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Air Kerma Rate Constants for Nuclides Important to Gamma Ray Dosimetry and Practical Application

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1. Introduction

It is often necessary to estimate the exposure rate at a distance from radionuclide emitting gamma or X rays. Such calculations may be required for planning radiation protection measures around radioactive sources, for calibration radiation monitoring instruments, for patient containing radionuclides or for estimating the absorbed dose to patients receiving brachytherapy. The factor relating activity and exposure rate has been various names: the k factor (Johns, 1961), the specific gamma ray constant (ICRU Rep. 10a, 1962), exposure rate constant (Parker et al., 1978) and gamma rate constant (Kereiakes & Rosenstein, 1980). Conversion to SI units required that this factor be replaced by the air kerma rate constant Γ_{δ}, which is now defined as:

$$\Gamma_{\delta} = \frac{l^2}{A} \left(\frac{dK_{air}}{dt} \right)_{\delta} \quad (1)$$

where $(dK_{air}/dt)_{\delta}$ is the air kerma rate due to photons of energy >δ, at a distance l from a point source of activity A. The SI unit for Γ_{δ} is J m^2 kg^{-1} which, when the terms gray and becquirel are used, becoms Gy m^2 s^{-1} Bq^{-1}.

In the process of analysing accessible data on the are kerma rate constants and its precursos for many radionuclides often used in practice (Nachtigal, 1969; Ninkovic & Mladenovic, 1970; NCRP Rep. 49, 1976; Ungar & Trabey, 1982; Aird et al., 1984; Attix, 1986; Ninkovic, 1987; Wasserman & Groenwald, 1988; Ninkovic & Raicevic, 1992,1993; Sabol & Weng, 1995; Ninkovic et al., 2005) it was concluded that published data are in strong disagreement. That is the reason we decided to recalculate this quantities on the basis of the latest data on gamma ray spectra and on the latest data for mass energy-transfer coefficients for air.

2. Derivation of the equation for calculation of Γ_{δ}

The kerma K_{air}, for interaction of X-rays and gamma rays with air is given by:

$$K_{\text{air}} = \Phi \frac{\mu_k}{\rho} E \tag{2}$$

where Φ is the flunce, E the photon energy, and μ_κ/ρ the energy-dependent mass energy-transfer coefficient for air.

The kerma rate, dK /dt, is obtained from the kerma by substituting the flux density ψ for the fluence Φ in Equation 2:

$$\frac{dK_{air}}{dt} = \psi \frac{\mu_k}{\rho} E \tag{3}$$

where ψ is expressed in $m^{-2}\,s^{-1}$. The quantity ψ is derived from the activity A, of a radiation source in accordance with inverse square low:

$$\psi = \frac{A}{4\pi l^2} \tag{4}$$

By inserting Equation 4 in Equation 3, the following equation is obtained:

$$\frac{dK_{air}}{dt} = \frac{A}{4\pi l^2} \frac{\mu_k}{\rho} E \tag{5}$$

If photons with energy E_i are emitted per decay event with yield p_i, Equation 5 becomes:

$$\frac{dK_{air}}{dt} = \frac{A}{4\pi l^2} \sum_i \left(\frac{\mu_k}{\rho}\right)_i p_i E_i \tag{6}$$

By inserting Equation 6 in Equation 1, the following equation is obtained for Γ_δ:

$$\Gamma_\delta = \frac{1}{4\pi} \sum_i \left(\frac{\mu_k}{\rho}\right)_i p_i E_i \tag{7}$$

3. Calculation of Γ_δ

Starting from Equation 7, the air kerma rate constants, Γ_δ, were calculated using data on mass energy-transfer coefficients for air (Hubbell, 1969; Hubbell & Seltzer, 2001) and data on photon emission yield in the process of decay of the radionuclides (Firestone, 1996; Stabin & Luz, 2002). The subscript δ , implies that only photons with energy $>\delta$, in MeV are included in the calculation.

Concerning the radiation spectra emitted per decay of a radionuclide, there are three types of photons: the gamma ray photons, those characteristic X-ray photons, those from internal conversion of gamma rays and electron capture and those accompanying bremsstrahlung processes of electrons from β^- decay and internal conversion of gamma rays and X rays. In this calculation gamma rays and characteristic X-ray photons with energies >20 keV as δ – value are only ones to have been taken into account. The contribution of bremsstrahlung radiation has not been included.

In the calculation, instead of gamma ray total transition intensities, the gamma ray intensities corrected for internal conversion of gamma rays were used.

The particular air kerma rate constants were calculated for each discrete line of the photon spectrum of the radionuclide, with effective yield per decay >0.01% and energy >20 keV. Since the energy structure of the photon spectra and accessible discrete numerical values of the mass energy-transfer coefficient for air are not the same, the cubic spline interpolation was used to calculate the coefficient , where photon spectrum data are available.

4. Results

4.1 New recalculated values of Γ_δ

Table 1, lists recalculated air kerma rate constants for the 35 radionuclide used most often in gamma ray dosimetry and practical applications. For every radionuclide in the table are given the following data:

in column 1 the symbol of gamma-emitting nuclide,
in column 2 the half-life,
in column 3 the low- energy photon spectra limit,
in column 4 the high-energy photon spectra limit ,
in column 5 the calculated value of the constant in basic SI units, and finaly
in column 6 the calculated value of the constant in practical units (μGy m^2 GBq^{-1} h^{-1})

The last unit, for air kerma rate constant, is the practical one especially, for radiation protection and safety calculations in nuclear medicine laboratories, industrial radiography and many others applications of point gamma radiation sources.

The accuracy of calculation of air kerma rate constants is not more than three significant figures. The major portion of the standard error associated with these calculated values of Γ_δ arise from uncertainties in relative intensity measurements of the X ray and gamma ray photon spectra and intensity of omitted bremsstrahlung radiation.

Bremsstrahlung radiation contributes to the total air kerma rate constant by, for exam≤≤le, for ^{60}Co, not more than 0.4%, and this decreases markedly with decreasing photon energy (BCRUM, Br.J.Rad., 55, 1982). The contribution to Γ_δ from the omitted photons of energies < 20 keV, varies from radionuclide to radionuclide, this is not interesting for the purposes of practical health physics, but is of interest in specific nuclear medicine radionuclide applications.

