Bremsstrahlung Radiation Dose in Yttrium-90 Therapy Applications

Michael G. Stabin, Keith F. Eckerman, Jeffrey C. Ryman and Lawrence E. Williams

Radiation Internal Dose Information Center, Medical Sciences Division, Oak Ridge Institute for Science and Education, Metabolism and Dosimetry Group, Health and Safety Research Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee; and Division of Radiology, City of Hope National Medical Center, Duarte, California

The bremsstrahlung component of the decay scheme of beta emitters has been traditionally ignored in internal dosimetry calculations. **Methods:** We have estimated the radiation dose from the bremsstrahlung component of the decay scheme of ^{90}Y as a function of distance from a point source in a liquid medium and to body organs from distributed sources of ^{90}Y in the liver and spleen. **Results:** These estimates agree with measurements of bremsstrahlung dose measured in a Rando phantom, and give an estimate of the importance of this contribution to the overall dosimetry. **Conclusions:** The bremsstrahlung radiation absorbed dose contribution from an organ to itself is very small compared to that from the beta dose, but the contribution to other organs is not always negligible, especially when large amounts of ^{90}Y may be involved, as in therapy applications.

Key Words: internal dosimetry; bremsstrahlung radiation; therapy

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The bremsstrahlung component of the decay scheme of beta emitters has been traditionally ignored in internal dosimetry calculations. This may have been due to a lack of available methods for including this component in the calculations, or to the belief that the contribution of this component is negligible compared to that of other emissions. The phenomenon of bremsstrahlung production is most important at high energies and high medium atomic numbers (*1*). With the use of ^{90}Y in therapy for certain types of cancers, especially through use of monoclonal antibodies (Mabs), evaluation of the bremsstrahlung contribution to dosimetry calculations should be examined. In a paper given at the Annual Meeting of the Society of Nuclear Medicine in 1987 (*2*), Williams et al. reported measured dose rates at different distances from a small source of ^{90}Y placed in a Rando phantom. Results of this work were published later in a slightly different form (*3*). Their results showed that this dosimetry component may not be negligible, especially considering the amounts of activity which may be used in Mab therapy. Simpkin et al. (*4*) studied the spatial distribution of energy deposition from bremsstrahlung radiation near point sources in a water medium. In this paper, we will further investigate the importance of this effect through evaluation of the results of Williams et al. against calculations using bremsstrahlung spectra and photon point kernels. We will also extend the results of these calculations to calculate the bremsstrahlung radiation dose from organs in the heterogeneous phantom most often used in internal dosimetry calculations (*5*).

METHODS

We sought to confirm by calculation the results of Williams et al. (*2*) for a point source and then to extend the results to estimate the bremsstrahlung component from some standard organs. We used the following expression (*5*) for the specific absorbed fraction of energy at a distance x from a point source monoenergetic photon emitter:

$$\Phi(x) = \frac{\mu_{en}\, e^{-\mu x}\, B_{en}(\mu x)}{4\pi x^2 \rho}, \qquad \text{Eq. 1}$$

where $\Phi(x)$ is the specific absorbed fraction of energy at distance x (g^{-1}); x is the distance from the point source (cm); μ_{en} is the linear absorption coefficient for photons of the given energy (cm^{-1}); μ is the linear attenuation coefficient for photons of the given energy (cm^{-1}); $B_{en}(\mu x)$ is the energy absorption buildup factor at the number of relaxation lengths μx; and ρ is the medium density ($g\ cm^{-3}$).

We used the buildup factors of Spencer and Simmons (*6*), the μ and μ_{en} values for (ICRU 33) soft tissue of Hubbell (*7*) and the bremsstrahlung photon spectrum for ^{90}Y given by the EDISTR computer code (*8*). The specific absorbed fraction for a source of ^{90}Y was estimated by integrating over the entire bremsstrahlung spectrum:

$$\Phi(x) = \int_0^{E_{max}} \Phi_E(x)\, dE \approx \sum_0^{E_{max}} \Phi_E(x)\, \Delta E, \qquad \text{Eq. 2}$$

E_{max} for ^{90}Y is 2.27 MeV.

