STANDARD IRRADIATION FACILITY FOR THE CALIBRATION OF RADIATION PROTECTION INSTRUMENTS EMPLOYING RADIONUCLIDE SOURCES

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INTRODUCTION

Measuring instruments used for radiation protection purposes should in principle be calibrated in terms of those quantities for which the limits have been specified by regulations or recommendations. In practice, however, operational quantities must be used in order to link the calibration quantities to the limiting quantities /1/. The dose equivalent ceiling /2/ has up to now been used as operational quantity. It is based on the recommendations given in ICRP Publication 21 /3/.

In routine testing radionuclide sources are particularly suitable for producing standard neutron fields. The ISO-working group TC 85/SC 2/WG 2/SG 3 has therefore proposed neutron reference radiations for the calibration of neutron measuring devices used for radiation protection purposes. These include the following radionuclide sources: ^{252}Cf (bare and moderated by D_2O), ^{241}Am-B(α,n), and ^{241}Am-Be(α,n). From these sources bare ^{252}Cf and ^{241}Am-Be(α,n) should preferably be used for calibrations /4/. The American National Standards Institute (ANSI) has recently adopted the moderated ^{252}Cf-source as the sole source for calibrating personnel dosimeters /5/. At the Physikalisch-Technische Bundesanstalt (PTB) a standard irradiation facility is being installed which makes use of sources of this type.

The following sections deal with the calibration procedure in general and with the special arrangements to be made. The specifications of the sources and results of the calibration of a commercial remmeter are given for demonstration purposes.

CALIBRATION PROCEDURE

To calibrate it, an instrument is brought into a well-defined neutron field. The dose equivalent H produced at the point of reference is related to the indication M of the instrument (i.e. the number of counts) which would instead be produced at the same place under defined conditions. The calibration factor is then defined by $N = H/M$, or $N = \dot{H}/\dot{M}$ if time-related quantities are used. In the special case of irradiations with a broad parallel beam of unidirectional monoenergetic neutrons of energy E the dose equivalent can be calculated from the fluence ϕ using fluence-to-dose equivalent conversion factors $h_\phi(E) = H/\phi$ which are based on the recommendations given in ICRP Pub. 21 /3/ and on German regulations /6/. The behaviour of the instrument in this special field is described by the fluence response $R_\phi(E) = M/\phi$. In the case of neutrons with a broad energy spectrum as is generally emitted by radionuclide sources, mean conversion factors $\bar{h}_\phi$ averaged over the neutron energy spectrum are used together with the fluence ϕ /7/. In this case the mean fluence response is given by $\bar{R}_\phi = M/\phi$ where M is the indication of the instrument in the broad neutron energy spectrum with fluence ϕ. The calibration factor is then given by $N = \bar{h}_\phi / \bar{R}_\phi$. It should be kept in mind that the value of N is valid only for the special neutron energy spectrum and the irradiation geometry used for calibration ("calibration conditions"). In practical measurements the energy of the neutrons and their directional dependence are not known or only to a certain extent.

Several problems arise in the evaluation of $\bar{h}_\phi$ and $\bar{R}_\phi$:

For the calculation of $\bar{h}_\phi$ the neutron energy spectrum of the source must be known. In the case of the D_2O-moderated ^{252}Cf source the spectrum was calculated by Ing /8/ applying a Maxwell distribution with a spectrum parameter of 1.42 MeV for the bare ^{252}Cf source which corresponds to a mean energy of 2.13 MeV. $\bar{h}_\phi$ amounts for the moderated source to $9.0 \cdot 10^{-11}$ Sv.cm^2 /8/ and to $3.4 \cdot 10^{-10}$ Sv.cm^2 in the case of the bare ^{252}Cf source /4/. For the ^{241}Am-Be(α,n) source the neutron energy spectrum was recently measured yielding an $\bar{h}_0$-value of $3.8 \cdot 10^{-10}$ Sv.cm^2 /7/.

For the determination of the mean fluence response $\bar{R}_\phi$ the fluence ϕ and the indication M of the instrument induced by neutrons coming directly from the source are needed. The fluence ϕ can be calculated from the source strength taking into account the anisotropic emission of neutrons from the source. The value of ϕ must be corrected for air scattering. If the background is measured by means of a shadow cone only outscattering has to be considered using mean values of the cross section density for scattering on air averaged over the neutron energy spectrum of the special neutron source used.

The contribution of room and air-scattered neutrons to the indication of the instrument can be taken into account by measuring the scattered portion with a shadow cone the transmission of which can be neglected, or by recording the indication at different distances. From the latter, the fluence response $\bar{R}_\phi$ is derived assuming a constant background of room-scattered neutrons /9/ or a distance dependence of the indication M which can be described by the relation $M(L) = A/L^2 + B/L + C$ (L distance) /10/. Shadow cone measurements have shown that there is a noticeable distance dependence of background due to scattered neutrons. If the fluence response is determined assuming a constant background /9/, in special cases the deviations to be anticipated for $\bar{R}_\phi$ can be corrected /11/.