4.2 Examples of our previous measurements of photon spectra and calculation of Γ_δ for selected radionuclide

The next section of the text shows, as examle, the data of our previous measurement of the photon spectrum and the results of calculating the air kerma rate constants for the three selected radionuclides (^{182}Ta, ^{192}Ir and ^{226}Ra in equilibrium with its decay products).

4.2.1 Photon spectra and recalculated of Γ_δ for ^{182}Ta radionuclide

As can be seen from Table 2, the entire of photon ray spectrum of ^{182}Ta is divided into five characteristic groups of photon lines. The air kerma rate constant was calculated for every

Radionuclide	Half – life	Energy interval (MeV)		Air kerma rate constant	
		from	to	aGy m^{-2} Bq^{-1} s^{-1}	μGy m^{-2} GBq^{-1} h^{-1}
^{11}C	20.38 min	-	0.5110	38.7	139.3
^{13}N	9.965 min	-	0.5110	38.7	139.4
^{15}O	2.037 min	-	0.5110	38.7	139.5
^{18}F	109.8 min	0.0005	0.5110	37.5	135.1
^{24}Na	14.96 h	1.3690	3.8660	121.3	436.7
^{42}K	12.36 h	0.3126	2.4240	9.10	32.8
^{43}K	22.3 h	0.2206	1.3940	35.5	127.8
^{51}Cr	27.70 h	0.0005	0.3201	1.17	4.22
^{52}Fe	8.275 h	0.0006	1.0399	27.01	97.24
^{59}Fe	44.50 d	0.0069	1.4817	40.54	145.9
^{57}Co	271.74 d	0.0007	0.6924	3.92	14.11
^{58}Co	70.86 d	0.0007	1.6747	35.84	129.0
^{60}Co	5.271 a	1.1732	1.3325	85.82	309.0
^{67}Ga	3.261 d	0.0010	0.8877	5.40	19.45
^{68}Ga	1.127 h	0.0010	1.8830	35.84	129.0
^{75}Se	119.79 d	0.0013	0.5722	13.40	48.25
^{99}Mo	65.94 h	0.0024	0.9608	5.49	19.77
^{99m}Tc	6.01 h	0.0024	0.1426	3.92	14.10
^{111}In	67.31 h	0.0031	0.2454	23.09	83.13
^{113m}In	99.49 min	0.0033	0.3917	12.22	44.00
^{123}I	13.27 h	0.0038	0.7836	10.0	36.1
^{125}I	59.4 d	0.0038	0.0355	10.48	37.73
^{131}I	8.021 d	0.0041	0.7229	14.50	52.20
^{127}Xe	36.4 d	0.0039	0.6184	14.19	51.09
^{133}Xe	5.243 d	0.0043	0.1606	3.98	14.33
$^{137}Cs/^{137}Ba$	30.04 a	0.0045	0.6617	22.80	82.10
^{152}Eu	13.537 a	0.0056	1.7691	41.36	148.9
^{154}Eu	8.593 a	0.0061	1.5965	44.23	159.2
^{170}Tm	128.6 d	0.0070	0.0843	0.154	0.554
^{182}Ta	114.43 d	0.0084	1.4531	44.45	160.0
^{192}Ir	73.827 d	0.0089	1.0615	30.30	109.1
^{197}Hg	2.672 d	0.0097	0.2687	3.159	11.37
^{198}Au	2.695 d	0.0100	1.0877	15.15	54.54
^{201}Tl	3.038 d	0.0058	0.1674	2.84	10.22
^{241}Am	432.2 a	0.0139	0.1030	1.102	3.97

Table 1. Air kerma rate constant for some radionuclide considering photon energy above 20 keV

discrete photon line with yield per decay event >0.01 % and starting with energy of 0.03174 MeV as the delta value. That means that four characteristic X-ray lines are included. The group and total air kerma rate constant are obtained then by addition of partiale or single photon lines constant. Finally, a value of (44.8 ± 0.9) aGy m^2 s^{-1} Bq^{-1} for an unshielded ^{182}Ta source has been obtained. That value is in good agreement with a new recalculated value given in Table 1.

Bearing in mind that standard tantalum sources are usually packed into 0.1 mm of platinum, it was calculated the constant for this type of source also. For that goal, it was calculated the absorption of tantalum photons into 0.1 mm of platinum and obtained that in this way the air kerma rate constant is reduced by 4,46 %. After this correction, a value of (42.8 ± 0.9) aGy m^2 s^{-1} Bq^{-1} was obtained for air kerma rate constant for standard packaged encapsulated tantalum source (Ninkovic & Raicevic, 1992).

