A NEW TECHNIQUE FOR NEUTRON MONITORING IN STRAY RADIATION FIELDS

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INTRODUCTION

At reactors, accelerators and therapy facilities including linear accelerators there is the need to monitor and interprete low level stray radiation fields. The techniques applied in neutron monitoring today is based mainly on the measurement of the dose equivalent by means of rem counters. The response function of the different rem counter types, however, has been recently found to overestimate intermediate neutrons by a factor 6 (Leak type) or factor 8 (Anderson-Braun type) and to underestimate thermal neutrons up to a factor 0.34 (polyethylene sphere 30 cm diam) [4]. Both the Bonner multi spheres and spectrometers, on the other hand, are sophisticated techniques not applicable for routine work.

The new approach in neutron monitoring described here is based on a single sphere technique and passive thermoluminescence detectors which allows to measure

- the total dose equivalent of neutrons and gamma rays,
- the dose equivalent components of thermal neutrons < 0.4 eV, epithermal neutrons between 0,4 eV and 10 keV and fast neutrons above 10 keV,
- the effective neutron energy E_{eff} of the fast neutron component in unidirectional or isotropic stray radiation fields.

MEASUREMENT TECHNIQUE

The single sphere technique applied for the measurement of the dose equivalent and for the interpretation of the neutron spectrum makes use of a passive rem counter (polyethylene sphere of 30 cm diam) and a TLD600/TLD700 detector in the center (see Fig. 1). The rem counter sphere serves also as a phantom for two albedo dosimeters.

The Karlsruhe albedo dosimeter [1] designed as an analyser detector type contains three TLD600/TLD700 detector pairs inside a boron-loaded plastic capsule allowing a separate indication of albedo neutrons (detector i), incident thermal neutrons from the field (detector a) and epithermal neutrons (detector m).

By means of TLD600/TLD700 detector pairs, thermal neutrons are measured via the reaction $^6Li(n,\alpha)^3H$ and the neutron dose reading is given by the difference of TLD600 and TLD700. The TL detectors are calibrated in a ^{137}Cs gamma field which results in a gamma equivalent neutron dose reading presented here in the unit R.

In stray radiation fields the neutron detection is directionally independent for the rem counter sphere and in a first approximation also for the albedo dosimeter system if the corresponding readings in the opposite position at the phantom surface are summed up.

The response R of the albedo dosimeter i found by calculation [2] and calibration with monoenergetic neutrons [3] is presented in Fig. 1 as a function of neutron energy. The response function of the passive

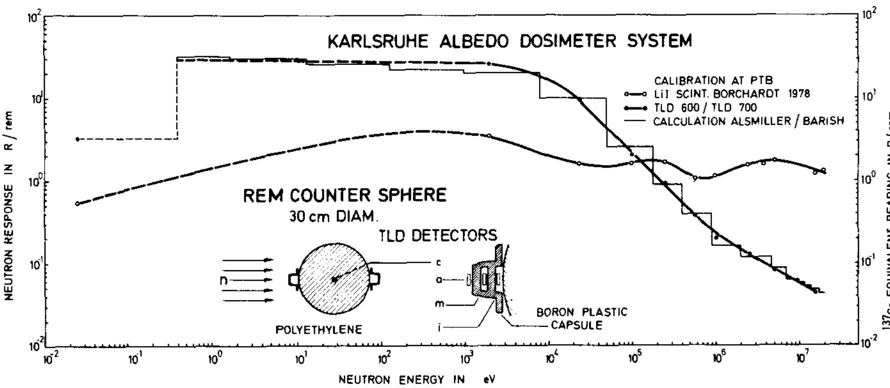

Fig. 1: Response of the Karlsruhe Single Sphere Albedo Dosimeter

TLD rem counter is expected to be equal to that of the rem counter with the LiI scintillation detector [4] and was related to a response of 1.6 R/rem found with Am-Be neutrons. The detector c in the sphere represents the true neutron dose equivalent H_n in a good approximation and the dose reading ratio $\alpha(i)/H_n$ the response R(i) of the albedo dosimeter. The high change in response in the energy range above 10 keV compared to the flat response of the rem counter is the basis for an estimation of an effective neutron energy in stray radiation fields.

