The Neutron Fluence and *H**(10) Response of the New LB 6411 Remcounter

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ABSTRACT

A new rem counter with a response tailored to match the shape of $H^*(10)/\Phi$ as defined by ICRU and ICRP has been recently developed in the frame of a Technology Transfer Project of the Research Center Karlsruhe with the industrial partner EG&G Berthold, Wildbad. In this paper, we provide for this detector a carefully established, consistent fluence and ambient dose equivalent response function as well as the effective response calculated for more than 500 neutron spectra from a catalogue.

INTRODUCTION

Rem counters are used for the routine area surveillance. Most are based on a neutron moderator with a central detector. In general, the moderator is a polyethylene sphere or cylinder and the central detector is commonly most sensitive to thermalized neutrons such as a ^{3}He proportional counter which allows discrimination against photons by the setting an appropriate threshold. One of the main advantages of rem counters is their reliability and their simple handling in practical use.

A new remcounter, LB 6411, with a response tailored to match the shape of $H^*(10)/F$ as defined by ICRP(1) and ICRU(2) has recently been developed in the frame of a Technology Transfer Project of the Research Center Karlsruhe with the industrial partner EG&G Berthold, Wildbad(3). In this paper a carefully established, fluence and ambient dose equivalent response function is provided for this detector as well as the effective response calculated for more than 500 neutron spectra from a catalogue[4]. The value of $H^*(10)/F$ as a function of neutron energy are taken from Ref. (5). The performance of the LB 6411 is compared with that of the Leake counter as described in Ref. (6).

INSTRUMENT

The rem counter LB 6411 consists of a polyethylene moderator sphere with a diameter of 25 cm, a central cylindrical ^{3}He proportional counter and internal Cd-absorbers and perforations. The instrument has an integrated high voltage-supply and signal processing and is connected to a microprocessor-controlled portable datalogger. The design of the counter is shown in Figure 1 and its essential features are summarized in Table 1.

The optimization of the $H^*(10)$ response function has been performed by extensive calculations with the Monte Carlo transport program MCNP(7) using a detailed modelling and the latest version of the European Fusion cross section File EFF. Many parameters have been varied in the search for an optimized response: the diameter of the moderator, and the material, position and perforated fraction of absorbing layers (Table 1). The resulting configuration has been confirmed by calibration measurements at the Physikalisch-Technische Bundesanstalt (PTB) using monoenergetic neutrons with energies from thermal up to 19 MeV(8). A single fit factor close to one was sufficient to adjust the calculated to the absolute experimental response. This factor accounts for the effective number of ^{3}He nuclei in the couter tube and the selected threshold.

Figure 1: The new ambient dose equivalent rate meter LB 6411 (not shown in this file/print)

Table 1. Essential features of the LB 6411.

Electronics	Integrated high voltage-supply and signal processing, connected to a microprocessor-controlled portable datalogger.
Physical basis	^{3}He proportional counter, moderating polyethylene sphere of 25 cm in diameter and Cd absorbers
Optimisation	Search for optimal physical instrument parameters using detailed MCNP modelling and the newest cross sections (European Fusion File, EFF).
Experimental verification	Monoenergetic neutrons from thermal through 19 MeV at the PTB
New quantity indication	Ambient dose equivalent H*(10) for neutrons according to ICRP 60 from thermal to 20 MeV neutrons
Low energy dependence	+10% to - 30% in the energy range 50 keV up to 10 MeV
High sensitivity	≈ 3 counts per nSv

EVALUATION OF FLUENCE AND DOSE EQUIVALENT RESPONSE FUNCTION

A special interactive homemade computer program based on a least squares spline interpolation has been used for the fitting procedure. This program achieves a sound compromise between the closeness to the data and the smoothness of the fit. The experimental data were given weights in accordance with their experimental variances and the values calculated with MCNP were given lesser weights and used for a well justified interpolation. Resonances in the fluence reponse due to carbon are not represented, as rem counters are designed for use in broad spectra. Therefore, a set of only 47 energy points and a cubic Lagrange interpolation are sufficient to describe all relevant structures of the response function. The interpolation formula for the cubic Lagrange interpolation is given by

$$P(x) = \sum_{i=1}^{4} y_i \left(\prod_{j=1, j\neq i}^{4} (x - x_j) / \prod_{j=1, j\neq i}^{4} (x_i - x_j) \right) \quad (1)$$

where y_i are the values of the responses and x_j the logarithms of the neutron energies and where x_2 £ x £ x_3, except for the begin and the end of the defined energy range ($E_{\text{n-min}}$, $E_{\text{n-max}}$).