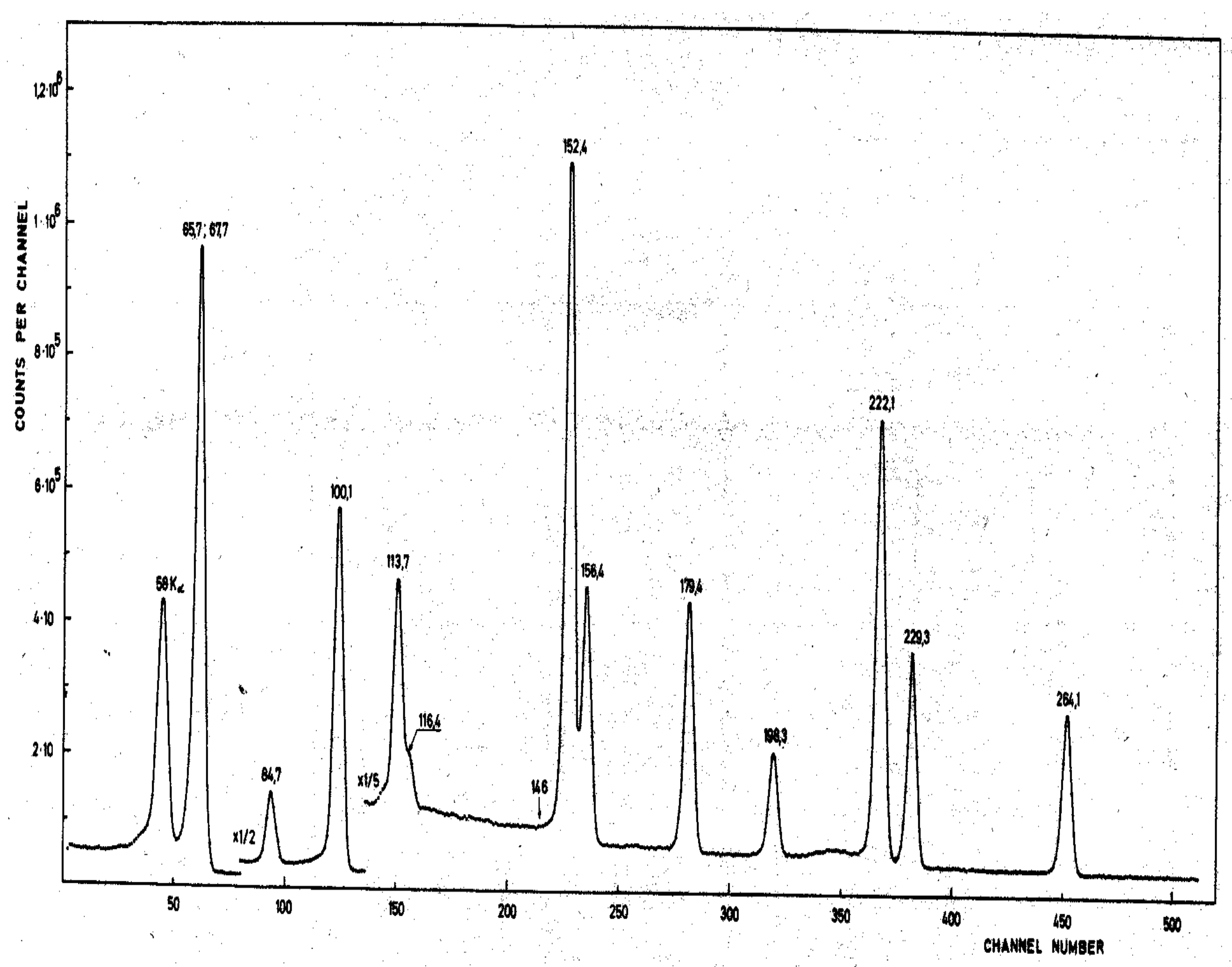

Fig. 1a. Low energy region (50-300 keV) of the photons spectrum emitted in decay of ^{182}Ta radionuclide

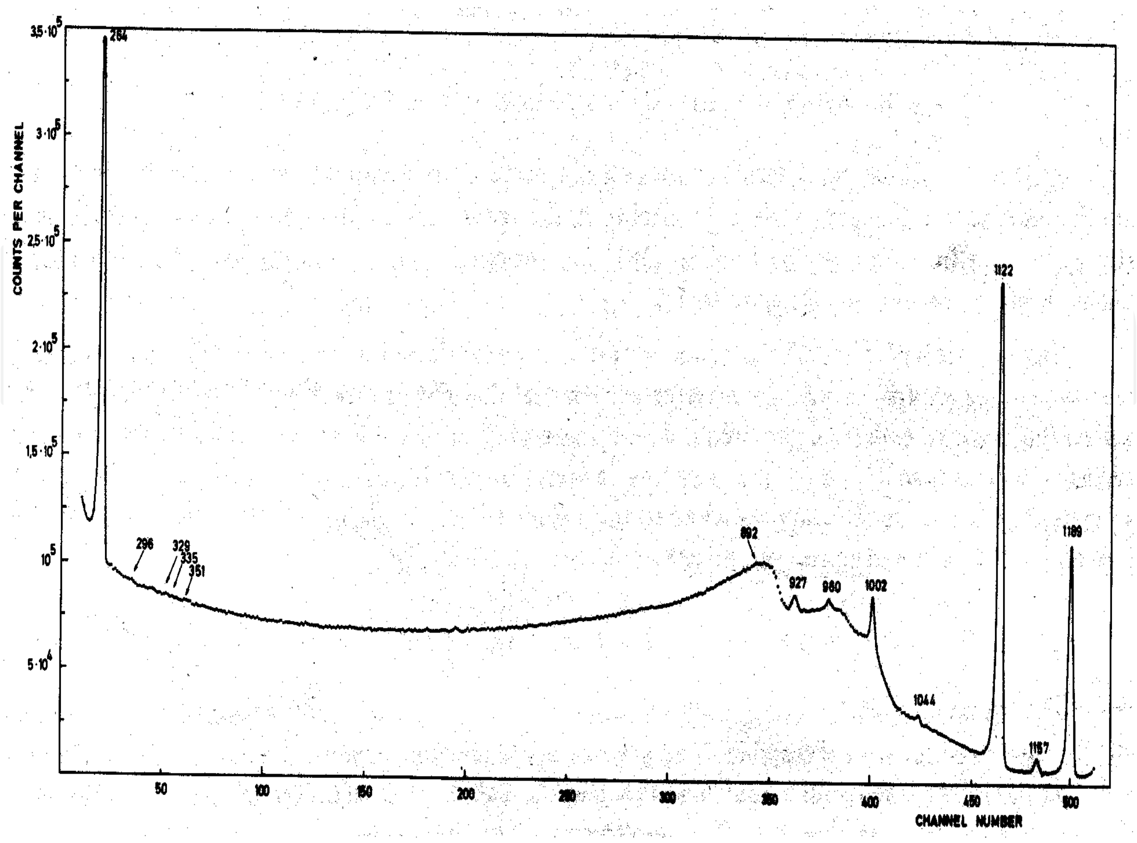

Fig. 1b. Middle energy region (250-1200 keV) of the photons spectrum emitted in decay of ^{182}Ta radionuclide

