A Compact System for Neutron Spectrometry*

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Abstract

A neutron spectrometer based on Bonner spheres has been calibrated in monoenergetic neutron beams. The response matrix has been interpolated using a one dimensional transport calculation. The unfolding code SAND has been implemented on a personal computer leading to a compact measuring system. The validation of the response matrix and of the unfolding procedure was performed using measurements of known spectra. The system has been applied satisfactorily as a reference instrument in nuclear power plants and near medical accelerators.

1. Introduction

Dosimetric quantities related to neutron irradiation are strongly dependent on the energy spectrum of the radiation. Two common methods are used in order to obtain relevant dosimetric information. In the first one the neutron energy fluence is measured using a set of moderating polyethylene spheres (Bonner spheres); the dosimetric quantities (absorbed dose, dose equivalent, quality factor and radiation weighting factors) are obtained by convoluting the energy spectrum with conversion factors derived from Monte Carlo calculations. The second method is based on microdosimetric measurements using a tissue equivalent proportional counter (TEPC); in this case the LET spectrum allows the calculation of the dosimetric quantities.

The first approach was chosen because it provides through the fluence energy spectrum a better insight into the radiation protection conditions. A particular effort has been devoted to the determination of the characteristics and the performances of the system and to its integration in a compact measuring system.

2. Description

The spectrometric system used [1] comprises 11 moderating spheres made of polyethylene with diameters of : 2, 2.5, 3, 4.2, 5, 6, 8, 9, 10, 12 and 15 inches (") (from 5.08 to 38.1 cm). Spheres with diameters smaller than 6" can be covered by a cylindrical cadmium box, in order to absorb the thermal component of the incident neutron spectrum. The thermal neutron detector used is a miniaturized proportional counter filled with helium-3. The preamplier located close to the counter is linked through 20 m long cables to a standard spectroscopy instrumentation. An optimal discrimination level which insures a good rejection of noise and γ rays without affecting the neutron sensitivity too much, has been chosen.

The dead time of the electronics is 6 μs and the gamma sensitivity of the ^{3}He counter is very low (0.01 imp. / μSv for the cobalt-60 γ field). The nominal value of the counter's sensitivity to thermal neutrons is 6.10^4 imp./μSv which leads to a relative sensitivity (n/γ) of 6.10^6. Even in the worst case where the bare counter is placed in a hard spectrum such as that of americium-berillium and where the sensitivity to neutrons is 1 imp./μSv only, the relative sensitivity (n/γ) of the counter remains of the order of 100.

The results obtained are corrected for the system's dead time and normalised to the indication of the fluence monitor. They are unfolded by a version of the code SAND [2] operating on a PC. The 640 energy groups originally used by SAND have been compressed into 120, in order to reduce the processing time. The SAND program has been implemented in an environment which allows to visualize the unfolded spectrum after each iteration. The program stops when a reasonable stability of the result is reached. The unfolding code provides, in addition to the neutron spectrum and the total neutron fluence, different dosimetric quantities such as : $\hat{D}_n$ and $\hat{H}_n$ using conversion factors given in ICRP publication 21; $D_n*(10)$, $H_n*(10)$, $Q_m = H_n*(10)/D_n*(10)$ and the effective dose equivalent, using conversion factors given in ICRP publication 51.

In a moderate field strength (≈ 100 μSv/h) the duration of a complete measurement, using all the spheres, is of the order of 30'; the deconvolution needs about 2' in order to get a precision on the dosimetric quantities better than 10%. The deconvolution can be monitored by visualizing the iteration steps of the spectrum on a screen.

3. Performances

The spectrometer has been calibrated with thermal neutrons at Cadarache (France), and with several monoenergetic neutron beams of energies : 8; 144; 250; 570 keV et 1,2; 2,5; 5,0; 14,8 MeV at the PTB, Braunschweig (Germany). The interpolation of the response curves between the calibration points is based on neutron transport calculations using the one dimensional code ANISN [3] and a recent condensed cross section library. The calculation has been matched to the measurement using a unique parameter, the intrinsic counter efficiency. The response functions of the spheres are presented in figure 1.