INTERPRETATION OF THE STRAY RADIATION FIELD

In practice the effective response $R_{eff}(i)$ of the albedo dosimeter may vary by one order of magnitude around one facility mainly caused by local changes of the thermal neutron fluence and/or the moderation of the fast neutrons.

For the interpretation of the neutron spectrum a computer program is used taking into account the response function of the rem counter (detector c) and of the detectors i, a, m in the Karlsruhe albedo dosimeter. In a neutron stray radiation field the neutron dose reading of the detectors in the albedo dosimeter can be interpreted on the basis of three energy components by the following response matrix

$$\alpha(a) = R_{th}(a) \cdot H_{th} + R_e(a) \cdot H_e + R_f(a) \cdot H_s$$
$$\alpha(m) = R_{th}(m) \cdot H_{th} + R_e(m) \cdot H_e + R_f(m) \cdot H_s$$
$$\alpha(i) = R_{th}(i) \cdot H_{th} + R_e(i) \cdot H_e + R_f(i) \cdot H_s$$

$\alpha(a)$, $\alpha(m)$, $\alpha(i)$	neutron dose reading in the ^{137}Cs equivalent unit R for the detectors a, m, i measured in the stray radiation field
H_{th}, H_e, H_f	neutron dose equivalent fraction in the unit rem due to thermal, epithermal and fast neutrons with the total neutron dose equivalent $H_n = H_{th} + H_e + H_f$
$R_{th}(k)$, $R_e(k)$, $R_f(k)$	neutron response in R/rem for thermal, epithermal and fast neutrons for the detector k = i, a or m.

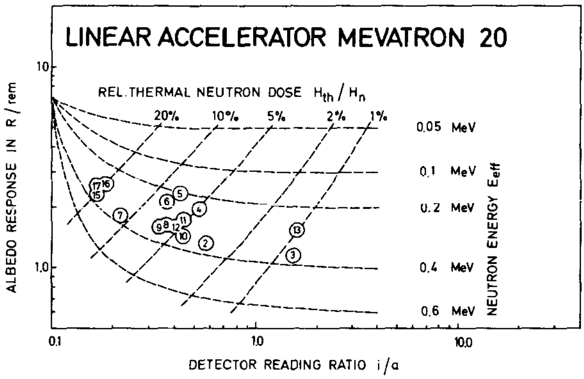

Fig. 2: Albedo dosimeter calibration at the Linac, Karlsruhe Vincentius Hospital

Taking into account the calibration data for $R_{th}(k)$, $R_e(k)$ and the relation $R_f(a) = R_f(m) = \varepsilon \cdot R_f(i)$ the response matrix can be solved resulting in analytical indications of the dose equivalent data H_{th}, H_e, H_f, H_n. For the estimation of the energy dependent response $R_f(i)$ the term H_f is calculated by $H_f = H_n' - A \cdot H_{th} - H_e$ taking into account the underestimation (factor A) of the rem counter reading H_n' for thermal neutrons.

The estimation of E_{eff} is based on the correlation between neutron energy and the albedo response $R_f(i)$ (see Fig. 1). In contrast to the calibration results for monoenergetic neutrons presented in Fig. 1 the applied program is fitted for neutron stray radiation fields assuming a homogeneous energy distribution for fast neutrons (Gaussian normal distribution).

In addition the statistical errors of all computed results are calculated based on the statistical error of each dose reading given by previous data of a reader test [5] (standard deviation vs. exposure) and caused also by the discrimination of the gamma dose reading in the detectors i, a, m and c [6].