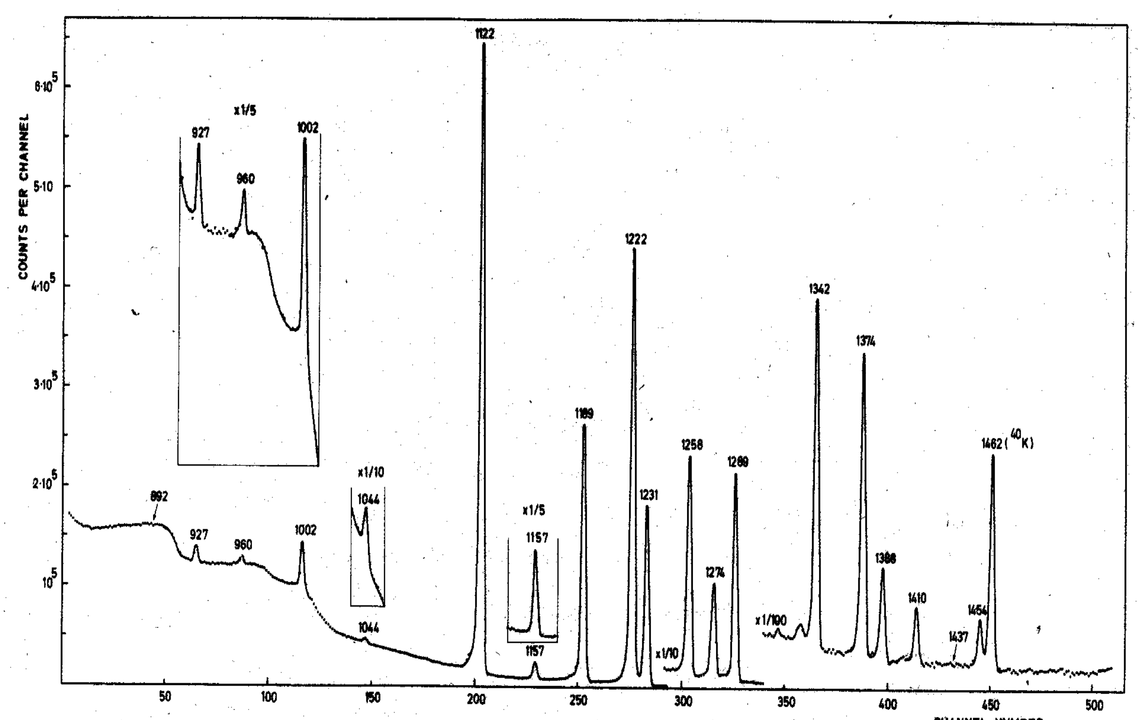

Fig. 1c. High energy region (800-1500 keV) of the photons spectrum emitted in decay of ^{182}Ta radionuclide

Group of lines	Energy [MeV]	Yield per decay [%]	Air mass energy transfer coeff. [10^{-3} $m^2 kg^{-1}$]	Air Kerma-rate const., Γ_δ [aGy $m^2 s^{-1} Bq^{-1}$]	Yield to total Γ_δ [%]
1	2	3	4	5	6
I	0.03174	0.46 ± 0.07	12.780	0.02 ± 0.003	0.05
	0.04272	0.24 ± 0.02	5.650	0.01 ± 0.001	0.02
	0.05798(*)	10.1 ± 0.4	3.145	0.24 ± 0.01	0.53
	0.05932(*)	17.6 ± 0.6	3.045	0.41 ± 0.02	0.91
	0.06572	3.00 ± 0.07	2.720	0.07 ± 0.002	0.16
	0.06695(*)	2.1 ± 0.1	2.760	0.05 ± 0.002	0.11
	0.0672(*)	7.5 ± 0.3	2.665	0.17 ± 0.01	0.38
	0.06775	41.0 ± 1.0	1.645	0.94 ± 0.02	2.10
	1.91 ± 0.1				4.26
II	0.08468	2.6 ± 0.3	2.352	0.07 ± 0.01	0.16
	0.10011	14.0 ± 0.4	2.320	0.41 ± 0.01	0.92
	0.11367	1.90 ± 0.04	2.345	0.06 ± 0.01	0.13
	0.11642	0.43 ± 0.01	2.350	0.02 ± 0.001	0.04
	0.15243	6.9 ± 0.1	2.500	0.34 ± 0.01	0.76
	0.15639	2.7 ± 0.2	2.520	0.14 ± 0.01	0.31
	0.17639	3.1 ± 0.2	2.595	0.18 ± 0.01	0.40
	0.19835	1.5 ± 0.1	2.665	0.10 ± 0.01	0.22
	0.22211	7.4 ± 0.2	2.735	0.57 ± 0.12	1.27
	0.22932	3.7 ± 0.1	2.750	0.30 ± 0.01	0.67
	0.26408	3.6 ± 0.1	2.830	0.34 ± 0.01	0.76
	2.53 ± 0.08				5.64
III	0.92798	0.63 ± 0.02	2.830	0.21 ± 0.01	0.47
	0.95872	0.36 ± 0.05	2.815	0.12 ± 0.02	0.27
	1.00170	2.1 ± 0.1	2.810	0.75 ± 0.04	1.67
	1.04443	0.24 ± 0.01	2.775	0.09 ± 0.004	0.20
	1.17 ± 0.22				2.61
IV	1.11341	0.38 ± 0.07	2.752	0.15 ± 0.03	0.33
	1.12130	35.0 ± 0.7	2.750	13.76 ± 0.27	30.71
	1.1575	0.98 ± 0.06	2.730	0.39 ± 0.02	0.87
	1.18905	16.3 ± 0.3	2.710	6.70 ± 0.12	14.96
	1.22141	27.2 ± 0.5	2.700	11.46 ± 0.21	25.58
	1.23102	11.6 ± 0.4	2.750	4.92 ± 0.17	10.98
	1.25742	1.50 ± 0.05	2.690	0.65 ± 0.03	1.45
	1.27373	0.65 ± 0.01	2.670	0.28 ± 0.01	0.63
	1.28916	1.35 ± 0.03	2.665	0.59 ± 0.02	1.32
	38.90 ± 0.82				86.83
V	1.34273	0.27 ± 0.01	2.645	0.12 ± 0.01	0.27
	1.37384	0.22 ± 0.01	2.635	0.10 ± 0.01	0.22
	1.38740	0.09 ± 0.01	2.625	0.04 ± 0.01	0.09
	1.41010	0.05 ± 0.01	2.618	0.02 ± 0.01	0.04
	1.45305	0.04 ± 0.01	2.600	0.02 ± 0.01	0.04
	0.30 ± 0.003				0.66
Total air-kerma rate constant 44.8 ± 0.9					100.0

