NEUTRON AREA SURVEY INSTRUMENT MEASUREMENTS IN THE EVIDOS PROJECT

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Neutron survey instruments have been exposed at all the measurement locations used in the EVIDOS project. These results have an important impact in the interpretation of the results from the project, since operationally the survey instrument will be used for an initial assessment of and routine monitoring of the ambient dose equivalent dose rate. Additionally, since the response of these instruments is in some cases very well characterised, their systematic deviations from the reference quantities provide an important verification of the determination of those quantities.

INTRODUCTION

Neutron survey instruments are important tools for controlling doses to individuals in the workplace. They are used routinely to determine the dose rates in areas where persons may be occupationally exposed, to delineate controlled areas, to prospectively establish systems of work, and to monitor dose rate levels. Most of the instruments in general use are of the moderator-type. Such instruments have less than perfect energy dependence of ambient dose equivalent response characteristics, over-responding in the energy region between 1 eV and 10 keV.

Measurements were made at each of the workplaces studied in the EVIDOS project(1) using a range of commercially available instruments: Berthold LB6411, Harwell Instruments N91, Studsvik 2202D and WENDI-II. These results are interpreted in terms of the known energy dependence of response of the instruments and the measured fluence-energy distributions of the fields. The ability of these instruments to provide accurate assessments of $H^{*}(10)$ and conservative estimates of $H_{\mathrm{p}}(10)$ is hence qualified.

Whilst the main focus of the EVIDOS project has been on personal dosemeters, the 'front line' for radiation protection in the workplace is the initial survey that is made to assess potential occupational doses. The accuracy of this survey is of primary importance:

- Overestimates of the dose rates may affect operational efficiency by restricting work practices.
- Underestimates of dose rates may lead to underestimates of the risks to workers from working in specific environments.

Consequently, the accuracy of radiation surveys is highly significant. Within the EVIDOS project, the ambient dose equivalent readings of this selection of survey instruments will be compared to the personal dose equivalent rate at the measurement positions.

Additional measurements were made with TEPC based systems, which can also be used to determine the ambient dose equivalent rate. One such system, and its results in the EVIDOS project, is discussed elsewhere in these proceedings(2).

RESPONSE OF SURVEY INSTRUMENTS

Most of the neutron survey instruments in this project use $1/v$ proportional counters, based on either the ^{3}He(n, p) or ^{10}B(n, α) reactions. Consequently, they rely on moderation of the field by a large hydrogenous mass to slow down the neutrons and enhance the detection efficiency for fast neutrons. The energy dependence of the response is then modified by the use of a perforated thermal neutron absorbing layer, cadmium or boron-loaded rubber, which ensures that the $H^{*}(10)$ response of the instrument is flatter than would otherwise be the case. In the case of the WENDI-II this layer is made from unperforated tungsten.

In practice, the ambient dose equivalent response of neutron survey instruments varies significantly with energy (Figure 1). In particular, the response peaks in the 1–10 keV region, just below

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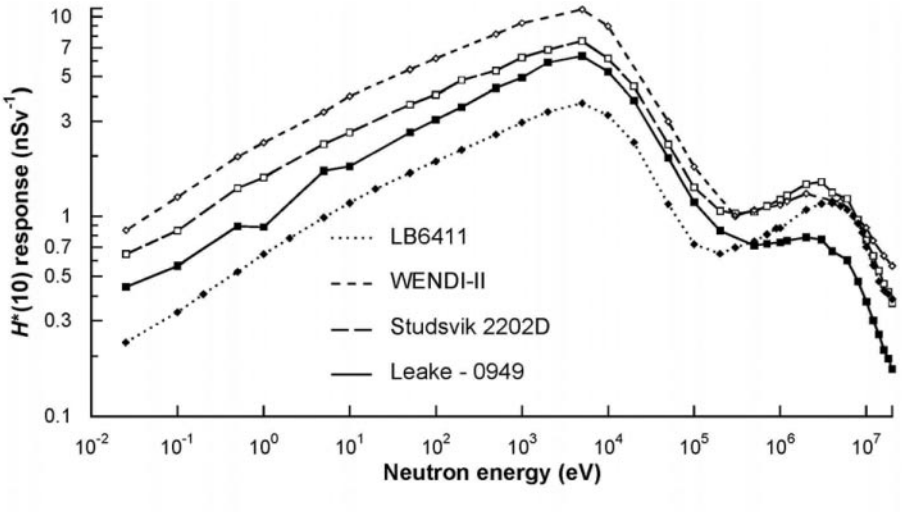

Figure 1. $H^*(10)$ response of the 2202D(2), LB6411(3), WENDI-II(4) and Leake(2) designs, from their reference direction.

the energy range where the fluence to dose equivalent conversion coefficient begins to rise steeply. Generally, workplace fields are determined as having a small component of dose equivalent in the energy range where these moderator-type instruments overestimate significantly.

