§11. Method of *H*(10)* Evaluation Using a Developed Spherical Type Neutron Dose

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A spherical type neutron dose monitor has been developed for the use of area monitoring around the neutron producing fields. Assuming the practical field that neutrons come from multiple directions with various energies and intensities, the study has been performed using MCNP simulation, in order to estimate the resultant direction of the sources and to find a suitable method of *H*(10)* evaluation.

Twelve radial directional TLD detectors are arranged between the layers at two consecutive depths and one in the centre. Total 25 TLDs are positioned at three depths of moderators and absorber. A series of calculation was performed to obtain the TLDs response at different depths of the moderators and absorber. It was done using MCNP5 by irradiating the monitor of two neutron sources with different energies and intensities placed at an angle between them. The wall and floor scattering effect of neutrons were also taken into account. Considering one source to be fixed at an angle, the other source was varied over a range of angles from -90° to $+90^{\circ}$ at an even interval of 30°.

For convenient, the MCNP calculation was performed using a single neutron source at incident angles of -90°, -60°, -30°, 0°, 30°, 60°, and 90°. The parallel beam of 50 cm radius with uniform density was injected to the surface of the monitor. In order to evaluate the dose response of the monitor, the spectrum of the two sources provided by ISO 8529; D_2O- moderated ^{252}Cf with energy ranges from 0.414 eV to 15 MeV (52 energy bins) and ^{252}Cf bare from 0.01 MeV to 18 MeV (45 energy bins) were used. The responses of the two single sources were summed up for selected angles and different intensities to get the responses of two directional sources. The responses of 25 TLD detectors can be obtained from two sources for different angles and intensities.

In order to estimate the resultant incident direction of two neutron sources of different incident angles, the first layer response of 12 TLDs were compared to the similar positioned TLDs responses of single sources. Comparing the response patterns between single sources and two directional sources, the direction of the source was estimated to be the average angle or near the average angle of two single sources. In some cases the direction could not be estimated due to the large angle in between two single sources. However, in the application at practical field it would not be possible to determine that how many directions of neutrons would come. But, from the distribution pattern of the source for the first depth responses of 12 TLDs, the resultant incident direction of the source can be obtained. In that case, the highest TLDs value would be the resultant incident direction of the neutron source.

The dose was calculated using Eq. (1) for two sources of different incident angles.

$$D = \sum_{i}^{N} \alpha_i R_i \qquad (1)$$

where, D is the calculated dose, i is the TLD positions, α_i is linear co-factors, R_i is TLD responses at ith position and N is the number of TLD groups. The co-factors were derived by solving the 52 linear combinational equations using an inverse matrix of Eq.(2).

$$[\alpha_k]_{1\times N} = \left[D_j^S\right]_{1\times 52}\left[R_{kj}^S\right]^{-1}_{52\times N} \qquad (2),$$

where, j is the 52 energy bins, D_j^{S} is the expected dose for standard source S in j energy bin to be found by multiplying the fluence and the fluence to dose conversion co-efficient of ICRP 74. R_{ij}^{S} is the expected response of TLDs of i positions in j energy bin.

To evaluate the dose, in each irradiation the largest three TLDs responses were considered from the first two depths of TLDs positions. From the responses of first depth 12 TLDs the highest three values were taken and their mean value was considered as first group. Similar to the first depth, three TLDs responses of same axes of the second depth were selected and their mean value was considered as the second group. A single TLD response of core depth was taken as third group. Using these three groups of TLDs and same linear co-factors, the dose was calculated by Eq. (1). Table 1 shows an example for the data of two similar sources.

Considering the similar parameters of Table 1, dose was evaluated for six cases of various energies and intensities of neutron sources. It was found that the ratio of the calculated to the expected dose was almost close to unity within the range from 0.94 to 1.08. The accuracy of the monitor for dose measurement was estimated to be within 8%. It is concluded that using the developed method neutron dose can be evaluated at unknown neutron field with good accuracy.

Table 1 Calculated dose for two same sources of D_2O-moderated ^{252}Cf (intensity 1:1)

Angle of two sources	Expected dose (pSv) (93+93)	Calculated Dose (pSv)	Ratio (Calculated to
0°	186	185	0.99
30°	186	182	0.98
60°	186	183	0.98
90°	186	187	1.01
120°	186	192	1.03
150°	186	201	1.08
180°	186	198	1.06