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The New Remcounter LB6411: Measurement of Neutron Ambient Dose Equivalent H*(10) according to ICRP60 with High Sensitivity

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Abstract

Since the International Commission on Radiological Protection, in publication ICRP60, has issued new recommendations on radiation protection quantities, there is now increasing interest in commercially available instruments optimized and calibrated for the measurement of neutron ambient dose equivalent H*(10).

Therefore within a joint cooperation agreement between the Research Center Karlsruhe and EG&G Berthold, the new neutron-dose-rate meter LB6411 was developed. The detector system with integrated electronics has a ^{3}He proportional counter tube centered in a moderating sphere. The response between thermal energies and 20 MeV was optimized with the help of extensive MCNP Monte-Carlo calculations.

The instrument has an extremely high sensitivity of approximately 3 counts per nSv and can be used both as a portable or as a stationary neutron monitor. Fluence responses have been measured in monoenergetic neutron beams provided by the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany. The ambient dose equivalent response of the LB6411 is reported over the whole energy range.

I. INTRODUCTION

As a consequence of the recommendations of the International Commission on Radiological Protection in publication ICRP60 [1], there is now in radiation protection a continuously increasing need for instruments which are optimized and calibrated to measure the newly defined quantities. This is especially true in neutron monitoring, where the fluence to dose equivalent conversion factors have considerably changed. These are shown for comparison in Figure 1. At neutron energies of a few hundred keV, H*(10) [3] exceeds the "maximum dose equivalent" H_{made} according to ICRP21 [2] up to 70%. This is illustrated in Figure 2.

As the ratio of new to the old conversion function is a function of neutron energy, a simple recalibration of existing remcounters by a trivial factor is not considered to be sufficient. Therefore within a joint cooperation agreement between the Research Center Karlsruhe and EG&G Berthold, the new neutron dose rate meter LB6411 was developed. There had been two major objectives for the new design. Firstly, it was intended to tune the energy dependent response to ambient dose equivalent H*(10) from thermal energies up to 20 MeV, and secondly an improved neutron detection efficiency in comparison with existing instruments should be achieved.

II. DETECTOR DESCRIPTION

A specially developed and patented [4] cylindrical ^{3}He proportional counter tube, used as a thermal neutron detector, is located in the center of a moderating sphere with diameter 25 cm. The diameter and the active length of the counter tube are both 4 cm. Thus the sensitive volume matches well with the spherical geometry of the moderator. The counter tube is made out of stainless steel and filled with ^{3}He and methane at partial pressures 3.5 bar and 1 bar respectively. The counter tube is surrounded by moderating and absorbing layers of material. The energy dependent response and the sensitivity