Estimation of the value of Φ allows calculation of the absorbed dose at fixed distances from the point source in the infinite, homogeneous tissue medium (*9*):

$$D(x) = \tau \sum_i \Delta_i \Phi_i(x), \qquad \text{Eq. 3}$$

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For correspondence or reprint requests contact: Michael Stabin, Radiation Internal Dose Information Center, Medical Sciences Division, Oak Ridge Institute for Science and Education, P.O. Box 117, Oak Ridge, TN 37831-0117.

where D(x) is the absorbed dose at distance x per unit initial activity (Gy/MBq); τ is the residence time of activity in the source region (hr); and Δ is the mean energy emitted per unit cumulated activity (Gy g MBq^{-1} hr^{-1}).

The quantity Δ is numerically equal to (2.13 n_i E_i), where n_i is the frequency of occurrence of emissions with energy E_i (*9*); the quantities n and E are provided by the EDISTR code (*8*).

We estimated D(x) between x = 1 and x = 50 cm, through complete decay of a ^{90}Y source (as was the case for the measured data). After obtaining the absorbed dose at a number of chosen distances from the source, we plotted the calculated estimates of absorbed dose per unit initial activity as a function of distance from the point source and fitted a multiple-exponential curve through the points.

We then developed S-values (*10*) for ^{90}Y bremsstrahlung emissions for activity uniformly distributed throughout the liver and spleen of the standard reference male phantom (*5*) by folding the EDISTR bremsstrahlung energy spectrum over the specific absorbed fractions (*5*) as a function of energy for these source regions. The liver and spleen were chosen because they are located near a number of organs in the phantom and often accumulate significant quantities of activity in therapy applications. Use of any other source organs in the phantom is straightforward. S-values for these two source organs were calculated for most available target regions.

RESULTS

The EDISTR bremsstrahlung spectra employed are shown in Figure 1. Our calculated values for the dose per unit activity as a function of distance from the point source are given in Table 1. The empirically observed function describing dose as a function of distance from the point source is given by the expression:

$$D(x) = 1.08 \times 10^{-2} \cdot e^{-1.85x} + 3.8 \times 10^{-4} \cdot e^{-0.423x} + 1.78 \times 10^{-5} \cdot e^{-0.125x} \qquad \text{Eq. 4}$$

where D(x) is the absorbed dose at distance x per unit initial activity (Gy/MBq) and x is the distance from the source (cm), between 1 and 50 cm.

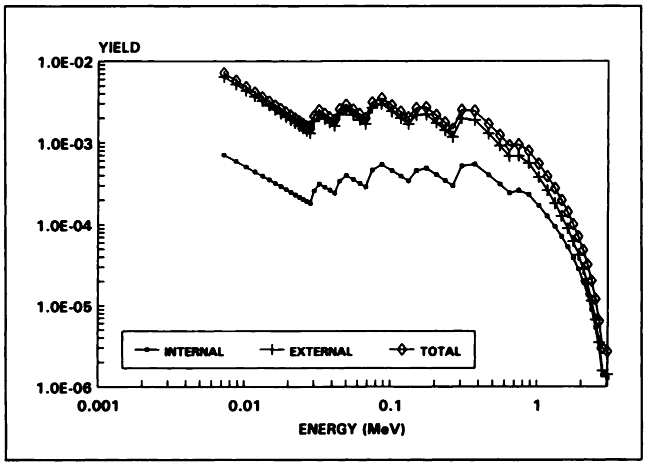

FIGURE 1. Spectrum given by the EDISTR code for internal, external (soft tissue medium), and total bremsstrahlung.

TABLE 1
Comparison of Calculations and Measurements of Bremsstrahlung Absorbed Doses Near a Point Source of Yttrium-90

Distance (cm)	Dose (Gy/MBq) Williams et al. (*2*)	This work
3.0	1.62×10^{-4}	1.61×10^{-4}
3.9	1.07×10^{-4}	9.05×10^{-5}
5.9	4.08×10^{-5}	4.00×10^{-5}
8.2	1.84×10^{-5}	1.84×10^{-5}
18	2.05×10^{-6}	2.05×10^{-6}
24	9.46×10^{-7}	9.46×10^{-7}
31	1.62×10^{-7}	3.51×10^{-7}

This function is shown in Figure 2, along with our calculated values and the measured data of Williams et al. S-values for a source uniformly distributed throughout the liver and spleen of the standard adult phantom (*5*) are shown in Tables 2 and 3. A comparison of beta and bremsstrahlung doses near a point source of ^{90}Y is given in Figure 3. The beta dose function is taken from the findings of Cross et al. (*11*).