(*)- Characteristic X-ray $K\alpha_2$, $K\alpha_1$, $K\beta_{\square}$ and $K\beta_1$ respectively

Table 2. Data for calculation and calculated Partial, Groups and Total Air kerma rate constant of ^{182}Ta radionuclide (Ninkovic & Raicevic, 1992)

4.2.2 Photon spectra and calculated of Γ_δ for ^{192}Ir radionuclide

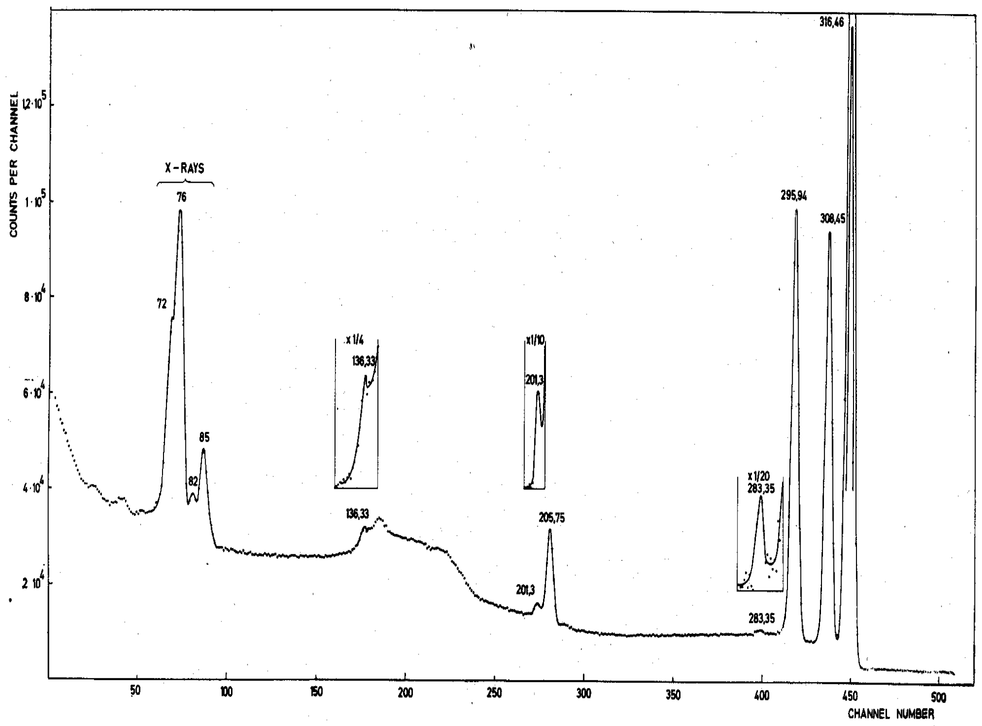

Fig. 2a. Energy spectrum of the photons emitted in decay of ^{192}Ir radionuclide in energy interval from 50 to 350 keV

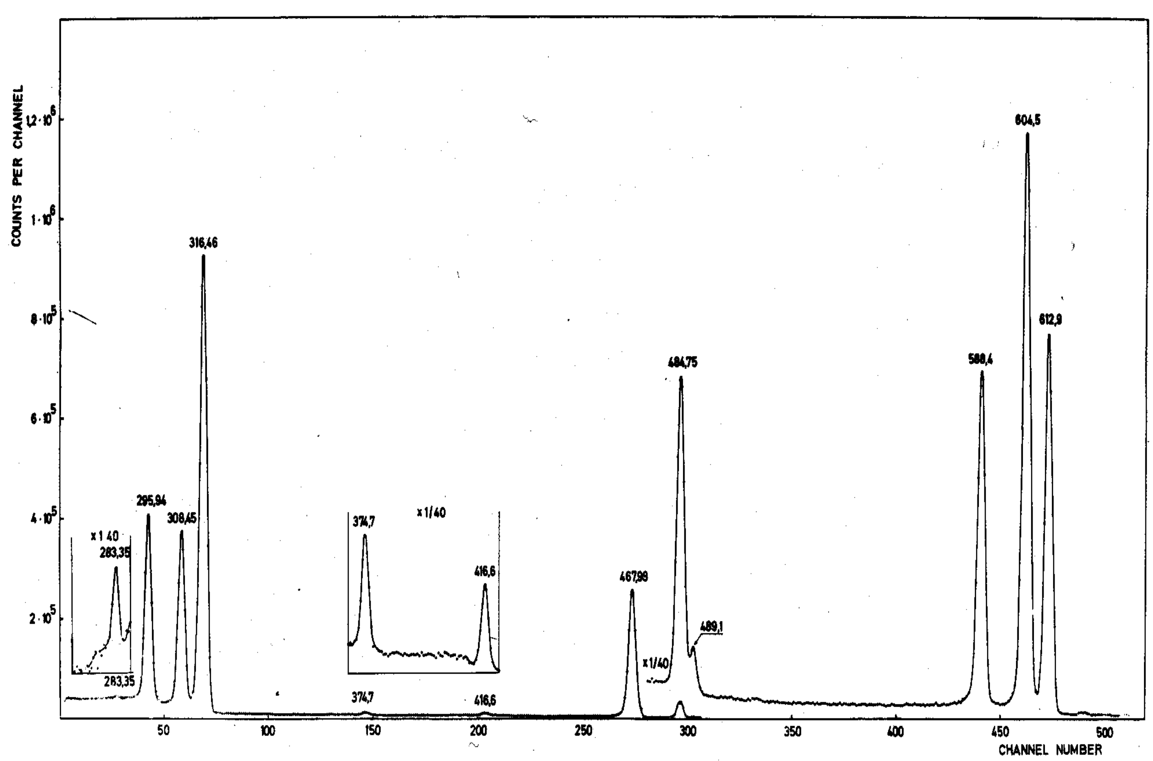

Fig. 2b. Energy spectrum of the photons emitted in decay of ^{192}Ir radionuclide in energy interval from 250 to 650 keV