The original data and the fitting results are shown in Figure 2 which demonstrates the quality of the fitting procedure, especially in the relevant high neutron energy range.

This fluence response has then been used to establish a numerical calibration factor for a broad calibration field, N, defined as the ratio of the ambient dose equivalent, H*(10), and the value indicated by the rem counter in the calibration field, M, by integration:

$$H^*(10) = \int_{E_{\text{n-min}}}^{E_{\text{n-max}}} \mathrm{d}E_{\text{n}} \cdot h_F^*(E_{\text{n}}) \cdot F_{E_{\text{n}}}(E_{\text{n}}) \quad (2)$$

$$M = \int_{E_{\text{n-min}}}^{E_{\text{n-max}}} \mathrm{d}E_{\text{n}} \cdot R_F(E_{\text{n}}) \cdot F_{E_{\text{n}}}(E_{\text{n}}) \quad (3)$$

where E_{n}, R_F and $F_{E\text{n}}$ are the neutron energy, the evaluated fluence response and the spectrum, respectively. $E_{\text{n-min}}$ and $E_{\text{n-max}}$ are taken as 1 meV and 20 MeV, respectively.

Table 2 shows neutron fluence and ambient dose equivalent response for the LB 6411 and fluence-to-ambient dose equivalent conversion coefficients at 47 Lagrange points.

The spectrum from the bare ^{252}Cf-neutron source (ISO 8529) has been used as the calibration spectrum. The numerical calibration factors, N, obtained are 324.34 pSv and 1372.0 pSv per count for the LB 6411 and the and the Leake counter. Leake counter, respectively.Figure 3 shows the H*(10) response of the LB 6411 numerically calibrated in the bare ^{252}Cf spectrum. The LB 6411 shows a three times lower overresponse for intermediate neutrons and provides a four times higher sensitivity than the Leake counter. The agreement between the numerical and the measured calibration factor for the LB6411 using a bare ^{252}Cf neutron source was found to be better than 10%. Table 3 shows for often used calibration spectra the fluence weighted ambient dose equivalent readings of the LB 6411, $N \cdot M / F$, and the mean neutron fluence to ambient dose equivalent conversion factor, $H^*(10) \; / \; F$. These data support the assumption, that the LB 6411 remcounter will reliably work in a wide range of spectra.

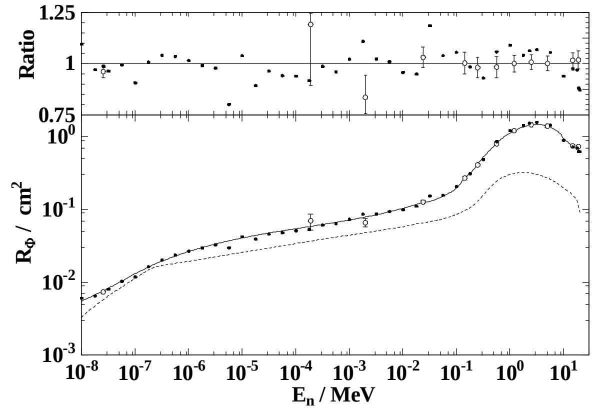

Figure 2: ***Bottom Part*: Experimental (circles), calculated (dots) and evaluated neutron fluence responses for the LB 6411 (solid line) and the Leake counter (dashed line) as function of neutron energy. *Upper Part*: Response ratios of experimental and calculated values to the fitted values.**