DISCUSSION

The calculated absorbed dose values are in excellent agreement with the measured values of Williams et al. (*2*), except at the largest distance (31 cm). The function for absorbed dose as a function of distance from a point source of ^{90}Y (Fig. 2) fit the measured data very well. D(x) from x = 1 to x = 50 cm is shown over this range. We find that the dose to soft tissue at about 3 cm from a 520-MBq (14 mCi) source of ^{90}Y (through complete decay) would be about 80 mGy (8 rad), in agreement with the estimate of 60 mGy (6 rad) given by Williams et al. (*2*).

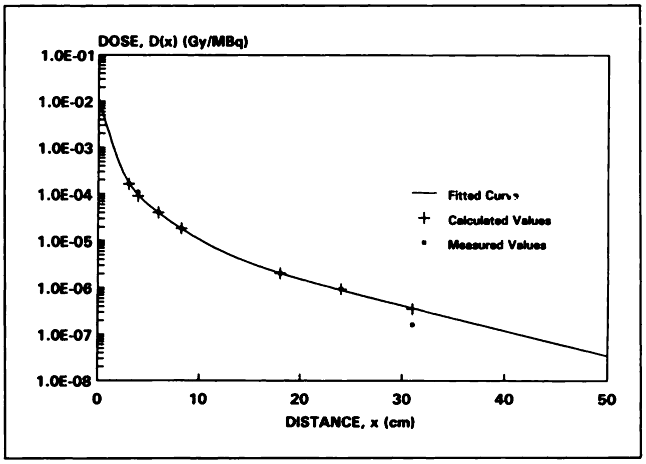

FIGURE 2. Absorbed dose in a water medium due to bremsstrahlung radiation near a point source of ^{90}Y, through complete decay: multiexponential fit of calculated values and comparison with calculated values (this work) and measured values of Williams et al. (*2*).

TABLE 2
S-Values for Bremsstrahlung Dose to Various Target Organs from a Uniform Source of Yttrium-90 in the Liver

Target organ	S-value (mGy/MBq-hr)
Adrenals	1.01×10^{-4}
Brain	3.70×10^{-7}
Breasts	1.64×10^{-5}
Gallbladder wall	2.07×10^{-4}
Lower large intestine wall	3.65×10^{-6}
Small intestine	2.55×10^{-5}
Stomach wall	3.27×10^{-5}
Upper large intestine wall	4.16×10^{-5}
Heart wall	5.24×10^{-5}
Kidneys	6.65×10^{-5}
Liver	6.30×10^{-4}
Lungs	4.81×10^{-5}
Muscle	1.81×10^{-5}
Ovaries	8.60×10^{-6}
Pancreas	8.38×10^{-5}
Red marrow	1.95×10^{-5}
Bone surfaces	2.38×10^{-5}
Skin	9.14×10^{-6}
Spleen	1.59×10^{-5}
Testes	6.97×10^{-7}
Thymus	1.34×10^{-5}
Thyroid	2.37×10^{-6}
Urinary bladder wall	3.41×10^{-6}
Uterus	7.41×10^{-6}

TABLE 3
S-Values for Bremsstrahlung Dose to Various Target Organs from a Uniform Source of Yttrium-90 in the Spleen