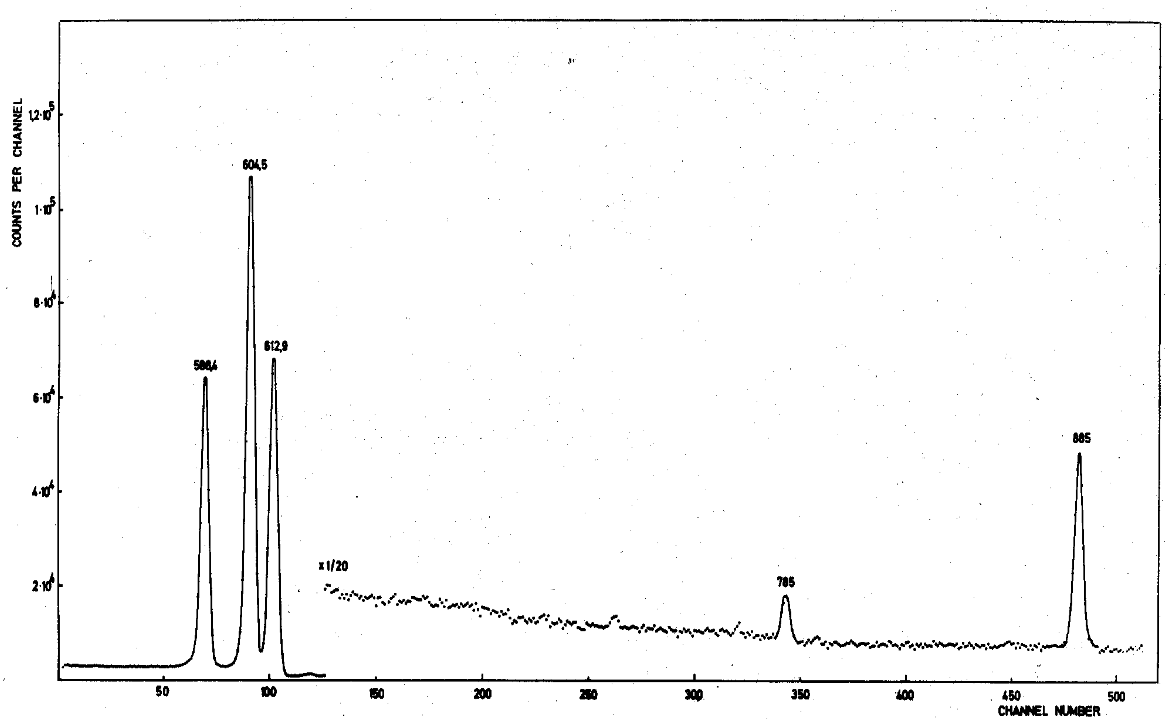

Fig. 2c. Energy spectrum of the photons emitted in decay of ^{192}Ir radionuclide in energy interval from 550 to 900 keV

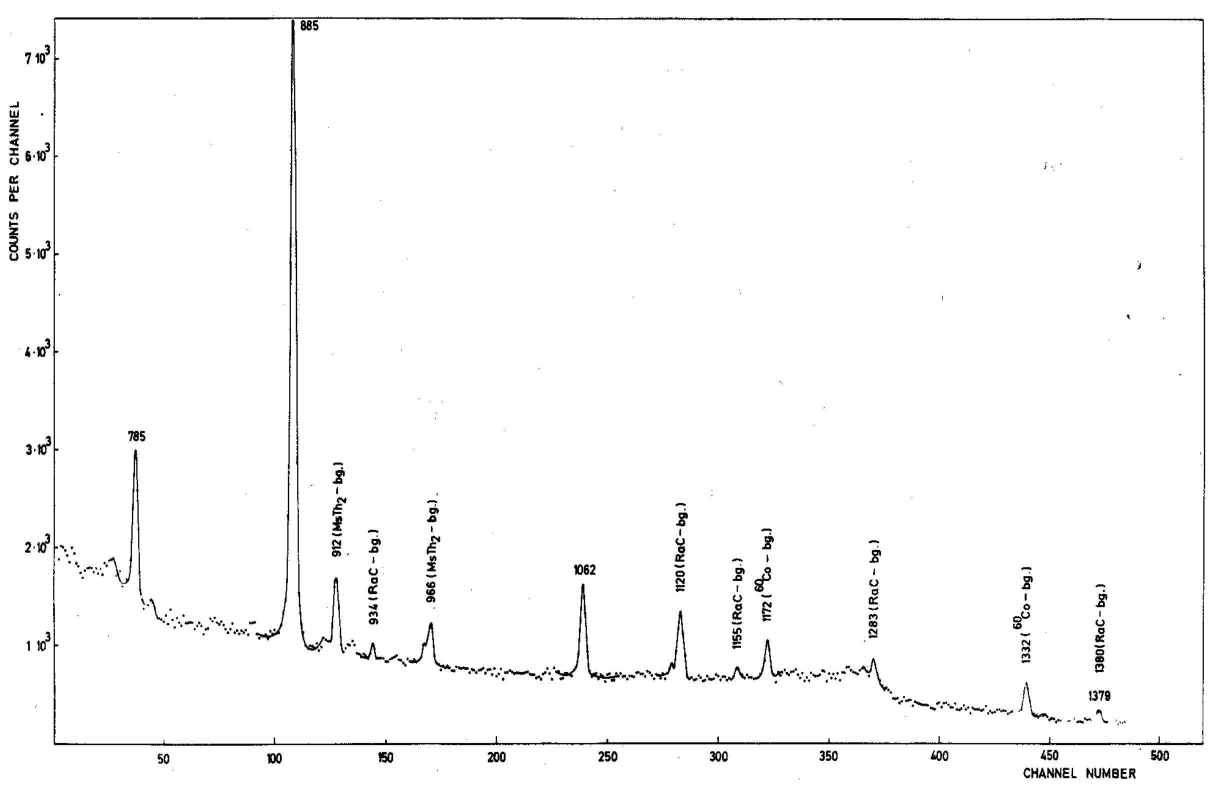

Fig. 2d. Energy spectrum of the photons emitted in decay of ^{192}Ir radionuclide in energy interval from 750 t0 1400 keV. This part of the spectrum contains many background lines from the RaC, MsTh and ^{60}Co