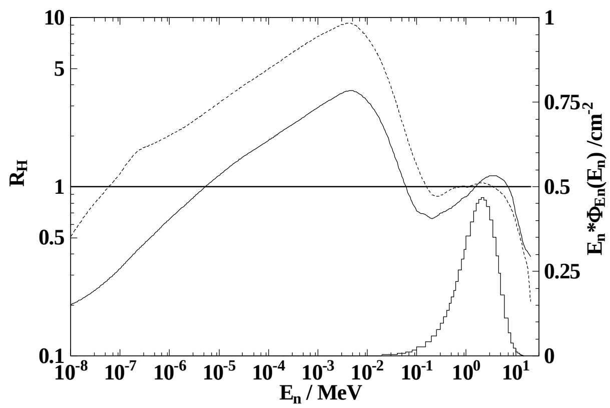

Figure 3: Ambient dose equivalent response as a function of neutron energy for the LB 6411 (solid line) and the Leake Counter (dashed line) numerically calibrated (Eqn. 2 and 3) in a bare ^{252}Cf-spectrum (histogram).

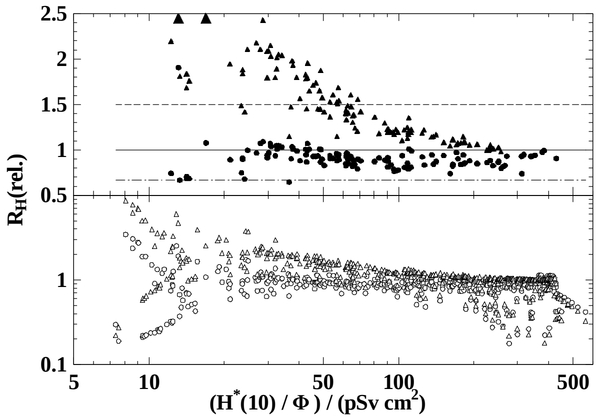

Figure 4: Calculated relative ambient dose equivalent response, R_H(rel.) for the LB 6411 (circles) and the Leake counter (triangles) as a function $H^*(10)/F$,. *Bottom Part*: In about 500 spectra found in a catalogue[(4)] and *Upper Part*: In a subset of over 100 spectra found in reactor environments, the values for the two enlarged triangle are 4.72 and 2.53, respectively.

Table 2. Neutron fluence and ambient dose equivalent response for the LB 6411 and fluence-to-ambient dose equivalent conversion coefficients at 47 Lagrange points

