An Assessment of Effective Dose to Staff in External Beam Radiotherapy

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Abstract

Radiation safety in external beam radiotherapy is governed by national legislation. Annual doses recorded by radiographers and others associated with external beam radiotherapy are typically much lower than the relevant dose limit. However, it is posssible that larger doses might be received as a result of an accidental irradiation. In the event of a significant exposure resulting in a dose at or near a relevant dose limit, an accurate conversion has to be made from the dose meter reading to the limiting quantity. A method was devised to demonstrate ratios of effective dose to personal dose equivalent which might be anticipated in the event of an individual other than the patient being irradiated within a radiotherapy treatment room consisting of a linear accelerator. The variation of ratios obtained under different conditions is discussed.

Introduction

Radiation safety in external beam radiotherapy, as in other practices involving ionising radiation is governed by national legislation which is largely derived from publication 26 of the International Commission on Radiological Protection (ICRP)[1]. In the UK, this resulted in the publication of The Ionising Radiations Regulations 1985 (IRR85)[2] and the associated Guidance Notes[3] and Approved Code of Practice[4] Since then, ICRP have introduced publication 60[5]. Although not yet fully translated into UK law, aspects of this are largely observed.

The Guidance Notes[3] specify that external beam radiotherapy must be carried out in a room with structural shielding providing adequate protection to all persons outside the room. The doors to the treatment room are then normally designated as the boundary to the radiation controlled area. The Approved Code of Practice[4] specifies that no person may enter a controlled area unless that individual is a classified person or is operating under a suitable system of work. All individuals, other than the patient, entering a radiotherapy treatment room are in general subject to personal monitoring, often through integrating dosemeters.

It is further specified[3] that all persons except the patient should normally be outside the room during a treatment, but that very occasionally and for compelling clinical reasons it may be necessary for a further person to be within the room during the time the beam operates. Such a person should wear a direct reading personal dosemeter.

It has been shown[6] that annual doses recorded by radiographers and others associated with external beam radiotherapy are typically much lower than the relevant dose limit. However, it is possible that larger doses might be received, perhaps as a result of an accidental irradiation of an individual remaining in the room with the beam having been switched on.

While any personal dosemeter should be calibrated to indicate the quantity personal dose equivalent[7], a personal dosimetry service is required to report a 'reasonable estimate' of the relevant limiting quantity, either effective dose, effective dose equivalent or organ dose equivalent[2]. In the event of a significant exposure resulting in a dose at or near a relevant dose limit, the service would have to make an accurate conversion from the dose meter reading to the limiting quantity. Published conversion factors exist[8], which cover the radiation quantities involved, but it is assumed that the radiation field is isotropic, parallel and monoenergetic. None of these features apply in practice in the case of an individual subject to scatter and leakage radiation from a linear accelerator.

The following was devised, therefore, to demonstrate ratios of effective dose to personal dose equivalent which might be anticipated in the event of an individual other than the patient being irradiated within a radiotherapy treatment room consisting of a linear accelerator.

Method Radiotherapy treatment using a linear accelerator is carried out over a wide range of conditions in a variety of different treatment rooms yielding a large range of conditions for room scatter and head leakage. All such variables will have an influence on the conversion factor to effective dose. The position of the dosemeter on the body will also be an influence factor. In order to simplify the task, a relatively small number of conditions regarded as most likely to occur were selected.

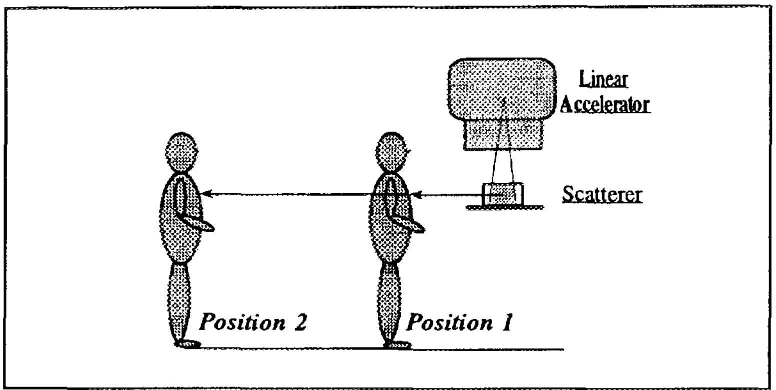

Figure 1

Organ	W_T
Gonads	0.20
Red Bone Marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone Surfaces	0.01
Remainder	0.05

