182	43,8	28,9	28,7	100,9%
10	CT16	182	31,2	20,5	20,4	100,1%
11	CT16	182	16,5	11,0	10,8	101,7%
12	CT4	185	17,2	10,2	11,5	88,7%
13	CT4	185	31,7	17,9	21,1	84,6%
14	CT4	185	61,5	33,6	40,9	82,1%
15	CT4	185	116,6	67,9	77,6	87,5%
16	CT4	185	211,4	137,4	140,8	97,6%
17	CT9	253	240,9	206,7	219,4	94,2%
18	CT9	253	119,5	101,8	108,8	93,6%
19	CT9	253	226,7	221,5	206,5	107,3%
20	CT9	253	117,3	116,7	106,9	109,2%
21	CT9	253	31,6	29,4	28,8	102,0%
22	CT5	254	32,8	36,9	29,9	123,1%
23	CT5	254	67,5	62,0	61,8	100,4%
24	CT5	254	140,6	116,4	128,6	90,5%
25	CT5	254	236,1	219,3	215,9	101,5%

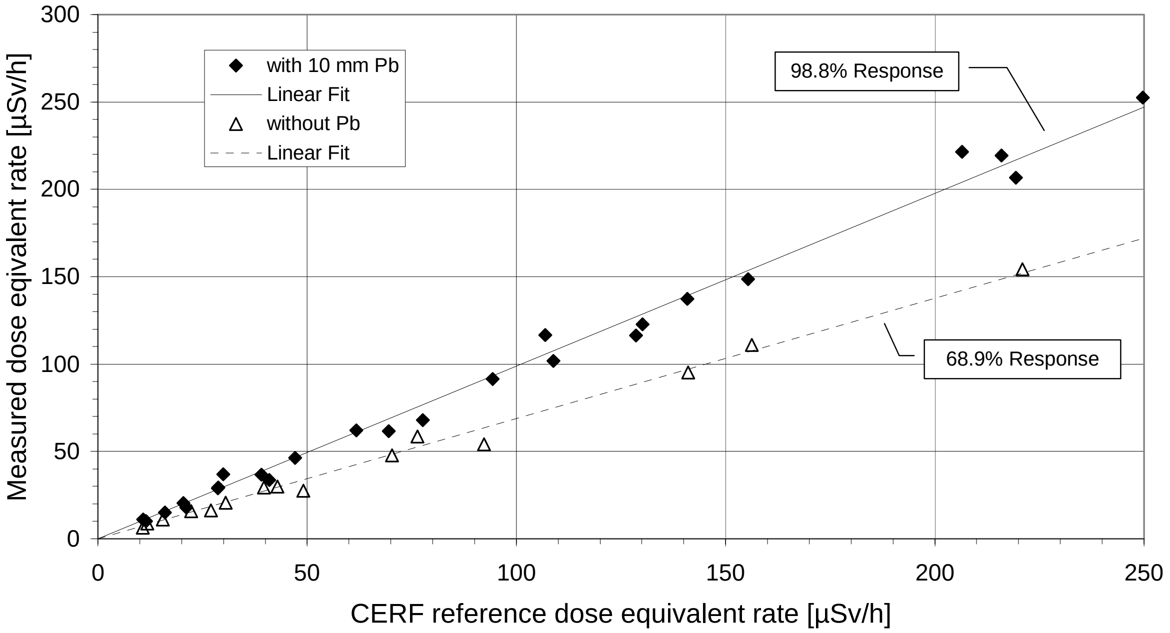

FIGURE 1. Response of LB 6411-Pb with lead layer and of LB 6411 as a function of the reference dose equivalent rate.

On 14/15th August 2004 all data were acquired in several runs of about 15 minutes with nearly constant beam intensities. The data of the conventional probe LB 6411 are given in table 1 and the data of the new version LB 6411-Pb are given in table 2. For each run the position, the dose equivalent rate per PIC count, the measured PIC count rate, the measured dose equivalent rate and the reference dose equivalent rate are listed. The response of the modified probe with lead was found to be substantially higher than that of a standard LB 6411 and it is very close to the reference dose equivalent values taken from [8]. The detector response as a function of the reference dose equivalent rate were separately fitted to linear functions for both detectors with resulting slopes of 68.9% and 98.8% respectively. All data including the fitting function are displayed in Figure 1.

CONCLUSION

In the CERN/CERF field with high-energy neutrons in the domain of several hundreds MeV the response of the modified probe LB 6411-Pb with an additional external layer of lead with a thickness of 10 mm was found to be substantially higher than that of a standard LB 6411. The reading of the instrument showed 98.8% of the reference ambient dose equivalent *H*(10)*, while the response of the standard LB 6411 instrument agreed only by 68.9%. This reflects the well known fact that conventional rem-counters show an underestimation of high-energy neutrons. The obtained results clearly indicate that in accelerator environments with high-energy neutron fields, as for instance at synchrotron light sources, the modified LB 6411-Pb measures neutron dose rates with an improved accuracy. Therefore, the new version is the preferred instrument for neutron dose rate monitoring in high-energy radiation fields.

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