The EVIDOS contract offers a unique opportunity to study the effect of the angle dependence of response of these instruments, since the direction dependence of the fields is being determined at the measurement locations(5). Unfortunately, there are not detailed energy and angle dependence of response data available for the LB6411 or WENDI-II, which will limit this aspect of the analysis. There are, however, detailed data available for the Studsvik 2202D and for a different model of the Leake design, the 0949(2): these data show that the angle dependence is less important than the energy dependence of response, except when the instrument is exposed through its electronics. In real workplaces, with significant scatter, this will always account for a component of the field, but when used wisely, it should not constitute a very significant fraction of the field.

RESPONSE IN EVIDOS FIELDS

The $H^*(10)$ rate measured using each of the instruments, divided by that calculated directly from the Bonner sphere determinations of the fluence-energy distribution(6,7), gives the bias in the reading of the instrument. A theoretical value for the bias can also be obtained by folding the instrument response with the energy distribution and dividing this value by the reference $H^*(10)$.

The bias in the $H^*(10)$ reading is of primary interest. However, the ratio of the measured $H^*(10)$ to the reference value for $H_p(10)$ is also of interest: if the measurement of $H^*(10)$ is a significant underestimate, then the instrument could underestimate $H_p(10)$ also; if $H^*(10)$ is overestimated when it is significantly larger than $H_p(10)$, then the reading can be excessively conservative.

The relationship between $H^*(10)$ and $H_p(10, \theta)$ is complex. For $\theta = 0°$ the two quantities are very similar, but $H_p(10)$ is much smaller than $H^*(10)$ for large angles of incidence for all neutron energies encountered in the EVIDOS project. The two quantities are most different in highly scattered fields.

Three parameters are plotted in Figure 2:

- Ratio of the measured ambient dose equivalent rate, $H^*(10)_M$, to the reference value(6,7), $H^*(10)_R$.
- Ratio of the calculated response of the instrument, $H^*(10)_C$, to $H^*(10)_R$. Differences between this ratio and the measured ratio will derive from deficiencies in the response data, the angle dependence of response of the instrument or problems with the determination of $H^*(10)_R$.
- Ratio of the reference personal dose equivalent(5), $H_p(10)_R$, to $H^*(10)_R$. The value of this ratio should be lower than $H^*(10)_M/H^*(10)_R$.

The response calculated for each instrument used the same calibration as was applied for the measurements:

- The Studsvik 2202D was calibrated at HPA using a bare ^{241}Am-Be source: 1242 μSv^{-1}.
- The N91 used the manufacturer's recommended value of 864 μSv^{-1}.

