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Letter to the Editor

Bremsstrahlung exposure of tissues from beta-therapeutic nuclides

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ABSTRACT

The Bremsstrahlung exposure rate from beta point source, probability of energy loss by beta during the Bremsstrahlung emission and the Bremsstrahlung activity of tissues have been calculated. The Bremsstrahlung yield for tissues in the wide energy range is also estimated from 0.01 to 100 MeV using the tabulated values given for elements by Lucien pages. The estimated Bremsstrahlung activities of pure beta nuclides in all types of tissues are extremely large (10^2–10^6 GBq). The patients receiving such nuclides would never receive that much activity because of prohibitive radiation toxicity (few 100 MBq). Thus the patients receiving these pure beta emitting nuclides do not have to be hospitalized for radiation precautions.

1. Introduction

In the therapeutic nuclear medicine, application of incorporated beta-emitting radionuclides finds extremely high potential in the treatment of both malignant and non-malignant conditions. In malignant conditions tumor-specific metabolic and biological characteristics are effectively deployed to optimize the targeting of nuclides and hence permit successful therapy. In order to maximize, self-irradiation of the target region and to minimize irradiation of non-target regions, therapeutic radionuclide should emit non-penetrating radiations such as β-particles. Increasingly, pure beta emitters (Table 1) are being considered and used as therapeutic radionuclides [1,2]. The beta-emitting nuclides are also used for therapy of non-malignant conditions such as radiosynovictomy. This includes the treatment of painful conditions associated with disease of joints such as rheumatoid arthritis or villonodular synovitis [3,4]. After careful evaluation and diagnosis, a small amount of radioisotope is injected into the joint. These radioisotopes emit beta rays which penetrate only from fraction of a millimeter to a few millimeters and destroy the inflammatory tissue and thus reduce swelling and pain. Beta-emitting nuclides such as ^{90}Y, ^{32}P, ^{165}Dy etc. offer clinically proven and cost effective alternative to surgical synovictomy [5,6].

Uchiyama et al. [7] reported that Strontium-89 chloride is being widely used as a palliative treatment for patients with bone pain caused by bone metastases. The radionuclides such as ^{89}Sr and ^{32}P have also been successfully and effectively utilized to provide palliative therapy to patients with multifocal skeletal metastatic lesions in cases of breast and prostatic cancers. Furthermore ^{90}Y appears to be a potential beta-emitting radionuclide, which has been shown to offer attractive considerations for being used in radioimmunotherapy [8]. In radioimmunotherapy, beta nuclide delivers lethal dose of radiation directly to cancerous tumor cells there by reducing the radiation exposure to surrounding tissues. Beta emitting radionuclide like ^{32}P also finds application in infusional brachytherapy [9].

The incorporated therapeutic beta emitting nuclides produces Bremsstrahlung radiation and could have different energies and intensities. The Bremsstrahlung yield is a function of two components namely internal Bremsstrahlung and external Bremsstrahlung. The intensity of external Bremsstrahlung (EB) largely depends on the energy of the emitted beta particles and atomic number of the surrounding matrix material. On the other hand, internal Bremsstrahlung component inherently depends on the interaction of the emitted beta particle with the nucleus of the source radionuclide itself. It can therefore be stated that the photon characteristics of external Bremsstrahlung depend on the surrounding matrix material (tissue), whereas, those of internal Bremsstrahlung would depend on the emission characteristics of radionuclide.

The Bremsstrahlung component of beta emitters has been traditionally ignored in internal dosimetry calculations. This may be 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 [10].

The radiation therapy needs experimental studies on the exposure of the Bremsstrahlung in tissues. But these experiments are very difficult to undertake and analyze, since

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many biochemical processes are taking place at the same time, competing with radiation effects. The resulting hazard of the Bremsstrahlung radiation released during beta therapy, may therefore be some of concern, at least theoretically, and should be systematically evaluated. In the present investigation, it has been estimated that the Bremsstrahlung exposure rate from beta point source, probability of energy loss by beta during the Bremsstrahlung emission, the Bremsstrahlung activity above which patient require medical confinement and Bremsstrahlung yield in tissues (Blood, Adipose, Brain, Breast, Cell nucleus, Eye lens, GI Track, Heart, Kidney, Liver, Lung deflated, Lymph, Muscle, Ovary, Pancreas, Cartilage, Red marrow, Spongiosa, Yellow marrow, Skin, Spleen, Testis, Thyroid, Skeleton-cortical bone, Skeleton cranium, Skeleton femur, Skeleton humerous, Skeleton mandible, Skeleton ribs, Skeleton sacrum, Skeleton-vertebral column (c4), Skeleton-vertebral column (D6, L3), Skeleton spongiosa) for most commonly used beta-therapeutic nuclides.

2. Present work

2.1. Probability of energy loss by beta during bremsstrahlung emission (P_{Br})

Markowicz et al. [11] proposed a new expression for the prediction of the Bremsstrahlung intensity (I) for compounds to take into account the self absorption and electron back scattering.

$$I = con\left(\frac{\Delta E}{E_\gamma}\right) Z_{\text{mod}}(E_0 - E_\gamma)\left[1 - f\right] \quad (1)$$

Here,

$$Z_{\text{mod}} = \frac{\sum_i^l \frac{W_i Z_i^2}{A_i}}{\sum_i^l \frac{W_i Z_i}{A_i}} \quad (2)$$

Table 1
Physical properties of β-ray emitters for radionuclide therapy.

Source	Half life (in days)	E_{max} (MeV)	E_{Br} (MeV)	Frequency of emission $(f_\beta)_i$/transformation
^{90}Y	2.67	2.280	0.251	1
^{143}Pm	13.60	0.930	0.102	1
^{169}Er	9.40	0.350	0.039	1
^{204}Tl	1387.00	0.770	0.085	1
^{210}Bi	5.01	1.160	0.128	1
^{89}Sr	50.50	1.490	0.164	1
^{45}Ca	163.00	0.257	0.028	1

Table 2
Composition of tissues.

	H	**C**	**N**	**O**	**Ca**	**P**	**Na**	**Mg**	**S**	**Cl**	**K**	**Fe**	**I**
Adipose tissue	0.110	0.598	0.007	0.278			0.001		0.001	0.001			
Blood	0.100	0.110	0.033	0.745			0.001		0.002	0.003	0.002	0.001	
Brain	0.110	0.145	0.022	0.712			0.002		0.002	0.003	0.003		
Breast	0.110	0.330	0.03	0.527			0.001		0.002	0.001			
Cell nucleus	0.110	0.090	0.032	0.742					0.004				
Eye lens	0.100	0.195	0.057	0.646			0.001		0.003	0.001			
GI track	0.110	0.110	0.022	0.751			0.001		0.001	0.002	0.001		
Heart	0.100	0.121	0.032	0.734			0.001		0.002	0.003	0.002	0.001	
Kidney	0.100	0.132	0.03	0.724	0.001	0.001	0.002		0.002	0.002	0.002		
Liver	0.100	0.139	0.03	0.716			0.002		0.003	0.002	0.003		
Hung (deflated)	0.100	0.105	0.031	0.749			0.002		0.003	0.003	0.002		
Lymph	0.110	0.040	0.011	0.832			0.003		0.001	0.004			
Muscle	0.100	0.143	0.034	0.71			0.001		0.003	0.001	0.004		
Ovary	0.110	0.900	0.024	0.768			0.002		0.002	0.002	0.002		
Pancreas	0.110	0.169	0.022	0.694			0.002		0.001	0.002	0.002		
Cartilage	0.100	0.099	0.022	0.744			0.005		0.009	0.003			
Redmarrow	0.110	0.419	0.034	0.439					0.002	0.002	0.002	0.001	
Spongiosa	0.090	0.401	0.028	0.367	0.074	0.074	0.001	0.001	0.002	0.002	0.001	0.001	
Yellowmarrow	0.120	0.640	0.007	0.231			0.001		0.001	0.001			
Skin	0.100	0.204	0.042	0.645			0.002		0.002	0.003	0.001		
Spleen	0.100	0.113	0.032	0.741			0.001		0.002	0.002	0.003		
Testis	0.110	0.990	0.002	0.766			0.002		0.002	0.002	0.002		
Thyroid	0.100	0.119	0.024	0.745			0.002		0.001	0.002	0.001		0.001
Skeleton-cortical bone	0.030	0.155	0.042	0.435	0.225	0.225	0.001	0.002	0.003				
Skeleton-cranium	0.050	0.212	0.002	0.435	0.176	0.176	0.001	0.002	0.003				
Skeleton-femur	0.070	0.345	0.028	0.368	0.126	0.126	0.001	0.001	0.002	0.001			
Skeleton-humerus	0.060	0.314	0.031	0.369	0.152	0.152	0.001	0.001	0.002				
Skeleton-mandible	0.050	0.190	0.041	0.435	0.187	0.187	0.001	0.002	0.003				
Skeleton-ribs (2nd, 6th)	0.060	0.263	0.039	0.436	0.131	0.131	0.001	0.001	0.003	0.001	0.001		
Skeleton-ribs (10th)	0.060	0.235	0.04	0.434	0.156	0.156	0.001	0.001	0.003	0.001	0.001		
Skeleton-sacrum	0.070	0.302	0.037	0.438	0.098	0.098		0.001	0.002	0.001	0.001	0.001	
Skeleton-spongiosa	0.090	0.404	0.028	0.367	0.074	0.074	0.001	0.001	0.002	0.002	0.001	0.001	
Skeleton-vertibral column (c4)	0.060	0.460	0.039	0.436	0.133	0.133	0.001	0.001	0.003	0.001	0.001	0.001	
Skeleton-vertibral column (D6, L3)	0.070	0.280	0.038	0.437	0.111	0.111		0.001	0.002	0.001	0.001	0.001	

Table 3
Modified atomic number of tissues.

