Neutron Personnel Dosimetry – State of Art

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Introduction.

The personnel neutron dosimetry continues to be one of the problems in the field of radiation protection, as no single method provides the combination of energy response, sensitivity, orientation dependence characteristics and accuracy necessary to meet the needs of a personnel dosimeter.

The most commonly used personnel neutron dosimeters for radiation protection purposes are listed below and will be reviewed :

1. Thermoluminescent albedo dosimeters.
2. Electrochemically etched plastics (CR-39).
3. Bubble dosimeters.
4. TLD chips (using separation of the glow peaks).

Thermoluminescent albedo dosimeters.

Albedo neutron dosimetry [1] is based on the effect of moderation and backscattering of neutrons by the human body, creating a neutron flux at the body surface in the thermal and intermediate energy range. These backscattered neutrons called albedo neutrons, can be detected by a dosimeter (usually a LiF TLD chip), placed on the body which is designed to detect thermal neutrons.

The neutron albedo factor, defined as the ratio of neutron fluence scattered from the body to the total incident neutron fluence entering the body, varies between approximately 0.8 for thermal neutrons and 0.1 for neutrons of 1 MeV. The response of an albedo dosimeter to monoenergetic neutrons was found to be high in the thermal and intermediate energy range, decreasing rapidly above 10 keV. Most of the albedo neutron dosimeters make use of special shields of cadmium, boron or graphite, mainly to absorb incident thermal neutrons, and thus to separate the backscattered neutrons. The Karlsruhe albedo dosimeter [1] employs three detectors inside a boron loaded plastic incapsulation allowing a separate indication of incident thermal neutrons and of intermediate energy neutrons.

The reading of an albedo neutron dosimeter depends on the special dosimeter design and is highly affected by field parameters such as shape and size of the dosimeter encapsulation, the distance of the detector from the body, the fraction of incident thermal neutrons and the fraction of thermal neutrons backscattered from the wall and the floor. The main disadvantages of albedo dosimetry are the relatively low response in the fast neutron energy range, the high contribution of incident thermal neutrons on the dose indication and therefore the need for a relatively sophisticated dosimeter design.

The advantages of LiF albedo dosimeters are the detection of neutrons without any energy threshold, the extended dose range from 0.1 mSv to about 10 Sv, a sufficient low fading for longer monitoring periods [2], only small influence of the body size on the dosimeter reading [3], a low dependence on the direction of the incident radiation if at least two dosimeters have been worn on the front and on the rear of the body, as well as an acceptable gamma dose discrimination.

Electrochemically etched plastics (CR-39).

CR-39 is a polymeric nuclear track detector [4] which is widely used for neutron dosimetry. Neutrons are detected by the path of the damaged molecules in the material. These tracks can be detected by a suitable etching process: either chemical etching (CE) or electrochemical etching (ECE), or both combined. An adequate calibration of the track density related to the neutron dose equivalent has to be performed.

The major shortcomings of CR-39 are the lack of a dosimetry grade material which causes batch variations, significant angular dependence and a sensitivity that may be marginal if a change in quality factor is adopted. CR-39 also under-responds for certain neutron energy ranges (lower energy neutrons from reactors or high energy accelerator-produced neutrons).

The electrochemically etched CR-39 is attractive because of the fast neutron effective response, low neutron energy threshold and photon insensitivity.

Bubble dosimeters.

The bubble detectors consist of a small container (measuring several cm.) filled with an elastic clear polymer [5]. Interspersed in this polymer are superheated freon droplets. Recoil protons may be produced by neutron interaction with the polymer. If these protons strike such a droplet it may vaporize and remain trapped as a visible bubble in the polymer. Recharging is accomplished by pressuring the polymer container above the vapor pressure of the freon gas mixture, therefore reforming the bubbles to liquid droplets.

The bubble detectors are very sensitive, having a detection limit of a few microSv. The neutron energy threshold of the standard option is 100 keV. These detectors need no electronics or power to operate and therefore cannot be disturbed by electromagnetic interference. They are insensitive to photons.

The main disadvantages of the bubble dosimeters are the strong temperature dependence (in the newer models temperature correction is employed to minimize this effect) and the severe shock sensitivity (upon a sharp impact the superheated drops vaporize, forming bubbles like those induced by neutrons).

It should be mentioned that bubble dosimeters can not be used to accumulate the dose information for periods longer than a few days, as the bubbles nucleation process is fast and the number of bubbles will decrease significantly within days.

Separation of glow peaks in TL chips.

Several attempts were made to measure the doses of fast neutrons in a mixed field of fast neutrons and gamma rays by employing this method. Busuoli [6] and Endres [7] tried to separate the fast neutron and the gamma dose using the height ratio of different peaks in TLD-100. The wide acceptance of thermoluminescence dosemeters (TLD's) for personnel dosimetry of photons and beta rays suggests that further efforts are expected in this direction.

The TL two peak method for neutron-gamma discrimination using CaF_2:Tm [8] or LiF:Mg,Ti [9] has long been considered of significant potential in neutron-gamma dosimetry, and indeed it is an accepted and useful technique at the high dose levels encountered in clinical and accident dosimetry.

When using LiF:Mg,Ti , the technique is based on the different sensitivity of peak 5, and the higher temperature peaks (peak 6 or/and peak 7), to low and high LET radiation. At low gamma dose levels encountered in personnel radiation protection, peak 7 cannot be observed above dosimeter or instrumental background. Even using computerized glow curve deconvolution (CGCD), the peak is measurable only at gamma dose levels above approximately 2 mGy [10]. The main disadvantages in the use of peaks 5 and 7 arise from the relatively high temperature of peak 7 and its strong, energy dependent gamma supralinearity. Peak 6 in LiF:Mg,Ti, although linear in its dose response, is difficult to extract reliably from peaks 5 and 7 below 0.01 Gy, even when using the CGCD analysis [10].

Conclusions

Forty years of research and development in the field of personnel neutron dosimetry did not produce a detector which combines acceptable energy response, sensitivity, orientation dependence characteristics and the range necessary to meet fully the needs of a personnel dosimeter.

Some laboratories have refined TLD albedo systems and developed enough confidence in their performance to fulfil the requirements of their national standards. Others have been concentrating on electrochemical etched CR-39, attracted by its fast neutron response and photon insensitivity. The most attractive neutron dosimetry technique, although not adequate to accumulate doses for more than a few days, is the bubble detection, having a high response to neutrons with energies above 100 keV and being isotropic and insensitive to gamma radiation. Peak separation may also be performed, but this method is suitable only for high doses.

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