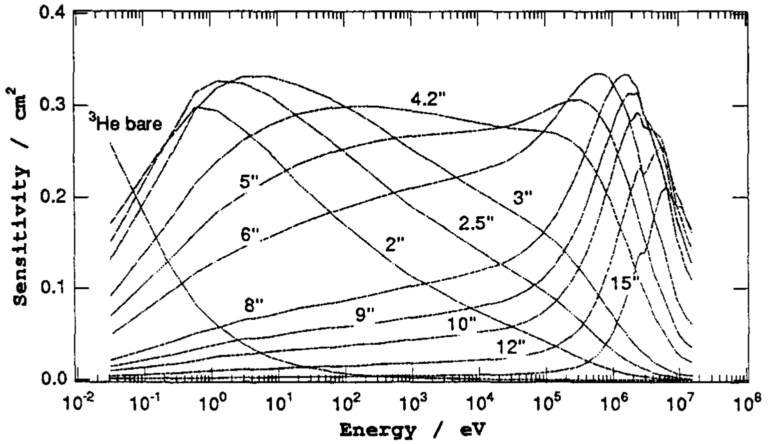

Figure 1. Response functions of the Bonner spheres

The validation of the deconvolution has been performed using the measurement in known neutron beams of americium-beryllium, californium and heavy water moderated californium sources [4]. The results obtained (examples are given in figure 2) confirm the good performances of the system, including the response matrix and the unfolding procedure.

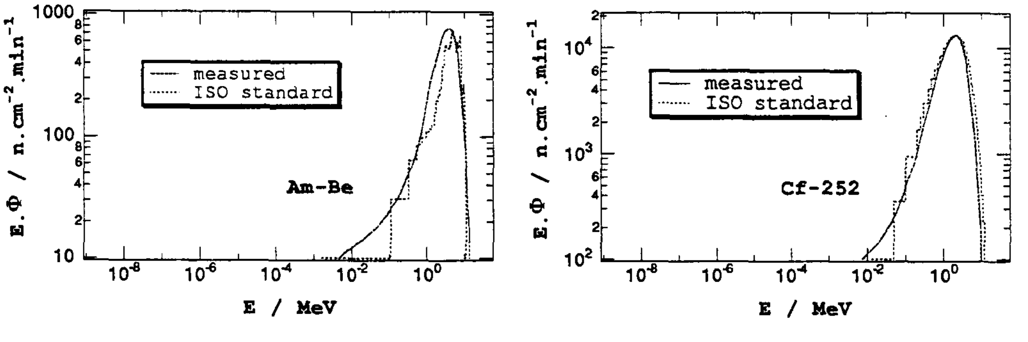

Figure 2. Comparison between the americium-beryllium and californium measured spectra and the ISO standard ones

4. Measurements of neutron fields

The system has been used in different neutron fields : nuclear power plants, medical accelerators, etc... It was not only possible to get the relevant dosimetric quantities, but also to calibrate operational instruments (rem-counters) in these fields [4]. On the other hand the knowledge of the spectrum gives a better insight into the radiation protection conditions.

In figure 3 the spectrum and the dosimetric quantities in two typical situations in a nuclear power plant are presented. The ratio of the response of the 9" sphere to that of the 3" sphere (9"/3") is given as a global indicator of the spectrum. The measurement near the entrance of the containment shows a moderated spectrum with a relatively low Q factor. The measurement performed near a transport flask presents a typical fission spectrum with hard components and a high Q factor.

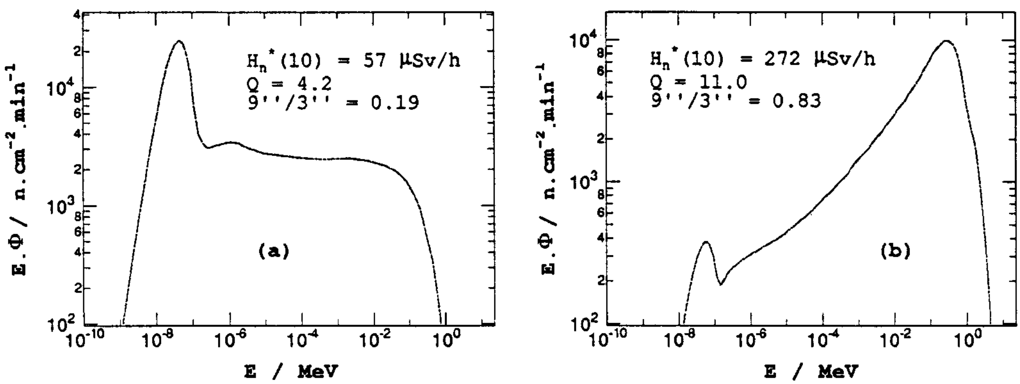

Figure 3. Examples of neutron spectra inside the containment of a nuclear power plant (a), and near a transport flask (b)

5. Conclusions

The system presented is based on a firm background consisting of a detailed calibration and a careful validation of the unfolding. The instruments are incorporated in a compact system allowing on-site evaluation. It has been succesfully applied in different neutron fields as a reference instrument.

References

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