Tissue	Z_{mod}
Adipose tissue	5.5048
Blood	6.5477
Brain	6.4301
Breast	6.0538
Cell nucleus	6.4593
Eye lens	6.3967
GI track	6.4657
Heart	6.5173
Kidney	6.4957
Liver	6.4912
Hung (deflated)	6.5405
Lymph	6.5978
Muscle	6.4808
Ovary	6.3065
Pancreas	6.3763
Cartilage	6.6479
Red marrow	5.9518
Spongiosa	7.4976
Yellow marrow	5.4098
Skin	6.3691
Spleen	6.5155
Testis	6.2778
Thyroid	6.5121
Skeleton-cortical bone	10.9907
Skeleton-cranium	10.0124
Skeleton- femour	8.6182
Skeleton-humerus	9.2136
Skeleton-mandible	10.1944
Skeleton-ribs (2nd, 6th)	8.9290
Skeleton-ribs (10th)	9.4867
Skeleton-sacrum	8.1959
Skeleton-spongiosa	7.4936
Skeleton-vertibral column (c4)	8.5447
Skeleton-vertibral column (D6, L3)	8.5035

E_γ and E_0 are emitted photon energy and incident electron energy, respectively. A_i, W_i and Z_i are mass number, weight fraction and atomic number of the ith element in a target material (Tissue). f is a function of E_0, E_γ and composition (For pure elements $f=0$). l denotes the number of elements in the compound. *Con* in the Eq. (1) refers constant.

The atomic number Z_{mod} defined for compound is more accurate than $Z_{mean}(=\sum W_i Z_i)$. The new Markowicz formula derived in a more rigorous way gives theoretical results of compounds/mixtures for the Bremsstrahlung process which are in better agreement with experiments. Shivaramu [12] evaluated the effective atomic number (Z_{eff}) of compounds for the Bremsstrahlung process using the interpolation method and reported that Z_{eff} agrees fairly well with Z_{mod} than Z_{mean}.

The incorporated therapeutic beta-emitting nuclides interacts with surrounding matrix material (tissue) and produces the Bremsstrahlung radiation. The beta nuclides lose their energy during this interaction. The probability of radiative energy loss (radiative energy loss) by beta particle i during the Bremsstrahlung emission $[(P_{Br})_\beta]_i$ depends on modified atomic number (Z_{mod}) of target material (tissue) and maximum initial kinetic energy of beta particle $\boldsymbol{i}$ that is $[(E_{max})_\beta]_i$

$$[(P_{Br})_\beta]_i = \frac{Z_{mod}[(E_{max})_\beta]_i}{3000} \quad (3)$$

The modified atomic number (Z_{mod}) for different tissues is calculated using the composition given in the Table 2 and Eq. (2). It has been estimated $[(P_{Br})_\beta]_i$ using the Eq. (3) and the evaluated values of Z_{mod}.

2.2. Specific bremsstrahlung constant (Γ_{Br})

The specific Bremsstrahlung constant is a quantity analogous to specific gamma ray constant for a radioisotope. The specific

Table 4
Specific Bremsstrahlung constant Γ_{Br} $\left(\text{in } \frac{C/kg-cm^2}{MBq-h}\right)$.

Tissues	^{90}Y	^{143}Pm	^{169}Er	^{204}Tl	^{210}Bi	^{89}Sr	^{45}Ca
Blood	1.61×10^{-03}	1.46×10^{-04}	2.31×10^{-05}	4.21×10^{-07}	4.04×10^{-05}	1.14×10^{-07}	1.21×10^{-12}
Adipose	1.37×10^{-03}	1.25×10^{-04}	1.96×10^{-05}	3.58×10^{-07}	3.44×10^{-05}	0.97×10^{-07}	1.03×10^{-12}
Brain	1.61×10^{-03}	1.47×10^{-04}	2.31×10^{-05}	4.22×10^{-07}	4.05×10^{-05}	1.14×10^{-07}	1.21×10^{-12}
Breast	1.98×10^{-03}	1.80×10^{-04}	2.84×10^{-05}	5.18×10^{-07}	4.97×10^{-05}	1.41×10^{-07}	1.49×10^{-12}
Cell nucleus	1.66×10^{-03}	1.51×10^{-04}	2.38×10^{-05}	4.35×10^{-07}	4.17×10^{-05}	1.18×10^{-07}	1.25×10^{-12}
Eye lens	1.60×10^{-03}	1.46×10^{-04}	2.39×10^{-05}	4.18×10^{-07}	4.02×10^{-05}	1.39×10^{-07}	1.20×10^{-12}
GI Track	1.61×10^{-03}	1.47×10^{-04}	2.32×10^{-05}	4.23×10^{-07}	4.06×10^{-05}	1.15×10^{-07}	1.21×10^{-12}
Heart	1.62×10^{-03}	1.48×10^{-04}	2.33×10^{-05}	4.25×10^{-07}	4.08×10^{-05}	1.15×10^{-07}	1.22×10^{-12}
Kidney	1.62×10^{-03}	$1. 48 \times 10^{-04}$	2.33×10^{-05}	4.25×10^{-07}	4.08×10^{-05}	1.15×10^{-07}	1.22×10^{-12}
Liver	1.62×10^{-03}	$1. 48 \times 10^{-04}$	2.33×10^{-05}	4.26×10^{-07}	4.09×10^{-05}	1.16×10^{-07}	1.22×10^{-12}
Lung deflated	1.62×10^{-03}	$1. 48 \times 10^{-04}$	2.34×10^{-05}	4.26×10^{-07}	4.09×10^{-05}	1.16×10^{-07}	1.22×10^{-12}
Lymph	1.64×10^{-03}	$1. 50 \times 10^{-04}$	2.36×10^{-05}	4.31×10^{-07}	4.14×10^{-05}	1.17×10^{-07}	1.24×10^{-12}
Muscle	1.62×10^{-03}	$1. 48 \times 10^{-04}$	2.33×10^{-05}	4.24×10^{-07}	4.07×10^{-05}	1.15×10^{-07}	1.22×10^{-12}
Ovary	1.63×10^{-03}	$1. 49 \times 10^{-04}$	2.34×10^{-05}	4.28×10^{-07}	4.11×10^{-05}	1.16×10^{-07}	1.23×10^{-12}
Pancreas	1.59×10^{-03}	1.45×10^{-04}	2.29×10^{-05}	4.18×10^{-07}	4.01×10^{-05}	1.13×10^{-07}	1.20×10^{-12}
Cartilage	1.70×10^{-03}	1.55×10^{-04}	2.44×10^{-05}	4.45×10^{-07}	4.27×10^{-05}	1.21×10^{-07}	1.28×10^{-12}
Red marrow	1.48×10^{-03}	1.58×10^{-04}	2.13×10^{-05}	3.88×10^{-07}	3.73×10^{-05}	1.05×10^{-07}	1.11×10^{-12}
Spongiosa	1.79×10^{-03}	1.64×10^{-04}	2.58×10^{-05}	4.70×10^{-07}	4.52×10^{-05}	1.28×10^{-07}	1.35×10^{-12}
Yellow marrow	1.35×10^{-03}	1.23×10^{-04}	1.94×10^{-05}	3.53×10^{-07}	4.02×10^{-05}	0.96×10^{-07}	1.01×10^{-12}
Skin	1.59×10^{-03}	1.45×10^{-04}	2.28×10^{-05}	4.17×10^{-07}	4.00×10^{-05}	1.13×10^{-07}	1.19×10^{-12}
Spleen	1.63×10^{-03}	1.63×10^{-04}	2.34×10^{-05}	4.27×10^{-07}	4.10×10^{-05}	1.16×10^{-07}	1.22×10^{-12}
Testis	1.62×10^{-03}	1.48×10^{-04}	2.33×10^{-05}	4.25×10^{-07}	4.09×10^{-05}	1.15×10^{-07}	1.22×10^{-12}
Thyroid	1.62×10^{-03}	1.47×10^{-04}	2.32×10^{-05}	4.24×10^{-07}	4.07×10^{-05}	1.15×10^{-07}	1.21×10^{-12}
Skeleton cortical bone	2.63×10^{-03}	2.40×10^{-04}	3.77×10^{-05}	6.88×10^{-07}	6.61×10^{-05}	1.87×10^{-07}	1.97×10^{-12}
Skeleton cranium	2.52×10^{-03}	2.30×10^{-04}	3.63×10^{-05}	6.61×10^{-07}	6.35×10^{-05}	1.79×10^{-07}	1.90×10^{-12}
Skeleton femur	2.05×10^{-03}	1.87×10^{-04}	2.95×10^{-05}	5.38×10^{-07}	5.17×10^{-05}	1.46×10^{-07}	1.54×10^{-12}
Skeleton humerous	2.19×10^{-03}	2.00×10^{-04}	3.15×10^{-05}	5.74×10^{-07}	5.51×10^{-05}	1.56×10^{-07}	1.65×10^{-12}
Skeleton mandible	2.42×10^{-03}	2.21×10^{-04}	3.48×10^{-05}	6.35×10^{-07}	6.10×10^{-05}	1.72×10^{-07}	1.82×10^{-12}
Skeleton ribs	2.13×10^{-03}	1.94×10^{-04}	3.05×10^{-05}	5.57×10^{-07}	5.35×10^{-05}	1.51×10^{-07}	1.60×10^{-12}
Skeleton sacrum	1.96×10^{-03}	1.79×10^{-04}	2.81×10^{-05}	5.13×10^{-07}	4.93×10^{-05}	1.39×10^{-07}	1.47×10^{-12}
Skeleton spongiosa	1.80×10^{-03}	1.64×10^{-04}	2.58×10^{-05}	4.71×10^{-07}	4.52×10^{-05}	1.28×10^{-07}	1.35×10^{-12}
Skeleton vertebral column (c4)	2.14×10^{-03}	1.95×10^{-04}	3.08×10^{-05}	5.61×10^{-07}	5.38×10^{-05}	1.52×10^{-07}	1.61×10^{-12}
Skeleton vertebral column (D6, L3)	2.02×10^{-03}	1.85×10^{-04}	2.91×10^{-05}	5.30×10^{-07}	5.09×10^{-05}	1.44×10^{-07}	1.52×10^{-12}

Table 5
Probability of radiative energy loss of β-ray [$(P_{Br})_{\beta}$] (keV).

