NRC Response to Inquiry from Rad Source Technologies, Inc.

Following a report published on cesium chloride by a subcommittee of the Advisory Committee on the Medical Uses of Isotopes, two questions were raised by external reviewers. The first question requested a literature reference to support the statement in the initial report that "the higher tube potential of a 320 kVp unit brings the RBE to the same value as a 137Cs gamma ray beam" (page 4, lines 6 and 7). The second asks to clarify the spectral changes between the radiation from a naked ^{137}Cs source in free space and that for a source in an enclosure, and what the effect of a spectral change might have on the relative biological effectiveness (RBE) of the resultant radiation field. The discussion below addresses these questions. In summary: 1). the RBE for a highly-filtered, 320 kVp x-ray unit with respect to radiotherapy-like biological end-points, is likely to be approximately 1.2 – 1.3 compared with a ^{137}Cs unit, but with an uncertainty of about 0.2, while for lymphocyte inactivation there is little data upon which to base an estimate; 2). The effect of a lead enclosure (as described below) would add about 7% to a ^{137}Cs beam, split approximately evenly between photons in the range of 180 keV and those of 88 keV, while for the x-ray beam the scatter from the housing would add about 5% to the beam, in the range of 110 – 88 keV. In neither case would the RBE be affected significantly with respect to the uncertainty.

RBE Comparisons between Radiation from ^{137}Cs and Highly-filtered X-ray Beams

The relative biological effectiveness compares the effectiveness of a given radiation in producing a specific biological end-point compared with a standard radiation. The standard radiation historically has been 200 kVp x rays [Johns 1984] or 250 kVp [Hall 1978] (often filtered with 0.5 or 1.0 mm Cu). Over the years, as orthovoltage units fell out of clinical use, in practice, ^{60}Co, and to a lesser extent ^{137}Cs, often became the defacto standard in many discussions in the literature. RBE remains a biological, and not a physical quantity, leading to the major problem in specifying RBE for a type of radiation: the values for RBE depend not only on the radiation but the species and the biological end-point used for the determination. For clinical treatments in humans, Johns and Cunningham [1984] give a value for RBE of ^{60}Co compared with 250 kVp x rays as 0.8 to 0.9, and Paterson [1963] give the range from 0.85 to 0.9. Fractionation of the radiation, such as used in radiotherapy, tends to reduce the value of RBE [Fowler 2004]. As best as can be determined, ^{137}Cs and ^{60}Co seem to have the same clinical RBE [Zellmer 1992; Wuu 1996; Brenner 1999] Inverting this information gives an RBE for 200 kVp x rays compared to ^{137}Cs as 1.07 – 1.2. The last three references give values for the RBE of ^{192}Ir compared with ^{137}Cs as 1.3, 1.3 and 1.1 respectively. The 380 keV effective energy of ^{192}Ir falls above that of even highly filtered orthovoltage beams. For example, an x-ray beam of 320 kVcp, no matter how filtered, could not have an effective energy of 320 keV or higher. Because the values for RBE increase with decreasing energy in this energy region, this places the value for the RBE of highly-filtered x-rays approximately at 1.2 to 1.3, with an uncertainty of approximately 0.2.

The foregoing discussion assumed that the biological endpoint was treatment of cancer in humans. A similar discussion on lymphocyte inactivation in man, the end-point of interest in blood irradiation, would differ in two ways. The first would be the paucity of data related to RBE for this end-point. None of the studies found in a literature search addressed the question directly. Given that doses used for blood irradiation fall in the range of 15 to 50 Gy, subtle differences on the order of 20% would not be apparent without a very large and detailed experiment. The second difference compared to the

cancer discussion concerns the radioresponse of the lymphocyte. These cells have a very small to non-existent shoulder to the radiation survival curve [CF Tomita 2008]. The lack of a shoulder leads to greatly reduced effects from fractionization and lower RBE variations [Fowler 2004; Brenner 1999]. While there is no data sufficient to compare the RBE for lymphocyte inactivation between ^{137}Cs and highly-filtered x rays, the difference, if one exists, would have to be small.

Spectral Effects of Enclosures

The question of the effect the enclosure has on the spectrum of the radiation field for a self-enclosed irradiator is challenging. Again, there is no direct information resulting from a literature search. An estimate could provide some guidance; however, the following is not to be taken as a comprehensive derivation – only a rough consideration to obtain an impression of the size of the effect. From Report 49 of the National Council on Radiation Protection and Measurements [NCRP 76 – Table B-3] the albedo (reflected fraction of a beam) as 0.0028 for ^{137}Cs. This quantity gives the fraction of the beam reflected from a barrier, 1 m from the barrier. Assuming that a chamber is 20 cm across, at 10 cm from the barrier the fraction becomes roughly 0.28, accounting only for inverse square decrease in intensity with distance. The incident intensity at the barrier compared with that in the center is 0.25. Assuming either an equilibrium of the reflected radiation due to a surrounding circular source or simply a unidirectional source, the reflected radiation at the center would be about 0.07 of the primary beam. The Compton backscattered photons would be approximately 180 keV. The fluorescence from photoelectric effect would mostly have an energy of 88 keV. The ratio of the mass attenuation coefficients in lead for the two processes would lead to an estimate that about 40% of the backscatter interactions would be photoelectric. With respect to RBE, the 88 keV would have a value about 2, and by interpolation, the 180 keV about 1.8. [Wuu 1996] A simple partition of the beam into components and summing the effects, not necessarily how the biological organisms may react, would predict about a 6% increase in the overall RBE of the radiation field due to the shielding.

A similar analysis for 300 kV x rays gives an albedo at the center of the chamber of 0.19 and thus a resultant fraction of the primary beam of 0.05. In this case, 75% of the interactions in the wall would be photoelectric, giving rise to 88 keV photons. The other 25% would be backscatter from Compton. If the effective energy of the highly filtered 320 kVp unit were about 200 keV (most likely it would be lower) the probable energy of the backscatter would be about 110 keV. These two components would have indistinguishable RBEs. Using an RBE for the primary of 1.25 (from the analysis in the previous section), the resultant RBE for the enclosed source would be 1.3

Combining the two parts of this analysis would suggest that comparing the ^{137}Cs and the highly filtered x-ray units in self-contained, shielded cabinets would give a net RBE for the x-ray source of 1.23, which falls within the uncertainty of the original estimate.

References

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