THE PRACTICAL APPLICATION OF ICRP RECOMMENDATIONS REGARDING DOSE-EQUIVALENT LIMITS FOR WORKERS TO STAFF IN DIAGNOSTIC X-RAY DEPARTMENTS

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In many diagnostic examinations using X-rays in hospitals, staff work in the X-ray room with the patient, and wear lead aprons to protect their bodies from the radiation. The effect of the protective apron is to reduce the dose-equivalent received by those parts of the body that the apron covers, leading to grossly non-uniform irradiation of the body as a whole. Under these circumstances we have to consider how best to monitor the exposure of the individual.

APPLICATION OF ICRP RECOMMENDATIONS

Where there is non-uniform irradiation, ICRP (1) recommends that the annual dose-equivalent limit of 50 millisieverts should be applied to the expression $\sum_T w_T H_T$ where w_T is a weighting factor representing the proportion of the stochastic risk resulting from tissue T to the total risk and H_T is the annual dose-equivalent in tissue T. This expression is referred to as the annual effective dose-equivalent.

Let us examine how the effective dose-equivalent is influenced by wearing a lead protective apron. We will assume that the radiation field is uniform and that the apron protects the trunk leaving the head, neck arms and legs exposed. Let us further assume that the annual dose-equivalent in protected organs is H_1 and that in unprotected organs is H_2. ICRP assigns weighting factors w_T to the gonads, breast, red bone marrow, lung, thyroid and bone surfaces and the remainder of the body.

In the situation described the gonads, breast and lung are protected while the thyroid is unprotected. The red bone marrow is distributed so that approximately 80% is protected while 20% is unprotected (2). The mean dose-equivalent in this tissue is therefore $0.8H_1 + 0.2H_2$. Data for the distribution of bone surfaces are not available but from the distribution of dry bone (2) we may assume that they are divided in approximately equal proportions. The mean dose-equivalent here is therefore $0.5H_1 + 0.5H_2$.

For the remainder of the body, ICRP recommends that a value of $w_T = 0.06$ is applicable to each of the five organs or tissues receiving the highest dose-equivalents and that all others can be neglected. There are more than five organs and tissues in the head and neck (e.g brain, salivary glands, tongue, pharynx, larynx, etc) and these are all unprotected. It follows that they will receive higher dose-equivalents than organs in the trunk and therefore the dose-equivalent to be applied to the remainder is H_2. Table 1 shows the derivation of the annual effective dose-equivalent.

TABLE 1. Annual Effective Dose Equivalent when a lead apron is worn.

Tissue	Weighting Factor (w_T)	Annual Dose-Equivalent (H_T)	Weighted Annual Dose-Equivalent ($w_T H_T$)
Gonads	0.25	H_1	$0.25H_1$
Breast	0.15	H_1	$0.15H_1$
Red Bone Marrow	0.12	$0.8H_1 + 0.2H_2$	$0.096H_1 + 0.024H_2$
Lung	0.12	H_1	$0.12H_1$
Thyroid	0.03	H_2	$0.03H_2$
Bone Surfaces	0.03	$0.5H_1 + 0.5H_2$	$0.015H_1 + 0.015H_2$
Remainder	0.30	H_2	$0.30H_2$
Annual Effective Dose-Equivalent			$0.631H_1 + 0.369H_2$

The value of the annual effective dose-equivalent obtained in this way may be rounded to give:-

$$\sum_T w_T H_T = 0.6H_1 + 0.4H_2 \text{ ---- Formula 1}$$

To make use of Formula 1 in practical situations, H_1 may be estimated by means of a dosemeter worn on the trunk under the protective apron and H_2 may be estimated by means of a dosemeter worn on the collar or forehead.

COMPARISON WITH PUBLISHED DATA.

Formula 1 is subject to a number of simplifying assumptions (notably the uniformity of the radiation field as a whole and the uniformity of irradiation of tissues within the protected and unprotected parts of the body). It is therefore important to compare the result of using the formula with that obtained by measurement of individual organ or tissue doses. Wøhni and Stranden (3) have published measurements of the absorbed dose in most of the relevant tissues in a variety of operating conditions using a phantom, fitted with a lead apron (0.25 mm lead equivalent), to represent a physician or nurse standing close to a patient undergoing X-ray examination.