Group of lines	Energy [MeV]	Yield per decay [%]	Air mass energy transfer coeff. [10^{-3} m^2 kg^{-1}]	Air Kerma-rate const., Γ_δ [aGy m^2 s^{-1} Bq^{-1}]	Yield to total Γ_δ [%]
1	2	3	4	5	6
I	0.1363	0.17 ± 0.02	2.47	0.01 ± 0.001	<0.1
	0.2013	0.47 ± 0.04	2.67	0.03 ± 0.003	0.1
	0.2058	3.32 ± 0.18	2.68	0.23 ± 0.002	0.8
	0.2832	0.27 ± 0.02	2.85	0.03 ± 0.003	0.1
	0.30 ± 0.03				<1.1
II	0.08468	28.67 ± 0.50	2.86	3.10 ± 0.12	10.3
	0.10011	29.65 ± 0.45	2.88	3.35 ± 0.12	11.2
	0.11367	82.90 ± 0.4	2.88	9.63 ± 0.28	32.1
	16.08 ± 0.44				53.6
III	0.3745	0.70 ± 0.03	2.94	0.10 ± 0.01	0.3
	0.4165	0.64 ± 0.04	2.95	0.10 ± 0.01	0.3
	0.4681	47.94 ± 0.80	2.97	8.50 ± 0.31	28.4
	0.4846	3.18 ± 0.15	2.98	0.58 ± 0.04	1.9
	0.4891	0.40 ± 0.04	2.98	0.08 ± 0.01	0.2
	9.36 ± 0.34				31.1
IV	0.5886	4.47 ± 0.35	2.97	1.00 ± 0.10	3.3
	0.6044	8.25 ± 0.45	2.96	1.88 ± 0.14	6.3
	0.6125	5.26 ± 0.27	2.96	1.22 ± 0.09	4.1
	4.10 ± 0.30				13.7
V	0.785	0.05 ± 0.01	2.88	0.01 ± 0.003	<0.1
	0.8845	0.29 ± 0.05	2.88	0.09 ± 0.02	0.3
	1.062	0.06 ± 0.01	2.76	0.02 ± 0.004	0.1
	0.12 ± 0.03				0.5
Total air-kerma rate constant: 30.0 ± 0.9					100.0

Table 3. Data for calculation and calculated Partial, Groups and Total Air kerma rate constant of ^{192}I radionuclide (Ninkovic & Raicevic, 1993)

As can be seen from Table 3, the entire of photon ray spectrum of ^{192}Ir is divided into five characteristic groups of photon lines. The air kerma rate constant was calculated for each discrete photon line with yield per decay event >0.05 % and starting with energy of 0.1363 MeV as the lowest energy. That means X-ray were not included. The air kerma rate constant for the groups and for the total were obtained by addition of partial or single photon lines constant. Finally, a value of (30.0 ± 0.9) aGy m^2 s^{-1} Bq^{-1} for an unshielded ^{192}Ir source has been obtained. That value is in good agreement with a new recalculated value given in Table 1.

Keeping in mind that standard iridium sources are usually packed into 0.15 mm of platinum, the constant for that type of source was also calculated. For that goal, it was calculated the absorption of iridium photons into 0.15 mm of platinum and found that in the air kerma rate constant is reduced by 7.33 %. After this correction, a value of (27.8 ± 0.9) aGy m² s⁻¹ Bq⁻¹ was obtained for the air kerma rate constant for standard packaged iridium source (Ninkovic & Raicevic, 1993).

4.2.3 Results of Γ_δ calculation for ^{226}Ra (in equilibrium with its decay product) radionuclide

Group of lines	Energy [MeV]	Yield per decay [%]	Air mass energy transfer coeff. [10^{-3} m² kg⁻¹]	Air Kerma-rate const., Γ_δ [aGy m² s⁻¹ Bq⁻¹]	Yield to total Γ_δ [%]
1	2	3	4	5	6
I	0.1857	4.83 ± 0.26	2.63	0.301 ± 0.020	0.51
	0.2419	8.56 ± 0.42	2.78	0.737 ± 0.033	1.25
	0.2588	0.49 ± 0.04	2.28	0.046 ± 0.004	0.08
	0.2748	0.38 ± 0.15	2.84	0.038 ± 0.013	0.06
	0.2952	19.74 ± 1.00	2.86	2.125 ± 0.104	3.61
	0.3520	38.27 ± 2.00	2.92	5.015 ± 0.262	8.51
	0.3868	- -	2.94	- -	-
	0.3888	0.76 ± 0.14	2.94	0.111 ± 0.020	0.19
	0.4550	0.28 ± 0.07	2.98	0.048 ± 0.013	0.08
	0.4621	0.16 ± 0.06	2.98	0.028 ± 0.006	0.06
	0.4805	- -	2.98	- -	-
	0.4872	0.38 ± 0.05	2.98	0.080 ± 0.007	0.12
	0.6094	46.46 ± 1.42	2.96	10.685 ± 0.334	18.14
	19.20 ± 0.96				32.60
II	0.6656	1.68 ± 0.05	2.945	0.420 ± 0.013	0.71
	0.7031	0.58 ± 0.05	2.935	0.135 ± 0.013	0.26
	0.7199	0.40 ± 0.05	2.925	0.107 ± 0.013	0.18
	0.7684	4.88 ± 0.05	2.892	1.383 ± 0.026	2.35
	0.7860	1.10 ± 0.05	2.89	0.319 ± 0.013	0.54
	0.8062	1.31 ± 0.04	2.89	0.389 ± 0.013	0.66
	0.8212	0.10 ± 0.04	2.88	0.030 ± 0.012	0.05
	0.8392	0.52 ± 0.05	2.875	0.160 ± 0.013	0.27
	0.9340	3.20 ± 0.15	2.83	1.078 ± 0.033	1.83
	0.9641	0.38 ± 0,05	2.82	0.132 ± 0.020	0.22
	0.0520	0.35 ± 0.04	2.78	0.130 ± 0.013	0.22
	0.1040	0.15 ± 0.04	2.76	0.058 ± 0.012	0.10
	0.1204	16.70 ± 0.42	2.75	6.560 ± 0.231	11.14
	10.92 ± 0.40				18.54
III	1.1338	0.28 ± 0.04	2.745	0.111 ± 0.013	0.19
	1.1553	1.58 ± 0.10	2.735	0.636 ± 0.040	1.08
	1.2078	0.42 ± 0.05	2.715	0.176 ± 0.020	0.30
	1.2382	6.03 ± 0.16	2.695	2.565 ± 0.066	4.35
	1.2811	1.52 ± 0.05	2.675	0.664 ± 0.020	1.13