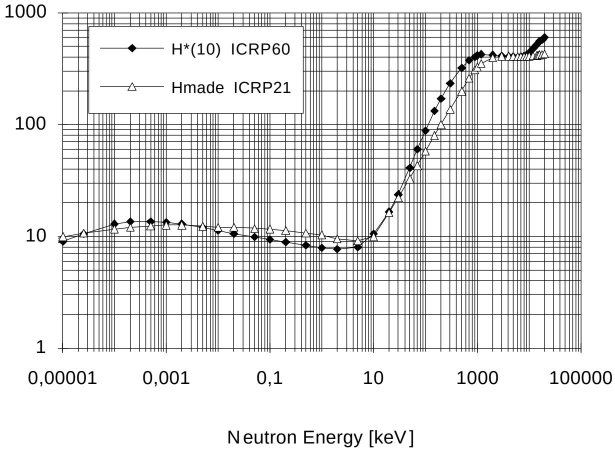

Figure 1: Neutron fluence-to-dose conversion functions

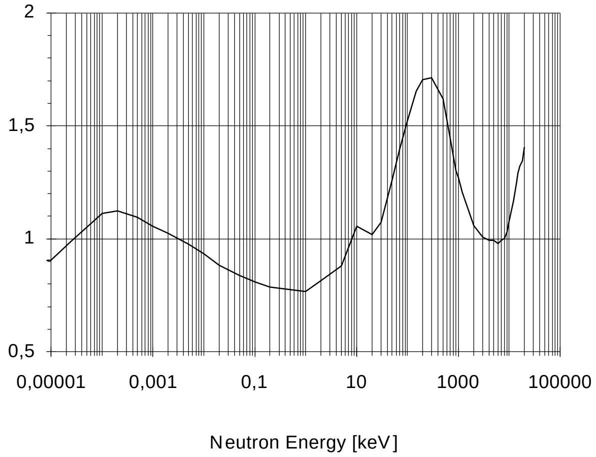

Figure 2: Ratio of neutron dose equivalents $H^*(10)/H_{made}$

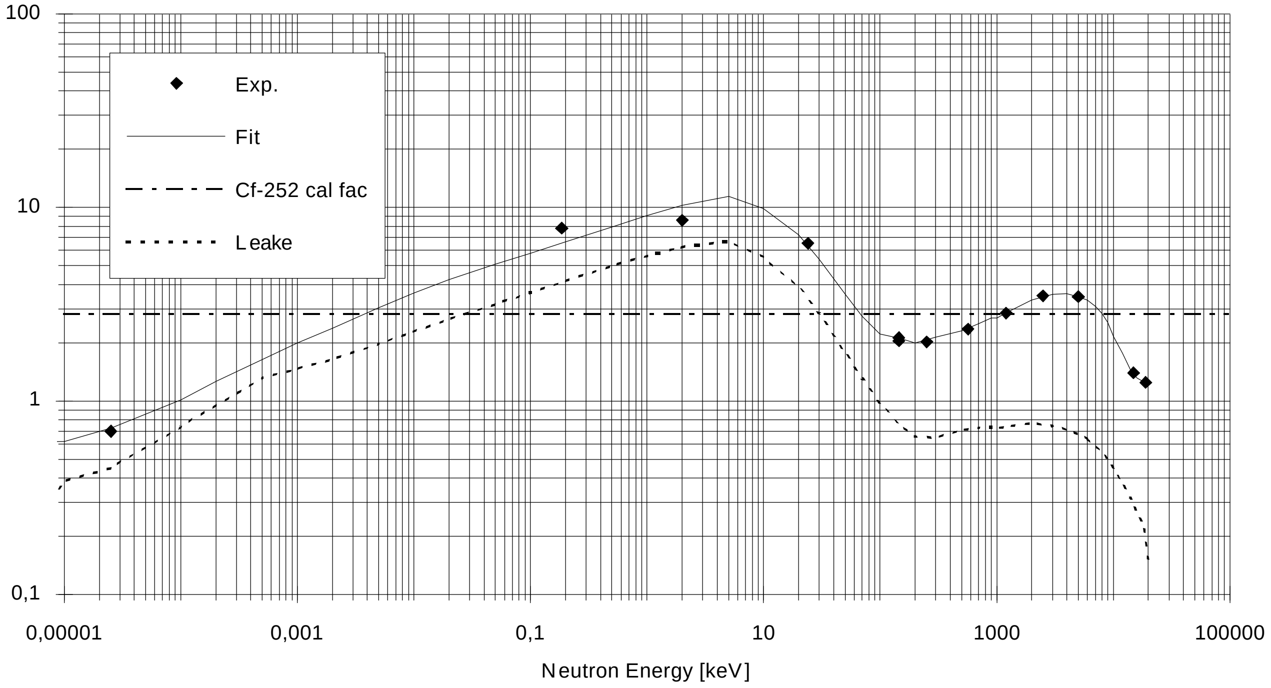

Figure 3: Ambient dose equivalent H*(10) response of LB6411

are essentially based on the geometrical arrangement, choice of materials and on the properties and the size of the counter tube. These parameters have been optimized with the help of extensive MCNP [5] Monte-Carlo calculations with semi-realistic modelling of all detector components and true material compositions [6].

The instrument has integrated electronics including preamplifier, discriminator and high voltage supply. The weight of the LB6411 is below 10 kg. For the use as a portable survey meter the battery driven datalogger LB1230 supports data acquisition with up to 250 memory locations to store measured values, scaler-timer mode, dose integration, autorepetition mode and an optical serial port to connect a printer or personal computer.

III. DETECTOR RESPONSE AND CALIBRATION

The fluence response of the LB6411 was determined experimentally at the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany. At the accelerator and at the reactor facility of the PTB, there are several ISO standard neutron fields available, where the LB6411 was irradiated with quasi-monoenergetic neutron beams at 12 different neutron energies [6]. From the measured fluence responses, the ambient dose equivalent responses are calculated using the latest conversion factors from the PTB [3]. These values are shown in Figure 3 as experimental datapoints. In addition, calculations with MCNP over the whole range of neutron energies have been performed [6]. The experimental and theoretical results agree at least within 20%. In order to get a smooth response function through experimental and calculated datapoints, a least square spline fit was used with decisive weights given to experimental data. A finite number of datapoints have been calculated, which describe, together with a cubic Lagrange interpolation, the structure of the response function with sufficient precision [7]. The smooth fit function representing the ambient dose equivalent response of the LB6411 as a function of energy is shown in the diagram as solid line. Numerical values for the fluence response R_ϕ, the conversion factor h_ϕ*(10) [3], the ambient dose equivalent response $R_{H*(10)}$ and for the quotients R/R_{req} of response and required response are given in Table 1 as functions of neutron energy E.