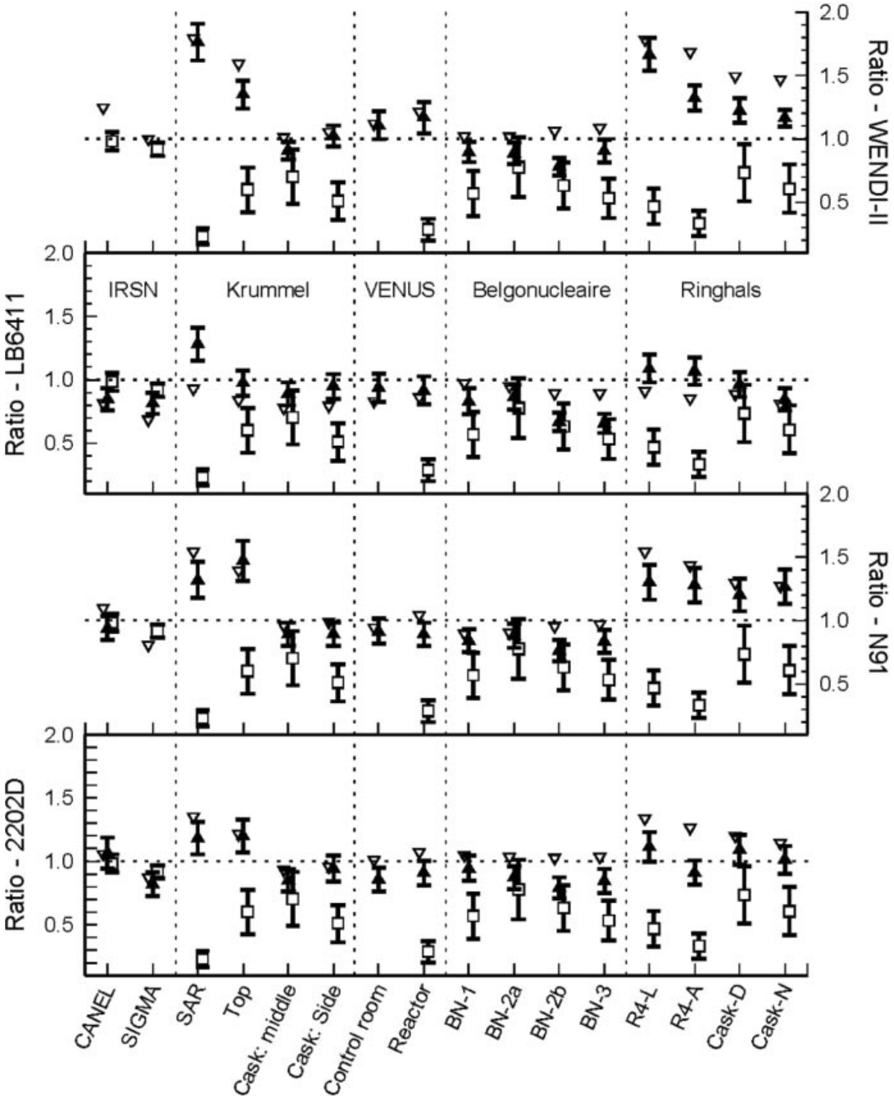

Figure 2. Results from the Studsvik 2202D, N91, LB6411 and WENDI-II in the EVIDOS fields: ▲ = the ratio of the measured $H^{*}(10)$ to the reference value; △ = the ratio of the calculated response to the measured response; □ = the ratio of the reference value for $H_{\mathrm{p}}(10)$ to that for $H^{*}(10)$. Responses have been calculated for instrument/field combinations irrespective of whether a measurement was made. There is no value potted for the ratio of the dose equivalent quantities for the VENUS Control Room because there is no reference value for $H_{\mathrm{p}}(10)$ for that location.

- $H^{*}(10)$ readings were taken directly from the LB6411 display. The instrument is calibrated in terms of a bare ^{252}Cf source, for which the manufacturer specifies a response of 2830 μSv^{-1}.
- A calibration of 2640 μSv^{-1} was used for the WENDI-II based on a calibration using a bare ^{241}Am-Be source at PTB.

Figure 2 and Table 1 show the results from the EVIDOS project. A few data points are missing: the ratio of $H_{\mathrm{p}}(10)_{\mathrm{R}}/H^{*}(10)_{\mathrm{R}}$ for the VENUS Control Room, for which the dose rate was too low for a reliable $H_{\mathrm{p}}(10)$ determination; WENDI-II measurement in the CANEL field; WENDI-II and N91 measurements in the SIGMA field.

Generally, the measured results show good agreement with the reference values for $H^{*}(10)$. Compared to these reference values, the mean biases for the instruments are relatively small, ranging from −9% for the LB6411 to +15% for the WENDI-II. The potential for positive biases is greater, with +76%

Table 1. Bias, the ratio of the measured $H^*(10)$ rate to the reference value for the four instruments.

Bias	2202D	N91	LB6411	WENDI-II
Maximum +ve	1.20 (0.13) (KKK Top)	1.47 (0.16) (KKK Top)	1.28 (0.13) (KKK SAR)	1.76 (0.14) (KKK SAR)
Mean	0.96 (0.03)	1.05 (0.06)	0.91 (0.04)	1.15
Maximum –ve	0.79 (0.08) (BN-2b)	0.76 (0.08) (BN-2b)	0.65 (0.08) (BN-3)	0.78 (0.07) (BN-2b)

The mean bias is the average for the 16 fields, with the quoted uncertainty deriving from the distribution of values. The maximum positive and negative biases have uncertainties quoted that include the calibration uncertainty and counting statistics

for the WENDI-II in the KKK SAR field being the maximum value. Negative biases are never greater than −35% for the LB6411 in the BN-3 field.

Negative biases are of concern where they can lead to an underestimate of $H_p(10)$. The field that comes closest to this situation is the BN-2b field, a relatively unidirectional, moderated field. Here the $H^*(10)$ measurement and $H_p(10)$ value effectively coincide within experimental uncertainties.

The predicted and measured responses show generally good agreement. The full analysis of these data will require consideration of the direction dependence of the field, although this aspect of the analysis can only be properly undertaken for the 2202D, which has full energy and angle dependence of response data available.

CONCLUSIONS

The accuracy of the survey instrument readings in the EVIDOS project will be significant in terms of the interpretation of the final results of the project. Significant biases in survey instrument readings can have implications for either workplace practice or the assessment of personal and effective dose.

In general, the results show small underestimates of $H^*(10)$, although the Krümmel BWR fields are an exception: since those fields have high $H^*(10)/H_p(10)$ ratios, the readings of ambient dose equivalent provide substantial overestimates of $H_p(10)$.

Since one of the instruments has detailed energy and angle dependence of response data available, its readings can also provide important checks on the $\Phi(E)$ and $\Phi(E, \Omega)$ distributions determined in this work. This aspect of the work is incomplete.

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