APPLICATION IN STRAY RADIATION FIELDS

For personnel monitoring by means of albedo dosimeters an extended field calibration with the single sphere technique is applied at various locations in the stray radiation field of each neutron facility [7-9]. The application in personnel monitoring is based on individual correction factors for energy dependence based on the correlation between the dose reading ratio $\alpha(i)/\alpha(a)$ and the experimental response $R_{eff}(i)$ found by field calibrations before.

In the neutron/gamma stray radiation field of a 20 MV electron linear accelerator, for instance, the albedo response varies between 1 and 2.8 R/rem (Fig. 2). The value for H_{th}/H_n increases from 1% in 1 m source distance up to 20% at the shielding's entrance. The neutron field interpretation results in E_{eff} values between 0.2 and 0.4 MeV in agreement to results found at a similar accelerator by means of activation detectors and a computer unfolding calculation [10].

The single sphere albedo method is applied as a standard technique to interprete low level stray radiation fields [11]. Some experimental results are presented in Table 1. First applications at power reactor

Table 1: Interpretation of neutron stray radiation fields by means of the single sphere albedo technique

Facility		$\dot{H}_n$ mrem/h	H_n/H_γ	Rel. Neutron Dose in % H_{th}/H_n	H_e/H_n	H_f/H_n	E_{eff} keV	$R_{eff}(i)$ R/rem
^{252}Cf in air	2m	336	15.7	0.1	0.0	99.1	1900	0.31
20 MV Lin. Electr.	1m	13910	0.99	1.1	1.2	97.7	295	2.1
Accelerator	5m	1496	0.70	8.6	2.3	89.1	260	2.7
Mevatron 20	entrance	48	3.21	30.4	4.7	64.9	260	3.6
Linac SL 75-20	1m	64410	3.40	1.3	0.6	98.1	345	1.7
	entrance	613	4.21	13.5	3.7	82.8	240	3.2
	behind shield	13	1.55	37.3	5.8	56.8	120	5.1
14 MeV 'KARIN'	1m	4360	11.8	1.9	0.5	97.7	1140	0.67
Theraphy Fac.	9m	430	9.8	4.5	0.8	94.7	831	1.0
Compact Cyclotron	1m	500	20.2	2.2	0.4	97.4	1220	0.63
d(d,n), DKFZ	5m	146	13.6	5.0	1.0	94.0	720	1.2
	10m	138	5.1	14.6	2.2	83.3	400	2.2
	15m	16	1.7	43.9	4.9	51.2	410	3.5
Oak Ridge	Bare	6575	17.3	0.3	0.0	99.7	880	0.63
HPRR	Lucite	4715	12.2	4.3	0.4	95.3	850	0.88
	Concrete	4281	10.0	3.1	0.7	96.2	590	1.2
Jülich FRJ-1	Beam	62	2.33	3.0	1.2	95.8	235	2.5
Reactor	3m	8.7	4.08	20.6	5.1	74.3	140	4.6
GKN Power	in reactor cavity	5423	4.2	14.0	5.9	80.1	205	4.1
Reactor	23m	11	0.67	19.2	5.0	75.9	200	4.0
	64m	2.4	0.38	20.7	5.5	73.8	215	4.0
	entrance to	0.06	0.15	70.7	2.8	26.5	200	3.8
	sump	2.6	0.02	52.8	4.3	42.9	240	3.9
Kahl Exper.	containment	0.5	3.26	26.4	8.1	65.4	174	3.1
Reactor	steam heat exchanger	2.4	46.2	13.6	5.3	81.0	216	3.9
	valve in steam pipe	14.6	11.9	14.4	5.0	80.6	173	4.2

sites show that the local neutron spectrum varies only to a small extent for fast and epithermal neutrons but H_{th}/H_n may change from 5% to 70%.

The specific properties of the Karlsruhe albedo dosimeter was found in an effective response which is equal for thermal neutrons and neutrons with E_{eff} between 100 and 200 keV, therefore, at reactor sites only a small change of the dosimeter response $R_{eff}(i)$ is expected.

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