	^{90}Y	^{143}Pm	^{169}Er	^{204}Tl	^{210}Bi	^{89}Sr	^{45}Ca
Adipose tissue	4.184	1.706	0.642	1.413	2.129	2.734	0.472
Blood	4.976	2.030	0.764	1.681	2.532	3.252	0.561
Brain	4.887	1.993	0.750	1.650	2.486	3.194	0.551
Breast	4.601	1.877	0.706	1.554	2.341	3.007	0.519
Cell nucleus	4.909	2.002	0.754	1.658	2.498	3.208	0.553
Eye lens	4.861	1.983	0.746	1.642	2.473	3.177	0.548
GI track	4.914	2.004	0.754	1.660	2.500	3.211	0.554
Heart	4.953	2.020	0.760	1.673	2.520	3.237	0.558
Kidney	4.937	2.014	0.758	1.667	2.512	3.226	0.556
Liver	4.933	2.012	0.757	1.666	2.510	3.224	0.556
Hung (deflated)	4.971	2.028	0.763	1.679	2.529	3.248	0.560
Lymph	5.014	2.045	0.770	1.693	2.551	3.277	0.565
Muscle	4.925	2.009	0.756	1.663	2.506	3.219	0.555
Ovary	4.793	1.955	0.736	1.619	2.439	3.132	0.540
Pancreas	4.846	1.977	0.744	1.637	2.466	3.167	0.546
Cartilage	5.052	2.061	0.776	1.706	2.571	3.302	0.570
Red marrow	4.523	1.845	0.694	1.528	2.301	2.956	0.510
Spongiosa	5.698	2.324	0.875	1.924	2.899	3.724	0.642
Yellow marrow	4.111	1.677	0.631	1.389	2.092	2.687	0.463
Skin	4.841	1.974	0.743	1.635	2.463	3.163	0.546
Spleen	4.952	2.020	0.760	1.672	2.519	3.236	0.558
Testis	4.771	1.946	0.732	1.611	2.427	3.118	0.538
Thyroid	4.949	2.019	0.760	1.671	2.518	3.234	0.558
Skeleton-cortical bone	8.353	3.407	1.282	2.821	4.250	5.459	0.942
Skeleton-cranium	7.609	3.104	1.168	2.570	3.871	4.973	0.858
Skeleton-femur	6.550	2.672	1.005	2.212	3.332	4.280	0.738
Skeleton-humerus	7.002	2.856	1.075	2.365	3.563	4.576	0.789
Skeleton-mandible	7.748	3.160	1.189	2.617	3.942	5.063	0.873
Skeleton-ribs (2nd, 6th)	6.786	2.768	1.042	2.292	3.453	4.435	0.765
Skeleton-ribs (10th)	7.210	2.941	1.107	2.435	3.668	4.712	0.813
Skeleton-sacrum	6.229	2.541	0.956	2.104	3.169	4.071	0.702
Skeleton-spongiosa	5.695	2.323	0.874	1.923	2.898	3.722	0.642
Skeleton-vertibral column (c4)	6.494	2.649	0.997	2.193	3.304	4.244	0.732
Skeleton-vertibral column (D6,L3)	6.463	2.636	0.992	2.183	3.288	4.223	0.728

Table 6
$(A_{release})_{Br}$ in MBq.

Tissues	^{90}Y	^{143}Pm	^{169}Er	^{204}Tl	^{210}Bi	^{89}Sr	^{45}Ca
Blood	114456	248641	2450086	884292	2455306	85280	2.7733×10^{12}
Adipose	97408	211605	2085139	752574	2089582	72577	2.3091×10^{12}
Brain	114723	249220	2455788	886350	2461020	85478	2.7196×10^{12}
Breast	140811	305892	3014233	1087906	3020655	10491	3.3381×10^{12}
Cell nucleus	118168	256704	2529538	912968	2534927	88045	2.8013×10^{12}
Eye lens	113728	247059	2434499	878667	2439687	84737	2.6960×10^{12}
GI track	114923	249656	2460084	887901	2465325	85628	2.7244×10^{12}
Heart	115588	251099	2474301	893032	2479573	86123	2.7401×10^{12}
Kidney	115497	250902	2472363	892332	2477630	86055	2.7380×10^{12}
Liver	115737	251423	2477495	894185	2482773	86234	2.7436×10^{12}
Lung deflated	115760	251473	2477989	894363	2483269	86251	2.7442×10^{12}
Lymph	117159	254513	2507945	907175	2513289	87294	2.7774×10^{12}
Muscle	115376	250640	2469778	891399	2475040	85965	2.7351×10^{12}
Ovary	116248	252534	2488443	898136	2493745	86615	2.7558×10^{12}
Pancreas	113511	246589	2429861	876993	2435039	84576	2.6909×10^{12}
Cartilage	120951	262749	2589108	934468	2594624	90119	2.8673×10^{12}
Red marrow	105539	229271	2259211	815401	2264025	78636	2.5019×10^{12}
Spongiosa	127831	277695	2736379	987622	2742209	95345	3.0304×10^{12}
Yellow marrow	96088	208739	2056893	742380	2061276	71594	2.2779×10^{12}
Skin	113249	246018	2424235	874962	2429401	84380	2.6847×10^{12}
Spleen	116111	252237	2485516	897080	2490812	86513	2.7525×10^{12}
Testis	115675	251288	2476164	893705	2481440	86187	2.7422×10^{12}
Thyroid	115188	250213	2565748	889945	2471002	85825	2.7306×10^{12}
Skeleton-cortical bone	186950	406124	4001908	1444381	4010435	139294	4.4319×10^{12}
Skeleton cranium	179571	390095	3843955	1387372	3852145	133796	4.2569×10^{12}
Skeleton femur	146295	317806	3131624	1130275	3138297	109002	3.4681×10^{12}
Skeleton humerous	155874	338615	3336678	1204284	3343788	116139	3.6952×10^{12}
Skeleton-mandible	172537	374814	3693376	1333024	3701246	128555	4.0902×10^{12}
Skeleton ribs	151368	328828	3240234	1169475	3247138	112782	3.5883×10^{12}
Skeleton sacrum	139472	302984	2985569	1077561	2991931	103918	3.3063×10^{12}
Skeleton spongiosa	128003	278069	274006	988953	2745905	95373	3.0344×10^{12}
Skeleton vertebral column (c4)	152389	331046	3262092	1177364	3269043	113543	3.6126×10^{12}
Skeleton vertebral column (D6,L3)	144148	313141	3085663	1113687	3092238	107402	3.4172×10^{12}

gamma ray constant is the exposure rate per unit activity at a certain distance from a source (radioisotope). Similarly, the specific Bremsstrahlung constant is the Bremsstrahlung exposure rate (in C/Kg/h) at a distance of 1 cm from a 1 MBq beta source. An estimation of specific Bremsstrahlung constant is based on mean energy, rather than the actual Bremsstrahlung spectrum. It is given by Zanzonico et al. [13]

$$\Gamma_{Br} = \sum_{i=1}^{n} (f_\beta)_i [(P_{Br})_\beta]_i \Gamma_{Br}[(\overline{E_{Br}})_\beta]_i \tag{4}$$

where $(f_\beta)_i$ is frequency of emission (i.e., the number per nuclear transformation) of β-ray i. $[(\overline{E_{Br}})_\beta]_i$is the mean energy of Bremsstrahlung for β-ray i emitted by a radionuclide. It depends on $[(E_{\max})_\beta]_i$ and composition and geometry of the stopping material. Hence it is difficult to calculate precisely. In the Bremsstrahlung energy spectrum of a patient administrated by given beta nuclides, the maximum energy of the spectrum in vivo is essentially equal to one third of $[(E_{\max})_\beta]_i$. For such distribution, the mean energy of Bremsstrahlung for ith beta particle is one third of the maximum energy of the spectrum. Hence mean energy of Bremsstrahlung for ith beta particle is given by

$$[(\overline{E_{Br}})_\beta]_i = 0.11[(E_{\max})_\beta]_i \tag{5}$$

$\Gamma_{Br}[(\overline{E_{Br}})_\beta]_i$ is specific Bremsstrahlung constant (in C/kg-cm^2 /MBq-h) of β-ray yielding Bremsstrahlung of mean energy $[(\overline{E_{Br}})_\beta]_i$. An estimation of the specific Bremsstrahlung constant is based on the Bremsstrahlung mean energy rather the actual Bremsstrahlung spectrum, is a gross approximation. The energy-dependent $\Gamma_{Br}[(E_{Br})_\beta]_i$ corresponds to the conventional energy-dependent specific gamma ray constant [14]. A more accurate estimate would be obtained by replacing the Bremsstrahlung mean energy with the Bremsstrahlung energy spectrum.

2.3. Bremsstrahlung activity $(A_{release})_{Br}$

Bremsstrahlung activity (in MBq) is the activity of therapeutic beta nuclides below which patients can be released from medical confinement and above which patient should remain

Table 7
Bremsstrahlung yields.