Figure 2

Two positions within the room were selected to model the irradiation of the individual. One of these, position 1 on figure 1 simulated an individual standing position close to the side of the patient as if performing a patient procedure at the time of the irradiation. The other, position 2 on figure 1 simulated an individual further from the patient, and closer to the entrance maze. In both cases, the primary beam was vertical and the individual was simulated directly facing the patient. Couch height was adjusted such that the source of scatter (ie the simulated patient) was at the same height as the centre of the chest of the anthropomorphic phantom. The standing height of the phantom (both male and female) was 173.5cm. The source of head leakage radiation was approximately 2.5m above the floor. One radiation quality, a generating voltage of 8MV, was selected for modelling, being typical of clinical practice. Field sizes at the simulated patient representing the smallest (0.5x1cm) and largest (20x20cm) possible were selected. These sizes spanned the range of possible combinations of leakage and scatter radiation. Two phantoms were used. One of these simulated the patient and simply consisted of a rectangular block of commercial tissue equivalent material, WT1 (Radiation Physics Department, St Bartholomew's Hospital), 25cm square by 11cm deep set up on the central axis of the machine with an isocentric depth of 5cm and a focal-surface distance of 95cm, according to local procedure. An anthropomorphic phantom was used to simulate the irradiated member of staff. Both male and female versions were used. The phantoms had been designed to represent ICRP standard man (or woman) in both physical and radiation characteristics. They allow the placement of suitably calibrated thermoluminescent dosemeters (TLD-100, LiF:Mg:Ti) at appropriate positions in order to estimate a range of individual organ doses for the various irradiation conditions. The loading scheme for TLD within the various organs of the male phantom has been described previously[9,10]. The loading scheme for the female phantom was adapted from that of the male by reference to a CT atlas[11]. Doses to skin, red bone marrow and remainder organs were found using a method described by Huda and Sandison[12]. Effective dose was estimated from individual organ dose using organ weighting factors recommended by the ICRP[5] (Figure 2). Bicron-NE[13] whole body personal TLD dosemeters were also attached at appropriate points to the front surfaces of the anthropomorphic phantoms, enabling an estimate of the ratio effective dose to personal dose equivalent to be made.

No	Phantom	Field Type	Isocentre to chest wall (cm)	Shoulder Ratio	Chest Ratio	Waist Ratio
1	Male	Leakage	41	0.193	0.559	1.199
2	Male	Leakage +Scatter	41	2.686	1.591	0.850
3	Female	Leakage +Scatter	41	0.825	0.437	0.394
4	Female	Leakage +Scatter	241	1.286	1.082	0.940

Figure 3

Results Four irradiations were carried out, simulating the conditions selected. In each case the linear accelerator was operated for suitable period such that the radiation dose to the dosemeters on the surface of the anthropomorphic phantom was within the range 10-100mSv. Irradiation conditions are summarised in figure 3. Uncertainties on individual TLD results, estimated according to a method previously described[14], were in the range 6-12% at the 95% confidence interval. Values of the ratio of effective dose to personal dose equivalent were obtained for each irradiation and for each of three positions on the anthropomorphic phantom for placement of the personal monitor. Values of these ratios are shown in figure 3 . A ratio of greater than 1 means that the personal dosemeter is underestimating the effective dose.

Discussion The results show the largest variation in ratio for a personal dosemeter placed at the shoulder. This position is therefore the least reliable for personal monitoring purposes, since it appears to be unrepresentative of organ doses within the trunk. Ratios at position 4, which is some distance from the sources of scatter and leakage are close to unity, particularly at chest and waist positions. This result which is in broad agreement with previous work[8] using isotropic parallel beams, and indicates that for an individual some distance from the patient, but facing the source of scatter at the time of the exposure, a personal monitor when worn at the waist or chest is a good indicator of effective dose. For positions 1-3, ratios are more variable. In this situation, close to the source of both scatter and head leakage, there are considerable variations in dose between different parts of the body. For example, the waist badge overestimates effective dose when the radiation is dominated by scatter, but underestimates the effective dose when the radiation is predominately leakage which would be directed obliquely downwards. For all irradiation conditions measured, it may be seen that a personal monitor worn at either chest or waist will estimate effective dose to within +/-60%. It may be seen that results for irradiation 2 and 3 differ significantly. The only difference between these two is the gender of the phantom. An analysis of individual organ dose contributions to effective dose indicated that differences between irradiation 2 and irradiation 3 were dominated by gonad and breast components, both of which are relatively superficial organs. It may be postulated, therefore, that despite the penetrating nature of the radiation, some soft components exist within the near leakage and scatter field which may contribute to the dose distribution in an irradiated individual standing close to the treatment couch.

Conclusions

1 For the irradiation conditions studied here, a personal monitor worn at the chest or waist gives a good (+/-10%) indication of effective dose to a person some distance (~2.4m) from a radiotherapy treatment couch irradiated by scatter and leakage radiation.

2 For a person standing close (~41cm) to the source of scatter or leakage at the time of irradiation, the personal monitor is a less reliable indicator of effective dose, and may be in error by +/-60%.

3 In the event of an incident resulting in an apparent dose to a employee or member of the public close to a dose limit, it may be appropriate to measure retrospectively a conversion factor appropriate to the prevailing irradiation conditions.

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