In Table 2 the effective dose-equivalent has been calculated using the data of Wøhni and Stranden. Unfortunately their data do not include doses in organs of the head and neck with the exception of the eye lens and thyroid. Both organs being close to the body surface, doses in these organs will not be typical of organs such as the brain. Arbitrarily, therefore, and for want of better data, we have taken the mean absorbed dose in the gastrointestinal tract, measured <u>without</u> the lead apron, for the dose-equivalent in the "remainder". Also given in Table 2 are values for the effective dose-equivalent obtained by the use of Formula 1 (above). For this purpose the doses measured in the breast and thyroid have been assumed to be equal to the dose-equivalent as measured by a dosemeter located on the trunk under the apron (H_1) and one on the collar outside the apron (H_2) respectively. All the values in the table are expressed in the original units, i.e rads for 1 röntgen exposure on the outside of the apron at the right hand side of the thorax, and are quoted for a female phantom.

TABLE 2. Derived values of effective dose-equivalent in X-ray work.

	Radiological Conditions								
	60 kVp OC*	60 kVp UC	80 kVp OC	100 kVp OC	100 kVp UC	120 kVp OC	140 kVp OC	140 kVp UC	S+I**
Effective dose-equivalent derived from measured organ doses	0.08	0.19	0.12	0.14	0.25	0.15	0.16	0.29	0.29
$0.6H_1 + 0.4H_2$ ***	0.21	0.25	0.23	0.24	0.29	0.25	0.26	0.32	0.29

* OC = overcouch tube, UC = undercouch tube
** S+I was a simulated stomach and intestine examination
*** H_1 taken as the dose in the breast, H_2 taken as the dose in the thyroid.

Inspection of the values given in Table 2 shows that there is good agreement between the effective dose-equivalent obtained from measured values of organ doses and that obtained by application of the formula. In all but one of the cases the values differ by less than a factor of 2 and in none of the cases is the value based on the organ doses higher than the value obtained using the formula.

EFFECTIVE DOSE-EQUIVALENT AND EYE LENS.

Previous authors, e.g Littleton, et al (4), have considered that in work of this nature the principle cause for concern regarding the exposure of parts of the body not protected by an apron is the dose-equivalent received by the lens of the eye. In Table 3 we have compared the effective dose-equivalent derived from measured organ doses as a percentage of the annual dose-equivalent limit for the whole body (50 millisieverts) with the eye lens dose as a percentage of the annual dose-equivalent limit for the lens (300 millisieverts), in each of the conditions of measurement of Wøhni and Stranden (3) when a protecti apron is used.

The table shows that in all cases but the first (60 kVp, overcouch tube) the effective dose-equivalent calculated from organ doses is a bigger percentage of the annual limit than is the eye lens dose. In the first case the two are approximately equal percentages of the annual limits. It can be concluded therefore that if the effective dose-equivalent is limited to 50 millisieverts per annum the annual limit for the lens is most unlikely to be exceeded, particularly if the effective dose-equivalent is assessed by means of the formula.

TABLE 3. Dose-equivalent in lens, and effective (whole body) dose-equivalent, as percentages of annual limits (for 1 röntgen exposure)

	Radiological Conditions								
	60 kVp		80 kVp	100 kVp		120 kVp	140 kVp		S+I
	OC	UC	OC	OC	UC	OC	OC	UC	
Eye lens dose	1.8	2.0	1.9	2.0	1.8	2.0	1.9	1.9	1.1
Effective dose-equivalent	1.6	3.8	2.4	2.8	5.0	3.0	3.2	5.6	5.8

PRACTICAL APPLICATION

In principle, to limit the effective dose-equivalent to 50 millisieverts per annum, one should use two personal dosemeters and apply Formula 1 to the results obtained from the dosemeters. However, in practice it will not be necessary to insist on two dosemeters being worn in all cases. If, in the light of experience, the dose recorded by the body dosemeter (H_1) is found to be very small compared with that recorded at the collar (H_2), the former may be dispensed with. This would apply to the results in the first three columns of Table 2 where H_2 contributes less than 5% of the effective dose-equivalent. Under these conditions, an annual limit of 125 millisieverts can be applied to H_2 (i.e from the formula with H_1 taken as zero and the annual limit of effective dose-equivalent taken as 50 millisieverts). If on the other hand, despite the protective apron, there is significant exposure of the trunk, a single dosemeter worn at the collar will still suffice provided that the annual whole body limit of 50 millisieverts is applied. It is only in those few cases where such an approach would be too restrictive that two dosemeters need to be worn and the formula used.

REFERENCES.

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