Target organ	S-value (mGy/MBq-hr)
Adrenals	1.04×10^{-4}
Brain	3.70×10^{-7}
Breasts	1.09×10^{-5}
Gallbladder wall	2.69×10^{-5}
Lower large intestine wall	1.00×10^{-5}
Small intestine	2.20×10^{-5}
Stomach wall	1.74×10^{-4}
Upper large intestine wall	2.19×10^{-5}
Heart wall	3.57×10^{-5}
Kidneys	1.61×10^{-4}
Liver	7.27×10^{-5}
Lungs	3.86×10^{-5}
Muscle	2.56×10^{-5}
Ovaries	7.68×10^{-6}
Pancreas	3.24×10^{-4}
Red marrow	2.01×10^{-5}
Bone surfaces	2.46×10^{-5}
Skin	9.22×10^{-6}
Spleen	3.89×10^{-3}
Testes	8.62×10^{-7}
Thymus	7.73×10^{-6}
Thyroid	2.16×10^{-6}
Urinary bladder wall	2.67×10^{-6}
Uterus	6.49×10^{-6}

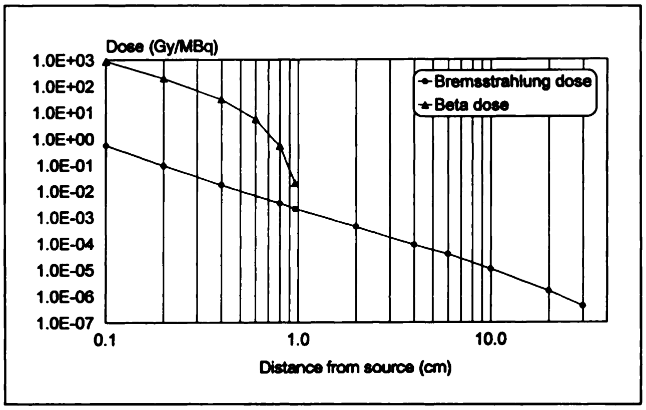

FIGURE 3. Bremsstrahlung and beta dose per unit activity of a ^{90}Y point source in a water medium, through complete decay. Bremsstrahlung doses calculated (this work); beta doses from (*11*).

The S-values for target organs from ^{90}Y activity in the liver and spleen of the adult (Tables 2 and 3) show that the bremsstrahlung contribution to the source organ is small compared to that from the beta particles themselves (S(liver ← liver) = 0.3 mGy/MBq-hr, S(spleen ← spleen) = 3.0 mGy/MBq-hr) (*10*). The contribution to other organs, however, may be considerable if large amounts of activity are in these regions. This contribution may still be small if these target regions receive a beta dose from activity they contain in their cells or blood content. Much depends on the radionuclide kinetics in a given situation; however, all contributions to total dose should be considered in therapy applications.

As shown in Figure 3, the beta point source function is greater than that of the bremsstrahlung function by more than three orders of magnitude at 0.1 cm in soft tissue (values below 1 cm in this plot were obtained directly by calculation, not by solution of Equation 4; this equation is only valid from x = 1–50 cm). This ratio decreases to near unity, however, as one approaches 1.0 cm. Near and beyond the cut-off of the beta absorbed dose component (near 1.1 cm in soft tissue), the bremsstrahlung dose component predominates, showing its importance to tissues in this distance interval. Clinically, this may have significance in the normal tissues adjacent to tumor surfaces. Examples include lung, liver and normal marrow parenchyma surrounding primary and metastatic lesion sites.

An example drawn from the literature involves hepatic artery infusion of ^{90}Y glass microspheres (*12*). If the microsphere density achieved in this study were reproduced in a human liver, the cumulated activity is estimated to be 9.74×10^4 MBq-hr. This would result in a bremsstrahlung dose to the gallbladder of approximately 20 mGy (2.0 rad), to the adrenals of 9.8 mGy (0.98 rad), to the pancreas of 8.2 mGy (0.82 rad), and to the kidneys of 6.5 mGy (0.65 rad), assuming no other significant sources of exposure.

CONCLUSIONS

Calculated values of absorbed dose due to bremsstrahlung radiation from a source of ^{90}Y have been shown to be in agreement with the measured absorbed doses of Williams et al. (*2*). The calculations employed the energy buildup factor method and the known bremsstrahlung photon spectrum for ^{90}Y. S-values for bremsstrahlung dose from activity in two organs of a heterogeneous phantom were also calculated by folding the bremsstrahlung photon spectrum over existing specific absorbed fractions for those organs as sources. The results showed that bremsstrahlung doses may not always be negligible in radionuclide therapy applications. These results can be easily extended to other radionuclides or geometries.

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