The calibration of the LB6411 is obtained from a bare ^{252}Cf source. As neutron sources are more easily available than monoenergetic neutron beams, calibration checks can be performed in many laboratories. The calibration factor is indicated in Figure 3 as a horizontal line. By calibrating the instrument with ^{252}Cf, a reasonable "averaging" behaviour was obtained. The ambient dose equivalent response is generally close to the calibration factor. For instance, for neutron energies from 50 keV to 10 MeV the relative deviations of response are below ±30%. This quality of measurement is standard in γ-monitoring, but remarkable in neutron dosimetry. For accurate measurement in real neutron fields, this energy range is of special importance because it usually contributes significantly to dose equivalent. There are also energy regions with more or less pronounced over or underresponse. At thermal energies H*(10) is clearly underestimated. But this has little affect on measured values,

Table 1
Fluence response and ambient dose equivalent H*(10) response of LB6411

E [MeV]	R_ϕ [cm²]	$h_\phi^*(10)$ [pSv cm²]	$R_{H^*(10)}$ [Counts/nSv]	R/R_{req}	E [MeV]	R_ϕ [cm²]	$h_\phi^*(10)$ [pSv cm²]	$R_{H^*(10)}$ [Counts/nSv]	R/R_{req}
1×10^{-9}	4.0×10^{-3}	6.6	0.61	0.21	0.2	0.34	170	2.00	0.71
1×10^{-8}	5.6×10^{-3}	9.0	0.62	0.22	0.3	0.50	233	2.15	0.76
2.5×10^{-8}	7.7×10^{-3}	10.6	0.72	0.26	0.5	0.75	322	2.31	0.82
1×10^{-7}	0.013	12.9	1.02	0.36	0.7	0.94	375	2.50	0.88
2×10^{-7}	0.017	13.5	1.26	0.44	0.9	1.07	400	2.68	0.94
5×10^{-7}	0.022	13.6	1.63	0.58	1	1.12	416	2.69	0.95
1×10^{-6}	0.027	13.3	1.99	0.70	2	1.40	420	3.33	1.18
2×10^{-6}	0.031	12.9	2.39	0.84	3	1.47	412	3.57	1.26
5×10^{-6}	0.037	12.0	3.04	1.07	4	1.46	408	3.58	1.26
1×10^{-5}	0.041	11.3	3.60	1.27	5	1.40	405	3.46	1.22
2×10^{-5}	0.045	10.6	4.24	1.50	6	1.33	400	3.33	1.17
5×10^{-5}	0.050	9.9	5.09	1.80	7	1.25	405	3.09	1.09
1×10^{-4}	0.055	9.4	5.81	2.05	8	1.16	409	2.84	1.00
2×10^{-4}	0.059	8.9	6.64	2.35	9	1.07	420	2.55	0.90
5×10^{-4}	0.066	8.3	7.93	2.80	10	0.95	440	2.16	0.76
1×10^{-3}	0.072	7.9	9.09	3.21	12	0.85	480	1.76	0.62
2×10^{-3}	0.079	7.7	10.3	3.62	14	0.76	520	1.46	0.52
5×10^{-3}	0.091	8.0	11.4	4.04	16	0.73	555	1.31	0.46
1×10^{-2}	0.104	10.5	9.90	3.50	18	0.72	570	1.26	0.45
2×10^{-2}	0.120	16.6	7.23	2.55	20	0.72	600	1.19	0.42
5×10^{-2}	0.146	41.1	3.55	1.25	Cf-252	1.09	385	2.83	1.00
1×10^{-1}	0.196	88.0	2.23	0.79	Am-Be	1.16	391	2.96	1.05

because in practical radiation protection the thermal neutron contribution to dose equivalent usually is small.

To demonstrate the improvements in comparison with existing technology the ambient dose equivalent H*(10) response of the Leake-counter [8], a wide-spread standard remcounter type, was calculated using the new conversion factors [3]. The Leake-counter's response is shown as a dashed line in Figure 3. The LB6411's sensitivity is much higher over the whole energy range. Especially in the MeV region, it is a factor of 4 more than that of the Leake-counter. The shape of the ambient dose equivalent response is also considerably better. This is illustrated by comparing ratios of minimal and maximum sensitivities in specified energy regions. The LB6411 is the first instrument optimized and calibrated to H*(10). With its excellent response function and high sensitivity, it guarantees quick and reliable measurements in neutron radiation fields.

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