The effective centre of the instrument must be determined. It is defined as the point of reference in the instrument for which the indication of neutrons coming directly from a point source follows the $1/L^2$ law. It can be determined from the indication of direct neutrons at different distances /12/.

In addition, the value of $\bar{R}_\phi$ must be corrected in the case of a divergent beam of incident neutrons. This correction is known only for spherical devices and point sources /13/.

The following requirements for a calibration facility must be seen in connection with the procedure and the problems mentioned above:

1. The room used for calibration should be as large as possible

in order to minimize the contribution of room-scattered neutrons to the indication. In general, thick walls will be necessary because of radiation protection when sources of large source strength are used.

2. The source should be positioned in the middle of the room in order to minimize the local dependence of fluence or fluence rate on room-scattered neutrons.

3. There should be as little scattering material as possible in the vicinity of the source and the detector.

4. For distance measurements, the neutron measuring device must be precisely positioned by remote control with respect to the neutron source. An uncertainty of about ±0.2 mm is sufficient also for very small distances down to 10 cm (centre to centre).

5. Sources of different type and source strength should be available by remote control to meet the requirements of the particular calibration with regard to dose equivalent average energy and dose equivalent rate.

STANDARD IRRADIATION FACILITY

The standard irradiation facility of the PTB is being installed in a "bunker" (dimensions 7 m x 7 m x 6,5 m) with concrete walls and ceiling 1 m thick. Five different sources can be positioned in the middle of the room at a height of 3.25 m, including a moderator sphere (30 cm in diameter) filled with heavy water (concentration: 99.67%), into the centre of which a ^{252}Cf source can be placed. This source is situated on the top of a small cylinder also filled with D_2O, so that the ^{252}Cf source is completely surrounded by heavy water. The moderator sphere is completely shielded by cadmium 1.1 mm thick. The source strength of the ^{252}Cf source used in the moderating sphere amounts to $6.50 \cdot 10^7$ s^{-1} (1 Oct. 1983) which corresponds to a source strength of the moderated source of $5.79 \cdot 10^7$ s^{-1} taking into account a factor of 0.89 for the absorption af thermalized neutrons in the Cd shielding /8,9/. A dose equivalent rate of 40.5 nSv/s (14.6 mrem/h) is then produced at a distance of 1 m.

Up to three bare ^{252}Cf sources with different source strengths are used. By changing the distance between source and detector, dose equivalent rates within the range from about 3.4 pSv/s (1.2 μrem/h) to about 13 μSv/s (4.7 rem/h) (1 Oct. 1983) can be produced for this type of source. In addition, a ^{241}Am-Be(α,n) source can be used for calibrations producing a dose equivalent rate of 9.3 nSv/s (3.3 mrem/h) at a distance of 1 m.

Source strength B and the function describing the anisotropic emission were determined for all sources. B is measured by gold foil activation in a water bath to an uncertainty of about ±1.5 % (standard deviation) /14/.

In a second procedure, the source strength can be determined by means of a long counter comparing the emission of the source under investigation with that of a reference source of the PTB /15/.

CALIBRATION OF A SPHERICAL REMMETER

A commercial remmeter (Centronic, diameter of moderator: 20.8 cm) was calibrated using a ^{252}Cf source (bare and moderated) and a ^{241}Am-Be(α,n) source. The background of scattered neutrons was measured using shadow cones. In the case of the moderated source a shadow cone of quadratic cross section 50 cm in length and consisting of borated polyethylene was used. The dose equivalent response of the instrument was adjusted in accordance with the instructions given by the manufacturer. Table 1 shows the results of the $\bar{R}_\phi$ values from which the calibration factor N was calculated using the mean conversion factors quoted. The quoted uncertainties (standard deviations) include contributions from the measurement of source strength, the correction for outscattering due to air, the background determination by means of the shadow cone, the choice of the geometric centre for distance measurement, the correction for the case of a divergent beam, and for counting statistics. No uncertainties were taken into consideration for the mean conversion factors used.

Table 1

Source	$\bar{R}_\phi$ in cm^2	$\bar{h}_\phi$ in $Sv.cm^2$	N in nSv
$^{252}Cf + D_2O$	0.112 ± 0.003	$9.0 \cdot 10^{-11}$	0.80 ± 0.02
^{252}Cf	0.268 ± 0.005	$3.4 \cdot 10^{-10}$	1.27 ± 0.02
^{241}Am-Be(α,n)	0.252 ± 0.005	$3.8 \cdot 10^{-10}$	1.51 ± 0.03

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