THE ACCURACY OF DOSE ASSESSMENT FOR EXTERNAL β-γ-RADIATION

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INTRODUCTION

Doses* to the body and skin from β- and γ-radiations are generally estimated from readings of dosimeters carried by exposed persons. The relationship between dose and reading may be expressed:

$$\text{Dose} = \text{Dosimeter Reading} \times S \times F.$$

where $$S = \frac{\text{measurement quantity at the dosimeter}}{\text{dosimeter reading}}$$

where $$F = \frac{\text{Dose}}{\text{measurement quantity at the dosimeter}}$$

The measurement quantity may be exposure, air dose, air kerma-in-air, or, in the case of β-rays, tissue dose at defined depths below the surface. Thus S is a measure of the response of the dosimeter to a known amount of radiation delivered under laboratory conditions. F, on the other hand, is a relationship between two measurement quantities and is independent of the dosimeter properties.

The fractional error in the dose estimate is thus the sum of the fractional errors in S and F. In order to set limits of uncertainty in dosimeter response it is necessary to have a realistic estimate of the uncertainties in F when measurements are made in the field. Until now we have had only measurements in the laboratory[1] and calculations[2] which relate only to defined conditions to estimate uncertainties.

If a certain value of F is chosen based on laboratory measurements or calculations are made errors will arise in field measurements because inevitably the conditions of irradiation will differ from the ideal. Three questions should be asked and answered about these errors.

1. How large can these errors be?
2. How large are they likely to be?
3. What can be done to diminish them?

This paper deals with these three questions.

LABORATORY DATA

The ratio F of the dose to the wearer of a dosimeter to the measurement quantity at the dosimeter depends upon the geometries[1,5] of radiation source, dosimeter and its wearer and the energy of the radiation (β or γ).

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*Dose is used here generally for the terms absorbed dose, dose equivalent or effective dose equivalent[3,4] as appropriate.

In the laboratory these factors can be varied independently and the consequence measured[1]. Thus, it is possible to measure the extent of error possible assuming these factors are unknown.

For example, if an effective dose equivalent (H_E) of 1 sievert is assigned to the wearer of a dosimeter exposed to 1 gray (kerma in air) of γ-rays the following has been noted[1].

- If the dosimeter is worn at the waist front the error in F will be less than 10% if the radiation is from all around or from in front and the energy is above 5 keV.
- If the radiation is from behind H_E is underestimated by a factor of four at 50 keV and a factor of two at 600 keV.

It is plausible that radiation from in front or from all around, or a combination of these source geometries is much more probable than radiation from behind. A worker generally faces his work and, if it is radioactive, it will irradiate him from in front, directly, and from around by scattering. However, laboratory experiments cannot teach anything about the probability of radiation direction in the working situation.

It is therefore necessary to make tests in the working environment since the laboratory experiments show that while errors in the 'plausible' situations are small (∿10%), errors in a possible situation are quite large (∿100-300%) and result in serious underestimates of dose.

In the case of β-radiation the errors can be much worse. If the source is behind the worker with a dosimeter at the front the failure to detect β-radiation is effectively total.

FIELD EXPERIMENTS

Two kinds of experiments can be performed in the working environment. By equipping workers with dosimeters placed on different body surfaces, data can be obtained about the direction of the radiation and by loading a realistic phantom with dosimeters at specific tissue sites and placing it at typical working positions and orientations in the working environment the ratio of dose to dosimeter measurement quantity (F) can be measured directly.

Workers in the lower header room of the NRX reactor at the Chalk River Laboratories were equipped with TL dosimeters at the front and back of their waists on 80 occasions. On 48 of these, when the doses were appreciable (≥0.5 mSv), the dosimeters at the back always received less than those at the front, the mean ratio of their readings being 0.64 with a standard deviation of 0.18. This showed that the radiation was primarily from in front.

In the same working area a realistic phantom was loaded with dosimeters, internally and externally and the dosimeters read after exposure. The dosimeter reading at the back of the waist was 58% of that at the front which was typical of the ratios found on workers in that area. Using the dosimeter at the waist front, the effective dose was estimated to be 6 mSv which was 18% higher than the effective dose observed with dosimeters sited throughout the phantom. [It is the practice at CRNL to assign an effective dose of 1 Sv for

1 Gy (kerma in air) to the dosimeter site].

The phantom experiment was next located at a place where the radiation source, a set of contaminated effluent filters, was behind the phantom and where the rear dosimeter reading was 2.7 greater than that at the waist front. In this case, the effective dose was underestimated by the dosimeter worn in the normal position by 47%. Had the direction of irradiation been known and the dosimeter been worn at the rear H_E would have been over-estimated by 49%.

Measurements reported by Walsh and Johns[6] on a phantom, set at eleven places in Ontario Hydro Nuclear Power Stations showed that H_E was over-estimated by 14 and 23%, for males and females respectively, if a mean, weighted for dose at each place (in the Nuclear Power Station) was calculated. At no place was the dose under-estimated by more than 17% or over-estimated by more than 26%.

THE USE OF TWO DOSIMETERS

The figure shows the relationship between H_E and the mean air kerma to two dosimeters, one at the waist front and one at the waist[1] rear. These measurements were made in the laboratory experiments referred to before. In this case, the ratio of the readings of the dosimeter could be used to determine the principal direction of the radiation. When this is done an appropriate factor can be chosen for converting the dosimeter kerma to H_E. Above 50 keV the conversion factor varies less than 15% regardless of energy and direction.

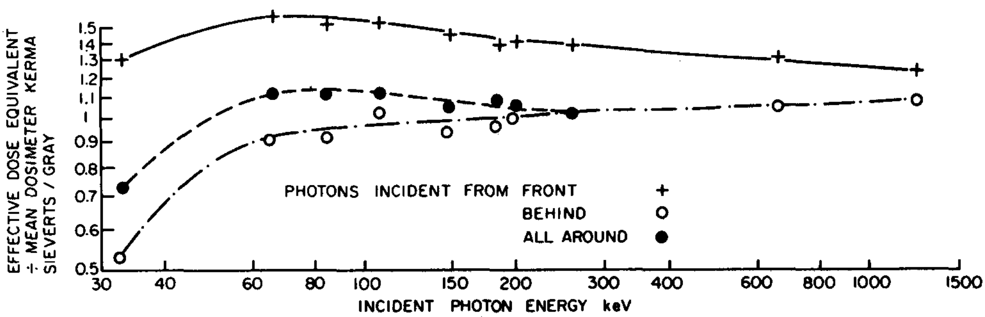

Figure 1. The dependence of energy and direction of the dose calculated from the mean of two dosimeter readings.

In the field measurements made at CRNL it was found that the error in estimating the effective dose, using two dosimeters, was only 6 and 3% when the radiation was from in front and behind respectively.

The approach to dosimetry illustrated in the figure can be taken without knowledge of the irradiation direction and as can be seen in the figure extreme errors can be eliminated.

However, it is recommended that two dosimeters be worn in situations where appreciable exposure can be anticipated and where the direction of irradiation is not known. A comparison of the two readings can be made to identify the small proportion of exposures where the dominant component is from behind. Then, in only those cases an appropriate correction need be made. In the case of skin dose, the larger of the two estimates should be used because the body is opaque to β-rays.

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