Energy (MeV)	Blood	Brain	Breast	Cell nucleus	Eye lens	GI 1
0.010	1.09×10^{-04}	1.11×10^{-04}	1.18×10^{-04}	1.07×10^{-04}	1.12×10^{-04}	1.11×10^{-04}
0.015	1.58×10^{-04}	1.61×10^{-04}	1.71×10^{-04}	1.55×10^{-04}	1.62×10^{-04}	1.60×10^{-04}
0.020	2.01×10^{-04}	2.04×10^{-04}	2.18×10^{-04}	1.97×10^{-04}	2.06×10^{-04}	2.04×10^{-04}
0.025	2.40×10^{-04}	2.44×10^{-04}	2.60×10^{-04}	2.36×10^{-04}	2.46×10^{-04}	2.43×10^{-04}
0.030	2.76×10^{-04}	2.81×10^{-04}	2.99×10^{-04}	2.72×10^{-04}	2.83×10^{-04}	2.80×10^{-04}
0.035	3.11×10^{-04}	3.16×10^{-04}	3.37×10^{-04}	3.06×10^{-04}	3.19×10^{-04}	3.15×10^{-04}
0.040	3.44×10^{-04}	3.50×10^{-04}	3.73×10^{-04}	3.39×10^{-04}	3.53×10^{-04}	3.49×10^{-04}
0.045	3.77×10^{-04}	3.83×10^{-04}	4.08×10^{-04}	3.70×10^{-04}	3.86×10^{-04}	3.82×10^{-04}
0.050	4.08×10^{-04}	4.15×10^{-04}	4.42×10^{-04}	4.01×10^{-04}	4.18×10^{-04}	4.14×10^{-04}
0.055	4.39×10^{-04}	4.46×10^{-04}	4.75×10^{-04}	4.31×10^{-04}	4.50×10^{-04}	4.45×10^{-04}
0.060	4.69×10^{-04}	4.76×10^{-04}	5.07×10^{-04}	4.61×10^{-04}	4.80×10^{-04}	4.75×10^{-04}
0.065	4.98×10^{-04}	5.06×10^{-04}	5.39×10^{-04}	4.90×10^{-04}	5.11×10^{-04}	5.05×10^{-04}
0.070	5.27×10^{-04}	5.36×10^{-04}	5.71×10^{-04}	5.19×10^{-04}	5.41×10^{-04}	5.35×10^{-04}
0.075	5.56×10^{-04}	5.65×10^{-04}	6.02×10^{-04}	5.47×10^{-04}	5.70×10^{-04}	5.64×10^{-04}
0.080	5.85×10^{-04}	5.94×10^{-04}	6.33×10^{-04}	5.75×10^{-04}	6.00×10^{-04}	5.93×10^{-04}
0.085	6.13×10^{-04}	6.23×10^{-04}	6.63×10^{-04}	6.03×10^{-04}	6.29×10^{-04}	6.22×10^{-04}
0.090	6.41×10^{-04}	6.51×10^{-04}	6.94×10^{-04}	6.31×10^{-04}	6.57×10^{-04}	6.50×10^{-04}
0.095	6.69×10^{-04}	6.80×10^{-04}	7.24×10^{-04}	6.58×10^{-04}	6.86×10^{-04}	6.78×10^{-04}
0.100	6.97×10^{-04}	7.08×10^{-04}	7.54×10^{-04}	6.86×10^{-04}	7.15×10^{-04}	7.07×10^{-04}
0.150	9.66×10^{-04}	9.81×10^{-04}	1.04×10^{-03}	9.50×10^{-04}	9.90×10^{-04}	9.79×10^{-04}
0.200	1.22×10^{-03}	1.24×10^{-03}	1.32×10^{-03}	1.20×10^{-03}	1.25×10^{-03}	1.24×10^{-03}
0.250	1.48×10^{-03}	1.50×10^{-03}	1.60×10^{-03}	1.46×10^{-03}	1.52×10^{-03}	1.50×10^{-03}
0.300	1.73×10^{-03}	1.76×10^{-03}	1.87×10^{-03}	1.70×10^{-03}	1.77×10^{-03}	1.75×10^{-03}
0.350	1.98×10^{-03}	2.01×10^{-03}	2.13×10^{-03}	1.95×10^{-03}	2.03×10^{-03}	2.01×10^{-03}
0.400	2.24×10^{-03}	2.27×10^{-03}	2.42×10^{-03}	2.20×10^{-03}	2.29×10^{-03}	2.27×10^{-03}
0.450	2.47×10^{-03}	2.51×10^{-03}	2.66×10^{-03}	2.44×10^{-03}	2.53×10^{-03}	2.50×10^{-03}
0.500	2.72×10^{-03}	2.76×10^{-03}	2.92×10^{-03}	2.67×10^{-03}	2.78×10^{-03}	2.75×10^{-03}
0.550	2.95×10^{-03}	3.00×10^{-03}	3.18×10^{-03}	2.91×10^{-03}	3.02×10^{-03}	2.99×10^{-03}
0.600	3.19×10^{-03}	3.24×10^{-03}	3.43×10^{-03}	3.14×10^{-03}	3.26×10^{-03}	3.23×10^{-03}
0.650	3.42×10^{-03}	3.47×10^{-03}	3.68×10^{-03}	3.37×10^{-03}	3.50×10^{-03}	3.46×10^{-03}
0.700	3.65×10^{-03}	3.70×10^{-03}	3.92×10^{-03}	3.60×10^{-03}	3.73×10^{-03}	3.70×10^{-03}
0.750	3.88×10^{-03}	3.93×10^{-03}	4.16×10^{-03}	3.82×10^{-03}	3.96×10^{-03}	3.92×10^{-03}
0.800	4.10×10^{-03}	4.16×10^{-03}	4.39×10^{-03}	4.04×10^{-03}	4.19×10^{-03}	4.15×10^{-03}
0.850	4.32×10^{-03}	4.38×10^{-03}	4.63×10^{-03}	4.26×10^{-03}	4.41×10^{-03}	4.37×10^{-03}
0.900	4.54×10^{-03}	4.60×10^{-03}	4.86×10^{-03}	4.48×10^{-03}	4.64×10^{-03}	4.59×10^{-03}
0.950	4.76×10^{-03}	4.82×10^{-03}	5.09×10^{-03}	4.69×10^{-03}	4.86×10^{-03}	4.81×10^{-03}
1.000	4.98×10^{-03}	5.04×10^{-03}	5.32×10^{-03}	4.91×10^{-03}	5.08×10^{-03}	5.03×10^{-03}
7.000	2.84×10^{-02}	2.85×10^{-02}	2.90×10^{-02}	2.83×10^{-02}	2.86×10^{-02}	2.85×10^{-02}
9.000	3.63×10^{-02}	3.64×10^{-02}	3.68×10^{-02}	3.62×10^{-02}	3.64×10^{-02}	3.64×10^{-02}
10.000	4.02×10^{-02}	4.03×10^{-02}	4.07×10^{-02}	4.01×10^{-02}	4.04×10^{-02}	4.03×10^{-02}
20.000	7.84×10^{-02}	7.83×10^{-02}	7.81×10^{-02}	7.84×10^{-02}	7.83×10^{-02}	7.835×10^{-02}
60.000	2.07×10^{-01}	2.06×10^{-01}	2.03×10^{-01}	2.08×10^{-01}	2.06×10^{-01}	2.065×10^{-01}
70.000	2.35×10^{-01}	2.34×10^{-01}	2.30×10^{-01}	2.36×10^{-01}	2.34×10^{-01}	2.34×10^{-01}
80.000	2.60×10^{-01}	2.59×10^{-01}	2.55×10^{-01}	2.61×10^{-01}	2.59×10^{-01}	2.59×10^{-01}
90.000	2.83×10^{-01}	2.82×10^{-01}	2.77×10^{-01}	2.84×10^{-01}	2.81×10^{-01}	2.82×10^{-01}
100.000	3.04×10^{-01}	3.03×10^{-01}	2.98×10^{-01}	3.06×10^{-01}	3.02×10^{-01}	3.03×10^{-01}

hospitalized on the basis of the projected Bremsstrahlung which is given by

$$(A_{release})_{Br} = \frac{580}{\Gamma_{Br}\Gamma_e(1-\Phi_{Br})} \tag{6}$$

where Γ_e is effective half life of radio nuclide; Φ_{Br} is the average total body (TB) to TB absorption fraction for the Bremsstrahlung photons of mean energy $[(\overline{E_{Br}})_\beta]_i$ and Γ_{Br} is specific Bremsstrahlung constant (in C/kg-cm^2/MBq-h) of the radionuclide. The term $(1-\Phi_{Br})$ is the fraction of photon energy of energy E_γ and this is not absorbed in the total body (TB), and is thus used to approximate the effect of shielding by the patient. A compilation of TB/TB absorbed fraction as a function of photon energy and TB mass is presented by Zanzonico et al. [15] as adopted from Christy and Eckerman [16]. The absorbed fractions for photon energies and TB masses not tabulated may be estimated by interpolation between the appropriate table entries.

2.4. Estimation of Bremsstrahlung yield

Bremsstrahlung yield is a fraction of the initial energy of the electron/beta which has been transformed into Bremsstrahlung radiation after complete stopping of the electron. We have also evaluated the Bremsstrahlung yields (I_{Br}) of tissues for energy range from 10 keV to 100 MeV based on the Bremsstrahlung yield of five elements tabulated by Lucien Pages et al. [17], whose atomic numbers are adjacent to the modified atomic number of compound (Z_{mod}) using the following Lagrange interpolation method

$$(I_{Br})_{Z_{\text{mod}}} = \sum (I_{Br})_Z \left(\frac{\prod_{Z_{\text{mod}} \neq z} (Z_{\text{mod}}-Z)}{\prod_{z \neq Z} (z-Z)} \right) \tag{7}$$

where lower case z is the atomic number of the element of known Bremsstrahlung yield $(I_{Br})_z$ adjacent to the modified atomic number Z_{mod} of the compound whose Bremsstrahlung yield $(I_{Br})_{Z_{\text{mod}}}$ is desired and Z is atomic number of other elements of known Bremsstrahlung yield adjacent to Z_{mod}.