E_n MeV	R_F cm^2	$R_{H^*(10)}$ pSv•cm^2	h^*_F (10) pSv•cm^2
$1,00 \times 10^{-9}$	$4,00 \times 10^{-3}$	$1,30 \times 10^{+0}$	$6,60 \times 10^{+0}$
$1,00 \times 10^{-8}$	$5,57 \times 10^{-3}$	$1,81 \times 10^{+0}$	$9,00 \times 10^{+0}$
$2,53 \times 10^{-8}$	$7,67 \times 10^{-3}$	$2,49 \times 10^{+0}$	$1,06 \times 10^{+1}$
$1,00 \times 10^{-7}$	$1,31 \times 10^{-2}$	$4,25 \times 10^{+0}$	$1,29 \times 10^{+1}$
$2,00 \times 10^{-7}$	$1,70 \times 10^{-2}$	$5,51 \times 10^{+0}$	$1,35 \times 10^{+1}$
$5,00 \times 10^{-7}$	$2,22 \times 10^{-2}$	$7,20 \times 10^{+0}$	$1,36 \times 10^{+1}$
$1,00 \times 10^{-6}$	$2,65 \times 10^{-2}$	$8,60 \times 10^{+0}$	$1,33 \times 10^{+1}$
$2,00 \times 10^{-6}$	$3,08 \times 10^{-2}$	$9,99 \times 10^{+0}$	$1,29 \times 10^{+1}$
$5,00 \times 10^{-6}$	$3,65 \times 10^{-2}$	$1,18 \times 10^{+1}$	$1,20 \times 10^{+1}$
$1,00 \times 10^{-5}$	$4,07 \times 10^{-2}$	$1,32 \times 10^{+1}$	$1,13 \times 10^{+1}$
$2,00 \times 10^{-5}$	$4,49 \times 10^{-2}$	$1,46 \times 10^{+1}$	$1,06 \times 10^{+1}$
$5,00 \times 10^{-5}$	$5,04 \times 10^{-2}$	$1,64 \times 10^{+1}$	$9,90 \times 10^{+0}$
$1,00 \times 10^{-4}$	$5,46 \times 10^{-2}$	$1,77 \times 10^{+1}$	$9,40 \times 10^{+0}$
$2,00 \times 10^{-4}$	$5,91 \times 10^{-2}$	$1,92 \times 10^{+1}$	$8,90 \times 10^{+0}$
$5,00 \times 10^{-4}$	$6,58 \times 10^{-2}$	$2,13 \times 10^{+1}$	$8,30 \times 10^{+0}$
$1,00 \times 10^{-3}$	$7,18 \times 10^{-2}$	$2,33 \times 10^{+1}$	$7,90 \times 10^{+0}$
$2,00 \times 10^{-3}$	$7,90 \times 10^{-2}$	$2,56 \times 10^{+1}$	$7,70 \times 10^{+0}$
$5,00 \times 10^{-3}$	$9,14 \times 10^{-2}$	$2,96 \times 10^{+1}$	$8,00 \times 10^{+0}$
$1,00 \times 10^{-2}$	$1,04 \times 10^{-1}$	$3,37 \times 10^{+1}$	$1,05 \times 10^{+1}$
$2,00 \times 10^{-2}$	$1,20 \times 10^{-1}$	$3,89 \times 10^{+1}$	$1,66 \times 10^{+1}$
$3,00 \times 10^{-2}$	$1,28 \times 10^{-1}$	$4,15 \times 10^{+1}$	$2,37 \times 10^{+1}$
$5,00 \times 10^{-2}$	$1,46 \times 10^{-1}$	$4,73 \times 10^{+1}$	$4,11 \times 10^{+1}$
$7,00 \times 10^{-2}$	$1,65 \times 10^{-1}$	$5,35 \times 10^{+1}$	$6,00 \times 10^{+1}$
$1,00 \times 10^{-1}$	$1,96 \times 10^{-1}$	$6,36 \times 10^{+1}$	$8,80 \times 10^{+1}$
$1,50 \times 10^{-1}$	$2,79 \times 10^{-1}$	$9,05 \times 10^{+1}$	$1,32 \times 10^{+2}$
$2,00 \times 10^{-1}$	$3,40 \times 10^{-1}$	$1,10 \times 10^{+2}$	$1,70 \times 10^{+2}$
$3,00 \times 10^{-1}$	$5,00 \times 10^{-1}$	$1,62 \times 10^{+2}$	$2,33 \times 10^{+2}$
$5,00 \times 10^{-1}$	$7,45 \times 10^{-1}$	$2,42 \times 10^{+2}$	$3,22 \times 10^{+2}$
$7,00 \times 10^{-1}$	$9,37 \times 10^{-1}$	$3,04 \times 10^{+2}$	$3,75 \times 10^{+2}$
$9,00 \times 10^{-1}$	$1,07 \times 10^{+0}$	$3,47 \times 10^{+2}$	$4,00 \times 10^{+2}$
$1,00 \times 10^{+0}$	$1,12 \times 10^{+0}$	$3,63 \times 10^{+2}$	$4,16 \times 10^{+2}$
$1,20 \times 10^{+0}$	$1,21 \times 10^{+0}$	$3,93 \times 10^{+2}$	$4,25 \times 10^{+2}$
$2,00 \times 10^{+0}$	$1,40 \times 10^{+0}$	$4,54 \times 10^{+2}$	$4,20 \times 10^{+2}$
$3,00 \times 10^{+0}$	$1,47 \times 10^{+0}$	$4,77 \times 10^{+2}$	$4,12 \times 10^{+2}$
$4,00 \times 10^{+0}$	$1,46 \times 10^{+0}$	$4,74 \times 10^{+2}$	$4,08 \times 10^{+2}$
$5,00 \times 10^{+0}$	$1,40 \times 10^{+0}$	$4,54 \times 10^{+2}$	$4,05 \times 10^{+2}$
$6,00 \times 10^{+0}$	$1,33 \times 10^{+0}$	$4,31 \times 10^{+2}$	$4,00 \times 10^{+2}$
$7,00 \times 10^{+0}$	$1,25 \times 10^{+0}$	$4,05 \times 10^{+2}$	$4,05 \times 10^{+2}$
$8,00 \times 10^{+0}$	$1,16 \times 10^{+0}$	$3,76 \times 10^{+2}$	$4,09 \times 10^{+2}$
$9,00 \times 10^{+0}$	$1,07 \times 10^{+0}$	$3,47 \times 10^{+2}$	$4,20 \times 10^{+2}$
$1,00 \times 10^{+1}$	$9,50 \times 10^{-1}$	$3,08 \times 10^{+2}$	$4,40 \times 10^{+2}$
$1,20 \times 10^{+1}$	$8,47 \times 10^{-1}$	$2,75 \times 10^{+2}$	$4,80 \times 10^{+2}$
$1,40 \times 10^{+1}$	$7,61 \times 10^{-1}$	$2,47 \times 10^{+2}$	$5,20 \times 10^{+2}$
$1,50 \times 10^{+1}$	$7,34 \times 10^{-1}$	$2,38 \times 10^{+2}$	$5,40 \times 10^{+2}$
$1,60 \times 10^{+1}$	$7,28 \times 10^{-1}$	$2,36 \times 10^{+2}$	$5,55 \times 10^{+2}$
$1,80 \times 10^{+1}$	$7,20 \times 10^{-1}$	$2,34 \times 10^{+2}$	$5,70 \times 10^{+2}$
$2,00 \times 10^{+1}$	$7,15 \times 10^{-1}$	$2,32 \times 10^{+2}$	$6,00 \times 10^{+2}$