3. Results and discussions

The physical properties of beta emitters which are used for therapeutic purpose is shown in Table 1. The composition of

Table 8
Bremsstrahlung yields.

Energy (MeV)	Heart	Kidney	Liver	Lung	Lymph	Muscle	Ovary
0.010	1.10×10^{-04}	1.10×10^{-04}	1.10×10^{-04}	1.09×10^{-04}	1.08×10^{-04}	1.10×10^{-04}	1.14×10^{-04}
0.015	1.59×10^{-04}	1.59×10^{-04}	1.59×10^{-04}	1.58×10^{-04}	1.57×10^{-04}	1.60×10^{-04}	1.65×10^{-04}
0.020	2.02×10^{-04}	2.02×10^{-04}	2.02×10^{-04}	2.01×10^{-04}	1.99×10^{-04}	2.03×10^{-04}	2.09×10^{-04}
0.025	2.41×10^{-04}	2.42×10^{-04}	2.41×10^{-04}	2.40×10^{-04}	2.38×10^{-04}	2.42×10^{-04}	2.49×10^{-04}
0.030	2.78×10^{-04}	2.79×10^{-04}	2.78×10^{-04}	2.76×10^{-04}	2.74×10^{-04}	2.79×10^{-04}	2.88×10^{-04}
0.035	3.13×10^{-04}	3.14×10^{-04}	3.13×10^{-04}	3.11×10^{-04}	3.09×10^{-04}	3.14×10^{-04}	3.24×10^{-04}
0.040	3.46×10^{-04}	3.47×10^{-04}	3.47×10^{-04}	3.44×10^{-04}	3.42×10^{-04}	3.48×10^{-04}	3.58×10^{-04}
0.045	3.79×10^{-04}	3.80×10^{-04}	3.79×10^{-04}	3.77×10^{-04}	3.74×10^{-04}	3.80×10^{-04}	3.92×10^{-04}
0.050	4.10×10^{-04}	4.12×10^{-04}	4.11×10^{-04}	4.08×10^{-04}	4.05×10^{-04}	4.12×10^{-04}	4.24×10^{-04}
0.055	4.41×10^{-04}	4.42×10^{-04}	4.42×10^{-04}	4.39×10^{-04}	4.36×10^{-04}	4.43×10^{-04}	4.56×10^{-04}
0.060	4.71×10^{-04}	4.73×10^{-04}	4.72×10^{-04}	4.69×10^{-04}	4.65×10^{-04}	4.73×10^{-04}	4.87×10^{-04}
0.065	5.01×10^{-04}	5.03×10^{-04}	5.02×10^{-04}	4.98×10^{-04}	4.95×10^{-04}	5.03×10^{-04}	5.18×10^{-04}
0.070	5.30×10^{-04}	5.32×10^{-04}	5.31×10^{-04}	5.27×10^{-04}	5.24×10^{-04}	5.33×10^{-04}	5.49×10^{-04}
0.075	5.59×10^{-04}	5.61×10^{-04}	5.60×10^{-04}	5.56×10^{-04}	5.52×10^{-04}	5.62×10^{-04}	5.79×10^{-04}
0.080	5.88×10^{-04}	5.90×10^{-04}	5.89×10^{-04}	5.85×10^{-04}	5.81×10^{-04}	5.91×10^{-04}	6.08×10^{-04}
0.085	6.16×10^{-04}	6.18×10^{-04}	6.17×10^{-04}	6.13×10^{-04}	6.09×10^{-04}	6.19×10^{-04}	6.38×10^{-04}
0.090	6.44×10^{-04}	6.47×10^{-04}	6.46×10^{-04}	6.41×10^{-04}	6.37×10^{-04}	6.48×10^{-04}	6.67×10^{-04}
0.095	6.72×10^{-04}	6.75×10^{-04}	6.74×10^{-04}	6.69×10^{-04}	6.64×10^{-04}	6.76×10^{-04}	6.96×10^{-04}
0.100	7.00×10^{-04}	7.03×10^{-04}	7.02×10^{-04}	6.97×10^{-04}	6.92×10^{-04}	7.04×10^{-04}	7.25×10^{-04}
0.150	9.70×10^{-04}	9.74×10^{-04}	9.72×10^{-04}	9.65×10^{-04}	9.59×10^{-04}	9.75×10^{-04}	1.00×10^{-03}
0.200	1.23×10^{-03}	1.23×10^{-03}	1.23×10^{-03}	1.22×10^{-03}	1.22×10^{-03}	1.24×10^{-03}	1.27×10^{-03}
0.250	1.49×10^{-03}	1.49×10^{-03}	1.49×10^{-03}	1.48×10^{-03}	1.47×10^{-03}	1.49×10^{-03}	1.54×10^{-03}
0.300	1.74×10^{-03}	1.75×10^{-03}	1.74×10^{-03}	1.73×10^{-03}	1.72×10^{-03}	1.75×10^{-03}	1.80×10^{-03}
0.350	1.99×10^{-03}	2.00×10^{-03}	1.99×10^{-03}	1.98×10^{-03}	1.97×10^{-03}	2.00×10^{-03}	2.06×10^{-03}
0.400	2.25×10^{-03}	2.26×10^{-03}	2.25×10^{-03}	2.24×10^{-03}	2.22×10^{-03}	2.26×10^{-03}	2.33×10^{-03}
0.450	2.48×10^{-03}	2.49×10^{-03}	2.49×10^{-03}	2.47×10^{-03}	2.46×10^{-03}	2.50×10^{-03}	2.57×10^{-03}
0.500	2.73×10^{-03}	2.74×10^{-03}	2.73×10^{-03}	2.72×10^{-03}	2.70×10^{-03}	2.74×10^{-03}	2.82×10^{-03}
0.550	2.97×10^{-03}	2.98×10^{-03}	2.97×10^{-03}	2.95×10^{-03}	2.93×10^{-03}	2.98×10^{-03}	3.06×10^{-03}
0.600	3.20×10^{-03}	3.22×10^{-03}	3.21×10^{-03}	3.19×10^{-03}	3.17×10^{-03}	3.22×10^{-03}	3.31×10^{-03}
0.650	3.44×10^{-03}	3.45×10^{-03}	3.44×10^{-03}	3.42×10^{-03}	3.40×10^{-03}	3.45×10^{-03}	3.55×10^{-03}
0.700	3.67×10^{-03}	3.68×10^{-03}	3.67×10^{-03}	3.65×10^{-03}	3.63×10^{-03}	3.68×10^{-03}	3.78×10^{-03}
0.750	3.89×10^{-03}	3.91×10^{-03}	3.90×10^{-03}	3.88×10^{-03}	3.85×10^{-03}	3.91×10^{-03}	4.01×10^{-03}
0.800	4.12×10^{-03}	4.13×10^{-03}	4.12×10^{-03}	4.10×10^{-03}	4.07×10^{-03}	4.13×10^{-03}	4.24×10^{-03}
0.850	4.34×10^{-03}	4.35×10^{-03}	4.35×10^{-03}	4.32×10^{-03}	4.29×10^{-03}	4.36×10^{-03}	4.47×10^{-03}
0.900	4.56×10^{-03}	4.57×10^{-03}	4.57×10^{-03}	4.54×10^{-03}	4.51×10^{-03}	4.58×10^{-03}	4.70×10^{-03}
0.950	4.78×10^{-03}	4.79×10^{-03}	4.79×10^{-03}	4.76×10^{-03}	4.73×10^{-03}	4.80×10^{-03}	4.92×10^{-03}
1.000	5.00×10^{-03}	5.01×10^{-03}	5.01×10^{-03}	4.98×10^{-03}	4.95×10^{-03}	5.02×10^{-03}	5.14×10^{-03}
7.000	2.84×10^{-02}	2.85×10^{-02}	2.84×10^{-02}	2.84×10^{-02}	2.83×10^{-02}	2.85×10^{-02}	2.87×10^{-02}
9.000	3.63×10^{-02}	3.63×10^{-02}	3.63×10^{-02}	3.63×10^{-02}	3.62×10^{-02}	3.63×10^{-02}	3.65×10^{-02}
10.000	4.02×10^{-02}	4.03×10^{-02}	4.03×10^{-02}	4.02×10^{-02}	4.02×10^{-02}	4.03×10^{-02}	4.05×10^{-02}
20.000	7.83×10^{-02}	7.83×10^{-02}	7.83×10^{-02}	7.84×10^{-02}	7.84×10^{-02}	7.83×10^{-02}	7.82×10^{-02}
60.000	2.07×10^{-01}	2.07×10^{-01}	2.07×10^{-01}	2.07×10^{-01}	2.07×10^{-01}	2.07×10^{-01}	2.05×10^{-01}
70.000	2.35×10^{-01}	2.34×10^{-01}	2.35×10^{-01}	2.35×10^{-01}	2.35×10^{-01}	2.34×10^{-01}	2.33×10^{-01}
80.000	2.60×10^{-01}	2.60×10^{-01}	2.60×10^{-01}	2.60×10^{-01}	2.61×10^{-01}	2.60×10^{-01}	2.58×10^{-01}
90.000	2.83×10^{-01}	2.83×10^{-01}	2.83×10^{-01}	2.83×10^{-01}	2.84×10^{-01}	2.82×10^{-01}	2.80×10^{-01}
100.000	3.04×10^{-01}	3.04×10^{-01}	3.04×10^{-01}	3.04×10^{-01}	3.05×10^{-01}	3.04×10^{-01}	3.01×10^{-01}

elements in soft tissues is given in Table 2. The estimated modified atomic number (Z_{mod}) for all tissues defined for the Bremsstrahlung process is as shown in Table 3. The modified atomic number (Z_{mod}) for all tissues (except skeleton) varies from 5.409 (for yellow marrow) to 7.497 (for spongiosa) and for skeleton tissues it varies from 7.503 (for skeleton-vertebral column (D6, L3) to 10.990 (for Skeleton-cortical bone).

An estimated Bremsstrahlung exposure rate (in C/Kg/h) at a distance of 1 cm from a 1 MBq beta ray point source (Γ_{Br}) in all tissues for all therapeutic nuclides are shown in Table 4. The exposure of Bremsstrahlung for yellow marrow is minimum compared to other tissues for all beta-therapeutic nuclides and maximum for Skeleton-cortical bone. It is found that Γ_{Br} for skeletal tissues are greater than other tissues. The exposure of Bremsstrahlung is approximately equal in heart, kidney and liver for all therapeutic nuclides. For all tissues, Γ_{Br} is maximum for ^{204}Tl beta nuclide and minimum for ^{89}Sr beta nuclide.

The estimated probability of energy loss by all Beta particles during the Bremsstrahlung emission (P_{Br}) is shown in Table 5 and these values are high for skeletal tissues compared to other tissues. In all types of tissues, ^{90}Y beta nuclide looses more energy during the Bremsstrahlung emission compared to other nuclides. Similarly ^{45}Ca beta nuclide looses comparably less energy in all tissues (including skeleton tissue). For all beta nuclides probability of energy loss by beta is maximum in Skeleton-cortical bone and minimum in yellow marrow.

The activity of therapeutic beta nuclides above which patient should remain hospitalized on the basis of the projected Bremsstrahlung (Bremsstrahlung activity, $(A_{release})_{Br}$) is as shown in Table 6. These activities have been calculated by assuming the effective half life equals the physical half life and an exposure factor 0.25 at a distance from a patient of 1 m. For systemic radionuclide therapy, the physical half life generally over estimates the effective half life and therefore the calculated values overestimate the activities at which patients systematically administrated therapeutic radionuclide may actually be released from medical confinement. The Bremsstrahlung activity is maximum in Skeleton-cortical bone and minimum in yellow marrow for all beta-therapeutic nuclides. The Bremsstrahlung activity of ^{45}Ca beta-therapeutic nuclide is comparably high in all tissues. Similarly the Bremsstrahlung activity of ^{89}Sr beta nuclide is comparably low in all tissues. $(A_{release})_{Br}$ is important parameter

Table 9
Bremsstrahlung yields.

Energy (MeV)	Panareas	Cartilage	Skin	Spleen	Tests	Thyroid
0.010	1.12×10^{-04}	1.04×10^{-04}	1.12×10^{-04}	1.09×10^{-04}	1.14×10^{-04}	1.10×10^{-04}
0.015	1.63×10^{-04}	1.51×10^{-04}	1.63×10^{-04}	1.59×10^{-04}	1.65×10^{-04}	1.59×10^{-04}
0.020	2.06×10^{-04}	1.92×10^{-04}	2.07×10^{-04}	2.01×10^{-04}	2.10×10^{-04}	2.02×10^{-04}
0.025	2.46×10^{-04}	2.29×10^{-04}	2.47×10^{-04}	2.40×10^{-04}	2.51×10^{-04}	2.41×10^{-04}
0.030	2.84×10^{-04}	2.64×10^{-04}	2.85×10^{-04}	2.77×10^{-04}	2.89×10^{-04}	2.78×10^{-04}
0.035	3.20×10^{-04}	2.98×10^{-04}	3.20×10^{-04}	3.12×10^{-04}	3.25×10^{-04}	3.13×10^{-04}
0.040	3.54×10^{-04}	3.30×10^{-04}	3.55×10^{-04}	3.45×10^{-04}	3.60×10^{-04}	3.47×10^{-04}
0.045	3.87×10^{-04}	3.61×10^{-04}	3.88×10^{-04}	3.78×10^{-04}	3.94×10^{-04}	3.79×10^{-04}
0.050	4.19×10^{-04}	3.91×10^{-04}	4.20×10^{-04}	4.09×10^{-04}	4.27×10^{-04}	4.10×10^{-04}
0.055	4.51×10^{-04}	4.20×10^{-04}	4.52×10^{-04}	4.40×10^{-04}	4.59×10^{-04}	4.41×10^{-04}
0.060	4.81×10^{-04}	4.49×10^{-04}	4.83×10^{-04}	4.70×10^{-04}	4.90×10^{-04}	4.71×10^{-04}
0.065	5.12×10^{-04}	4.77×10^{-04}	5.13×10^{-04}	5.00×10^{-04}	5.21×10^{-04}	5.01×10^{-04}
0.070	5.42×10^{-04}	5.05×10^{-04}	5.43×10^{-04}	5.29×10^{-04}	5.51×10^{-04}	5.31×10^{-04}
0.075	5.71×10^{-04}	5.33×10^{-04}	5.73×10^{-04}	5.58×10^{-04}	5.82×10^{-04}	5.60×10^{-04}
0.080	6.01×10^{-04}	5.60×10^{-04}	6.02×10^{-04}	5.87×10^{-04}	6.11×10^{-04}	5.88×10^{-04}
0.085	6.30×10^{-04}	5.87×10^{-04}	6.31×10^{-04}	6.15×10^{-04}	6.41×10^{-04}	6.17×10^{-04}
0.090	6.59×10^{-04}	6.14×10^{-04}	6.60×10^{-04}	6.43×10^{-04}	6.70×10^{-04}	6.45×10^{-04}
0.095	6.87×10^{-04}	6.41×10^{-04}	6.89×10^{-04}	6.71×10^{-04}	6.99×10^{-04}	6.73×10^{-04}
0.100	7.16×10^{-04}	6.67×10^{-04}	7.18×10^{-04}	6.99×10^{-04}	7.29×10^{-04}	7.01×10^{-04}
0.150	9.92×10^{-04}	9.25×10^{-04}	9.94×10^{-04}	9.68×10^{-04}	1.01×10^{-03}	9.71×10^{-04}
0.200	1.26×10^{-03}	1.17×10^{-03}	1.26×10^{-03}	1.23×10^{-03}	1.28×10^{-03}	1.23×10^{-03}
0.250	1.52×10^{-03}	1.42×10^{-03}	1.52×10^{-03}	1.48×10^{-03}	1.54×10^{-03}	1.49×10^{-03}
0.300	1.78×10^{-03}	1.66×10^{-03}	1.78×10^{-03}	1.74×10^{-03}	1.81×10^{-03}	1.74×10^{-03}
0.350	2.03×10^{-03}	1.90×10^{-03}	2.04×10^{-03}	1.99×10^{-03}	2.07×10^{-03}	1.99×10^{-03}
0.400	2.30×10^{-03}	2.14×10^{-03}	2.30×10^{-03}	2.24×10^{-03}	2.34×10^{-03}	2.25×10^{-03}
0.450	2.54×10^{-03}	2.37×10^{-03}	2.54×10^{-03}	2.48×10^{-03}	2.58×10^{-03}	2.49×10^{-03}
0.500	2.78×10^{-03}	2.61×10^{-03}	2.79×10^{-03}	2.72×10^{-03}	2.83×10^{-03}	2.73×10^{-03}
0.550	3.03×10^{-03}	2.84×10^{-03}	3.03×10^{-03}	2.96×10^{-03}	3.08×10^{-03}	2.97×10^{-03}
0.600	3.27×10^{-03}	3.07×10^{-03}	3.28×10^{-03}	3.20×10^{-03}	3.32×10^{-03}	3.21×10^{-03}
0.650	3.51×10^{-03}	3.29×10^{-03}	3.51×10^{-03}	3.43×10^{-03}	3.56×10^{-03}	3.44×10^{-03}
0.700	3.74×10^{-03}	3.51×10^{-03}	3.75×10^{-03}	3.66×10^{-03}	3.80×10^{-03}	3.67×10^{-03}
0.750	3.97×10^{-03}	3.73×10^{-03}	3.98×10^{-03}	3.89×10^{-03}	4.03×10^{-03}	3.90×10^{-03}
0.800	4.20×10^{-03}	3.95×10^{-03}	4.21×10^{-03}	4.11×10^{-03}	4.26×10^{-03}	4.12×10^{-03}
0.850	4.42×10^{-03}	4.16×10^{-03}	4.43×10^{-03}	4.33×10^{-03}	4.49×10^{-03}	4.34×10^{-03}
0.900	4.65×10^{-03}	4.37×10^{-03}	4.66×10^{-03}	4.55×10^{-03}	4.72×10^{-03}	4.56×10^{-03}
0.950	4.87×10^{-03}	4.59×10^{-03}	4.88×10^{-03}	4.77×10^{-03}	4.94×10^{-03}	4.78×10^{-03}
1.000	5.09×10^{-03}	4.80×10^{-03}	5.10×10^{-03}	4.99×10^{-03}	5.17×10^{-03}	5.00×10^{-03}
7.000	2.86×10^{-02}	2.81×10^{-02}	2.86×10^{-02}	2.84×10^{-02}	2.87×10^{-02}	2.84×10^{-02}
9.000	3.65×10^{-02}	3.60×10^{-02}	3.65×10^{-02}	3.63×10^{-02}	3.66×10^{-02}	3.63×10^{-02}
10.000	4.04×10^{-02}	3.99×10^{-02}	4.04×10^{-02}	4.02×10^{-02}	4.05×10^{-02}	4.02×10^{-02}
20.000	7.83×10^{-02}	7.85×10^{-02}	7.83×10^{-02}	7.84×10^{-02}	7.82×10^{-02}	7.83×10^{-02}
60.000	2.06×10^{-01}	2.09×10^{-01}	2.06×10^{-01}	2.07×10^{-01}	2.05×10^{-01}	2.07×10^{-01}
70.000	2.33×10^{-01}	2.38×10^{-01}	2.33×10^{-01}	2.35×10^{-01}	2.32×10^{-01}	2.35×10^{-01}
80.000	2.58×10^{-01}	2.63×10^{-01}	2.58×10^{-01}	2.60×10^{-01}	2.57×10^{-01}	2.60×10^{-01}
90.000	2.81×10^{-01}	2.86×10^{-01}	2.81×10^{-01}	2.83×10^{-01}	2.80×10^{-01}	2.83×10^{-01}
100.000	3.02×10^{-01}	3.08×10^{-01}	3.02×10^{-01}	3.04×10^{-01}	3.01×10^{-01}	3.04×10^{-01}

Table 10
Bremsstrahlung yields.