Performance At Workplaces

The quality and usefulness of a remcounter is determined by its ability to measure the ambient dose equivalent in spectra found at workplaces. A reliable test of remcounters with known response functions can be carried out numerically by computing the ratio of the ambient dose equivalent indicated, i.e. $N \cdot M$, to $H^*(10)$ in spectra found in workplaces(4). The values for M and $H^*(10)$ are obtained from Eqs. (2) and (3). The mean neutron fluence to ambient dose equivalent conversion factor, $H^*(10)/F$, is used as an indicator of the hardness of a spectrum. The results of this check on the performance are shown over in Figure 4 for about 500 spectra found in a catalogue(4) and for a subset of over 100 spectra measured in reactor environments. The dashed and dash-dotted lines in the upper part of Figure 4 enclose the allowed domain of R_H(rel.), namely, $2/3 \leq R_H(\text{rel.}) \leq 3/2$. In particular at workplaces in reactors (cf. upper part of Figure 4), the LB 6411 indicates $H^*(10)$ within + 10% and -30% for whole range of there.

But also for the other spectra the performance of LB6411 is seen to be much better than that of the Leake counter.

Table 3. Fluence weighted ambient dose equivalent readings for the LB 6411 and ambient dose equivalent in calibration spectra.

		^{252}Cf D_2O mod.	^{252}Cf bare	^{241}Am-Be	^{241}Am-Be
NM/ϕ	(pSv.cm²)	111	385	407	458
H*(10)/ ϕ	(pSv.cm²)	105	385	391	408
NM/ H*(10)		1.06	1.00	1.04	1.12

CONCLUSION

The LB 6411 rem counter has been established as a useful and sufficiently accurate survey instrument for the measurement of $H^*(10)$ in routine monitoring. The use of the consistent fluence and ambient dose equivalent response provided here even allows more accurate measurements.

DEDICATION

The authors wish to dedicate this work to their recently retired colleague Ernst Piesch, an eminent scientist in the field of dosimetry and much respected in this capacity and as a person.

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