Energy (MeV)	Skeleton-sacrum	Skeleton-spongiosa	Skeleton-femour	Skeleton-humerous	Skeleton-ribs 2,8	Skeleton-vertibral column (C4)	Skeleton-vertibral column (D6L3)
0.010	1.22×10^{-04}	1.34×10^{-04}	1.34×10^{-04}	1.44×10^{-04}	1.50×10^{-04}	1.60×10^{-04}	1.61×10^{-04}
0.015	1.77×10^{-04}	1.94×10^{-04}	1.94×10^{-04}	2.08×10^{-04}	2.18×10^{-04}	2.31×10^{-04}	2.33×10^{-04}
0.020	2.24×10^{-04}	2.46×10^{-04}	2.46×10^{-04}	2.64×10^{-04}	2.76×10^{-04}	2.93×10^{-04}	2.95×10^{-04}
0.025	2.68×10^{-04}	2.94×10^{-04}	2.94×10^{-04}	3.15×10^{-04}	3.29×10^{-04}	3.49×10^{-04}	3.52×10^{-04}
0.030	3.08×10^{-04}	3.38×10^{-04}	3.38×10^{-04}	3.63×10^{-04}	3.79×10^{-04}	4.02×10^{-04}	4.04×10^{-04}
0.035	3.47×10^{-04}	3.81×10^{-04}	3.81×10^{-04}	4.08×10^{-04}	4.26×10^{-04}	4.52×10^{-04}	4.54×10^{-04}
0.040	3.84×10^{-04}	4.21×10^{-04}	4.21×10^{-04}	4.52×10^{-04}	4.71×10^{-04}	4.99×10^{-04}	5.03×10^{-04}
0.045	4.20×10^{-04}	4.60×10^{-04}	4.60×10^{-04}	4.94×10^{-04}	5.15×10^{-04}	5.46×10^{-04}	5.49×10^{-04}
0.050	4.55×10^{-04}	4.99×10^{-04}	4.99×10^{-04}	5.35×10^{-04}	5.58×10^{-04}	5.91×10^{-04}	5.94×10^{-04}
0.055	4.89×10^{-04}	5.36×10^{-04}	5.36×10^{-04}	5.75×10^{-04}	6.00×10^{-04}	6.35×10^{-04}	6.39×10^{-04}
0.060	5.22×10^{-04}	5.73×10^{-04}	5.73×10^{-04}	6.14×10^{-04}	6.40×10^{-04}	6.78×10^{-04}	6.82×10^{-04}
0.065	5.55×10^{-04}	6.09×10^{-04}	6.09×10^{-04}	6.53×10^{-04}	6.81×10^{-04}	7.20×10^{-04}	7.25×10^{-04}
0.070	5.88×10^{-04}	6.44×10^{-04}	6.44×10^{-04}	6.91×10^{-04}	7.20×10^{-04}	7.62×10^{-04}	7.67×10^{-04}
0.075	6.20×10^{-04}	6.80×10^{-04}	6.80×10^{-04}	7.29×10^{-04}	7.60×10^{-04}	8.04×10^{-04}	8.09×10^{-04}
0.080	6.52×10^{-04}	7.15×10^{-04}	7.15×10^{-04}	7.66×10^{-04}	7.99×10^{-04}	8.45×10^{-04}	8.50×10^{-04}
0.085	6.83×10^{-04}	7.49×10^{-04}	7.49×10^{-04}	8.03×10^{-04}	8.37×10^{-04}	8.86×10^{-04}	8.91×10^{-04}
0.090	7.14×10^{-04}	7.83×10^{-04}	7.83×10^{-04}	8.40×10^{-04}	8.75×10^{-04}	9.26×10^{-04}	9.32×10^{-04}
0.095	7.45×10^{-04}	8.17×10^{-04}	8.17×10^{-04}	8.76×10^{-04}	9.13×10^{-04}	9.66×10^{-04}	9.72×10^{-04}
0.100	7.77×10^{-04}	8.51×10^{-04}	8.51×10^{-04}	9.12×10^{-04}	9.51×10^{-04}	1.01×10^{-03}	1.01×10^{-03}
0.150	1.08×10^{-03}	1.18×10^{-03}	1.18×10^{-03}	1.26×10^{-03}	1.32×10^{-03}	1.39×10^{-03}	1.40×10^{-03}
0.200	1.36×10^{-03}	1.50×10^{-03}	1.50×10^{-03}	1.60×10^{-03}	1.67×10^{-03}	1.76×10^{-03}	1.77×10^{-03}
0.250	1.64×10^{-03}	1.80×10^{-03}	1.80×10^{-03}	1.93×10^{-03}	2.01×10^{-03}	2.12×10^{-03}	2.14×10^{-03}
0.300	1.92×10^{-03}	2.11×10^{-03}	2.11×10^{-03}	2.26×10^{-03}	2.35×10^{-03}	2.48×10^{-03}	2.49×10^{-03}
0.350	2.20×10^{-03}	2.41×10^{-03}	2.41×10^{-03}	2.58×10^{-03}	2.68×10^{-03}	2.83×10^{-03}	2.84×10^{-03}
0.400	2.49×10^{-03}	2.71×10^{-03}	2.71×10^{-03}	2.90×10^{-03}	3.01×10^{-03}	3.17×10^{-03}	3.19×10^{-03}
0.450	2.74×10^{-03}	3.00×10^{-03}	3.00×10^{-03}	3.21×10^{-03}	3.34×10^{-03}	3.52×10^{-03}	3.54×10^{-03}
0.500	3.01×10^{-03}	3.29×10^{-03}	3.29×10^{-03}	3.52×10^{-03}	3.66×10^{-03}	3.85×10^{-03}	3.88×10^{-03}
0.550	3.27×10^{-03}	3.58×10^{-03}	3.58×10^{-03}	3.82×10^{-03}	3.97×10^{-03}	4.19×10^{-03}	4.21×10^{-03}
0.600	3.53×10^{-03}	3.86×10^{-03}	3.86×10^{-03}	4.12×10^{-03}	4.20×10^{-03}	4.51×10^{-03}	4.54×10^{-03}
0.650	3.78×10^{-03}	4.14×10^{-03}	4.14×10^{-03}	4.42×10^{-03}	4.59×10^{-03}	4.83×10^{-03}	4.86×10^{-03}
0.700	4.03×10^{-03}	4.41×10^{-03}	4.41×10^{-03}	4.71×10^{-03}	4.89×10^{-03}	5.15×10^{-03}	5.18×10^{-03}
0.750	4.27×10^{-03}	4.68×10^{-03}	4.68×10^{-03}	4.99×10^{-03}	5.18×10^{-03}	5.46×10^{-03}	5.49×10^{-03}
0.800	4.52×10^{-03}	4.94×10^{-03}	4.94×10^{-03}	5.27×10^{-03}	5.47×10^{-03}	5.76×10^{-03}	5.80×10^{-03}
0.850	4.76×10^{-03}	5.20×10^{-03}	5.20×10^{-03}	5.55×10^{-03}	5.76×10^{-03}	6.07×10^{-03}	6.10×10^{-03}
0.900	4.99×10^{-03}	5.46×10^{-03}	5.46×10^{-03}	5.83×10^{-03}	6.05×10^{-03}	6.36×10^{-03}	6.40×10^{-03}
0.950	5.23×10^{-03}	5.72×10^{-03}	5.72×10^{-03}	6.10×10^{-03}	6.33×10^{-03}	6.66×10^{-03}	6.70×10^{-03}
1.000	5.47×10^{-03}	5.97×10^{-03}	5.97×10^{-03}	6.37×10^{-03}	6.61×10^{-03}	6.95×10^{-03}	6.99×10^{-03}
7.000	2.96×10^{-02}	3.19×10^{-02}	3.19×10^{-02}	3.36×10^{-02}	3.46×10^{-02}	3.61×10^{-02}	3.63×10^{-02}
9.000	3.75×10^{-02}	4.03×10^{-02}	4.03×10^{-02}	4.25×10^{-02}	4.38×10^{-02}	4.56×10^{-02}	4.58×10^{-02}
10.000	4.14×10^{-02}	4.45×10^{-02}	4.45×10^{-02}	4.69×10^{-02}	4.83×10^{-02}	5.03×10^{-02}	5.05×10^{-02}
20.000	7.91×10^{-02}	8.46×10^{-02}	8.46×10^{-02}	8.87×10^{-02}	9.11×10^{-02}	9.45×10^{-02}	9.49×10^{-02}
60.000	2.05×10^{-01}	2.16×10^{-01}	2.16×10^{-01}	2.24×10^{-01}	2.29×10^{-01}	2.35×10^{-01}	2.36×10^{-01}
70.000	2.32×10^{-01}	2.44×10^{-01}	2.44×10^{-01}	2.53×10^{-01}	2.57×10^{-01}	2.64×10^{-01}	2.65×10^{-01}
80.000	2.57×10^{-01}	2.69×10^{-01}	2.69×10^{-01}	2.78×10^{-01}	2.83×10^{-01}	2.90×10^{-01}	2.91×10^{-01}
90.000	2.79×10^{-01}	2.93×10^{-01}	2.93×10^{-01}	3.02×10^{-01}	3.07×10^{-01}	3.14×10^{-01}	3.15×10^{-01}
100.000	3.00×10^{-01}	3.14×10^{-01}	3.14×10^{-01}	3.23×10^{-01}	3.28×10^{-01}	3.36×10^{-01}	3.37×10^{-01}

because it decides the amount of activity essential for radiotherapy for particular region (or tissue).

The estimated Bremsstrahlung yields (I_{Br}) as a function of energy for all types of tissues in the wide energy range from 0.01 to 100 MeV is shown in Tables 7–11. An evaluated Bremsstrahlung yields of soft tissue is lesser than skeletal tissues because Z_{mod} of soft tissues lesser (<7.5) than skeleton tissue (<10.99) due to presence of calcium in the skeleton. Thus I_{Br} varies with energy and modified atomic number of tissue matrix. An estimated result shows that, I_{Br} is significant at high energies. For all energies, the Bremsstrahlung yields are comparably high in Skeleton-cortical bone and low in yellow marrow. Thus the Bremsstrahlung production in skeleton tissues is greater than other tissue of different organs.

4. Conclusion

In all tissues, the Bremsstrahlung activity of ^{45}Ca is high and the Bremsstrahlung activity of ^{89}Sr is low. Logically it may be suggested that it is better to select beta nuclide with maximum A_{Br} value to avoid damage of other tissues. However the estimated activities of pure beta nuclides in all types of tissues (including skeletal tissues) requiring medical confinement is extremely large (10^2–10^6 GBq). The patients receiving such nuclides would never receive that much activity because of prohibitive radiation toxicity to the patient. For example, when using ^{89}Sr-strontium chloride for the palliation of bone pain, the standard administrated activity limited by hematologic toxicity secondary to marrow radiation is only 148 MBq. In contrast, ^{89}Sr activities requiring medical confinement are at least 139,294 MBq (Table 6). While using ^{90}Y for radiosynovectomy of joint disorders, the standard administrated activity is only 185 MBq [18]. In contrast ^{90}Y activities requiring medical confinement are at least 96,088 MBq (Table 6). Furthermore ^{169}Er beta nuclide is also used for radiosynovectomy of joint disorders the standard administrated activity is less than 200 MBq but ^{169}Er activities requiring medical confinement are at least 274,006 MBq (Table 6). Thus the patients receiving these pure beta-emitting nuclides do not have to be hospitalized for radiation precautions. The Bremsstrahlung

Table 11
Bremsstrahlung yields

Energy (MeV)	Skeleton cranium	Skeleton mandible	Skeleton ribs (10)	Skeleton cortical bone	Spongiosa
0.010	1.75×10^{-04}	1.71×10^{-04}	1.87×10^{-04}	1.99×10^{-04}	1.34×10^{-04}
0.015	2.53×10^{-04}	2.47×10^{-04}	2.70×10^{-04}	2.88×10^{-04}	1.94×10^{-04}
0.020	3.21×10^{-04}	3.13×10^{-04}	3.42×10^{-04}	3.64×10^{-04}	2.46×10^{-04}
0.025	3.82×10^{-04}	3.73×10^{-04}	4.07×10^{-04}	4.34×10^{-04}	2.93×10^{-04}
0.030	4.39×10^{-04}	4.29×10^{-04}	4.68×10^{-04}	4.98×10^{-04}	3.38×10^{-04}
0.035	4.94×10^{-04}	4.82×10^{-04}	5.26×10^{-04}	5.60×10^{-04}	3.80×10^{-04}
0.040	5.46×10^{-04}	5.33×10^{-04}	5.81×10^{-04}	6.19×10^{-04}	4.21×10^{-04}
0.045	5.96×10^{-04}	5.82×10^{-04}	6.35×10^{-04}	6.76×10^{-04}	4.60×10^{-04}
0.050	6.46×10^{-04}	6.30×10^{-04}	6.87×10^{-04}	7.32×10^{-04}	4.98×10^{-04}
0.055	6.94×10^{-04}	6.77×10^{-04}	7.38×10^{-04}	7.86×10^{-04}	5.36×10^{-04}
0.060	7.41×10^{-04}	7.23×10^{-04}	7.89×10^{-04}	8.40×10^{-04}	5.72×10^{-04}
0.065	7.87×10^{-04}	7.68×10^{-04}	8.38×10^{-04}	8.93×10^{-04}	6.08×10^{-04}
0.070	8.33×10^{-04}	8.13×10^{-04}	8.87×10^{-04}	9.45×10^{-04}	6.44×10^{-04}
0.075	8.78×10^{-04}	8.58×10^{-04}	9.35×10^{-04}	9.96×10^{-04}	6.79×10^{-04}
0.080	9.23×10^{-04}	9.01×10^{-04}	9.83×10^{-04}	1.05×10^{-03}	7.14×10^{-04}
0.085	9.67×10^{-04}	9.45×10^{-04}	1.03×10^{-03}	1.10×10^{-03}	7.49×10^{-04}
0.090	1.01×10^{-03}	9.88×10^{-04}	1.08×10^{-03}	1.15×10^{-03}	7.83×10^{-04}
0.095	1.06×10^{-03}	1.03×10^{-03}	1.12×10^{-03}	1.20×10^{-03}	8.17×10^{-04}
0.100	1.10×10^{-03}	1.07×10^{-03}	1.17×10^{-03}	1.25×10^{-03}	8.51×10^{-04}
0.150	1.52×10^{-03}	1.48×10^{-03}	1.62×10^{-03}	1.72×10^{-03}	1.18×10^{-03}
0.200	1.92×10^{-03}	1.88×10^{-03}	2.04×10^{-03}	2.18×10^{-03}	1.49×10^{-03}
0.250	2.31×10^{-03}	2.26×10^{-03}	2.46×10^{-03}	2.62×10^{-03}	1.80×10^{-03}
0.300	2.70×10^{-03}	2.64×10^{-03}	2.87×10^{-03}	3.06×10^{-03}	2.11×10^{-03}
0.350	3.08×10^{-03}	3.01×10^{-03}	3.27×10^{-03}	3.48×10^{-03}	2.41×10^{-03}
0.400	3.46×10^{-03}	3.38×10^{-03}	3.67×10^{-03}	3.91×10^{-03}	2.71×10^{-03}
0.450	3.83×10^{-03}	3.74×10^{-03}	4.06×10^{-03}	4.32×10^{-03}	3.00×10^{-03}
0.500	4.19×10^{-03}	4.10×10^{-03}	4.45×10^{-03}	4.73×10^{-03}	3.29×10^{-03}
0.600	4.90×10^{-03}	4.79×10^{-03}	5.20×10^{-03}	5.53×10^{-03}	3.86×10^{-03}
0.650	5.25×10^{-03}	5.13×10^{-03}	5.57×10^{-03}	5.92×10^{-03}	4.13×10^{-03}
0.700	5.59×10^{-03}	5.47×10^{-03}	5.93×10^{-03}	6.30×10^{-03}	4.41×10^{-03}
0.750	5.93×10^{-03}	5.79×10^{-03}	6.29×10^{-03}	6.68×10^{-03}	4.67×10^{-03}
0.800	6.26×10^{-03}	6.12×10^{-03}	6.63×10^{-03}	7.05×10^{-03}	4.94×10^{-03}
0.900	6.91×10^{-03}	6.75×10^{-03}	7.32×10^{-03}	7.78×10^{-03}	5.46×10^{-03}
1.000	7.54×10^{-03}	7.38×10^{-03}	7.99×10^{-03}	8.49×10^{-03}	5.97×10^{-03}
7.000	3.86×10^{-02}	3.79×10^{-02}	4.05×10^{-02}	4.33×10^{-02}	3.18×10^{-02}
8.000	4.37×10^{-02}	4.29×10^{-02}	4.58×10^{-02}	4.90×10^{-02}	3.61×10^{-02}
9.000	4.87×10^{-02}	4.78×10^{-02}	5.10×10^{-02}	5.47×10^{-02}	4.03×10^{-02}
10.000	5.36×10^{-02}	5.27×10^{-02}	5.62×10^{-02}	6.03×10^{-02}	4.45×10^{-02}
20.000	1.00×10^{-01}	9.86×10^{-02}	1.05×10^{-01}	1.13×10^{-01}	8.46×10^{-02}
30.000	1.42×10^{-01}	1.40×10^{-01}	1.48×10^{-01}	1.61×10^{-01}	1.22×10^{-01}
80.000	3.02×10^{-01}	2.99×10^{-01}	3.10×10^{-01}	3.33×10^{-01}	2.69×10^{-01}
90.000	3.26×10^{-01}	3.23×10^{-01}	3.34×10^{-01}	3.59×10^{-01}	2.92×10^{-01}
100.000	3.48×10^{-01}	3.44×10^{-01}	3.56×10^{-01}	3.78×10^{-01}	3.14×10^{-01}

production in skeleton tissues is greater than other tissue of different organs. Hence proper localization is possible through the Bremsstrahlung imaging.

In the present estimation, it has been considered the composition of different tissues separately, which is possible to estimate the Bremsstrahlung exposure rate of individual tissue which is essential for radiotherapy. While estimating the Bremsstrahlung radiation hazard, photon yield is also important and without this it is difficult to come for conclusion.

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