Group of lines	Energy [MeV]	Yield per decay [%]	Air mass energy transfer coeff. [10^{-3} m^2 kg^{-1}]	Air Kerma-rate const., Γ_δ [aGy m^2 s^{-1} Bq^{-1}]	Yield to total Γ_δ [%]
1	2	3	4	5	6
	1.3038	0.084 ± 0.035	2.70	0.048 ± 0.024	0.08
	1.3777	4.30 ± 0.10	2.63	1.986 ± 0.060	3.37
	1.4016	1.31 ± 0.05	2.62	0.613 ± 0.027	1.04
	1.4081	2.47 ± 0.05	2.61	1.157 ± 0.033	1.96
	1.5093	2.26 ± 0.05	2.57	1.118 ± 0.033	1.90
	1.5387	- -	2.56	- -	-
	1.5433	0.29 ± 0.06	2.555	0.146 ± 0.027	0.25
	1.5833	0.76 ± 0.05	2.54	0.390 ± 0.027	0.66
	1.5948	0.33 ± 0.04	2.535	0.170 ± 0.020	0.29
	1.6055	0.33 ± 0.05	2.53	0.171 ± 0.027	0.29
	1.6614	1.10 ± 0.04	2.505	0.584 ± 0.020	0.99
	1.6841	0.22 ± 0.0,04	2.495	0118 ± 0.020	0.20
	1.7298	2.91 ± 0.11	2.48	1.592 ± 0.060	2.70
	1.7646	16.70 ± 0.32	2.46	9.243 ± 0.231	15.69
	21.49 ± 0.79				36.49
IV	1.8386	0.34 ± 0.05	2.43	0.194 ± 0.026	0.33
	1.8476	2.14 ± 0.09	2.425	1.222 ± 0.043	2.07
	1.8735	0.20 ± 0.03	2.415	0.115 ± 0.019	0.20
	1.8967	0,06 ± 0.03	2.405	0.035 ± 0.014	0.06
	2.011	0.05 ± 0.02	2.36	0.030 ± 0.012	0.05
	2.017	- -	2.355	- -	-
	2.119	1.24 ± 0.02	2.325	0.779 ± 0.020	1.32
	2.2043	5.25 ± 0.03	2.305	3.401 ± 0.119	5.77
	2.294	0.34 ± 0.01	2.28	0.227 ± 0.007	0.38
	2.448	1.73 ± 0.03	2.235	1.207 ± 0.033	2.05
	7.21 ± 0.30				12.24
V	2.700	0.034 ± 0.005	2.16	0.025 ± 0.026	0.042
	2.770	0.028 ± 0.004	2.14	0.021 ± 0.043	0.036
	2.788	0.0058 ± 0.0010	2.135	0.001 ± 0.019	0.02
	2.885	0.0095 ± 0.0010	2.11	0.007 ± 0.014	0.012
	2.922	0.0162 ± 0.0030	2.10	0.001 ± 0.0005	0.002
	2.979	0.0162 ± 0.0010	2.08	0.001 ± 0.0002	0.002
	3.000	0.0089 ± 0.0010	2.075	0.001 ± 0.0001	0.002
	3.054	0.022 ± 0.003	2.065	0.018 ± 0.0.003	0.030
	3.082	0.0047 ± 0.00005	2.06	0.004 ± 0.001	0.007
	3.142	- -	2.05	- -	-
	0.08 ± 0.01				0.14
Total air-kerma rate constant: 58.9 ± 2.4					100.0

Table 4. Data for calculation and calculated partial, proup`s and total air kerma rate constant of ^{226}Ra radionuclide in equilibrium with its decay products (Ninkovic, 1987)

As it can be seen from this table , the entire of photon ray spectrum of ^{226}Ra (in equilibrium with its decay products) are divided into five characteristic groups of photon lines. The air kerma rate constant was calculated for each discrete photon line with yield per decay event >0.05 % and starting with energy of 0.1857 MeV as δ value. That means X-ray were not included. The air kerma rate constant for the groups and for the total were obtained by addition of partial or single photon lines constant. Finally, a value of (56.9 ± 2.4) aGy m^2 s^{-1} Bq^{-1} for an unshielded ^{226}Ra source has been obtained.

Having seen that standard radium sources are usually packed into 0.5 mm of platinum, the constant for that type of source was also calculated. For that goal it was used analyses of Shalek and Stoval (Shalek & Stovall, 1969), which is in good accordance with the earlier estimate of Aglincev et al. (Aglincev et al., 1960), that 0,5 mm of Pt by absorption of gamma radiation of radium and its decay products, reduce the air kerma rate constant with 9.25 %. After this correction, a value of (53.4 ± 2.2) aGy m^2 s^{-1} Bq^{-1} was obtained for the air kerma rate constant for standard packaged radium sources (Ninkovic, 1987). On the basis of this calculated value and experimentally measured value of Aglincev et al. (Aglincev et al., 1960) it was concluded (Ninkovic, 1987) that the real value of air kerma rate constant of ^{226} Ra in equilibrium with its decay product is smaller by about 1 to 2 %, than the value recommended by ICRU (ICRU, Handbook 86, 1963).

5. Conclussion

Presented process of recalculation the values for air kerma rate constants, for 35 of the most often used radionuclide in practice, was based on the newest appropriate decay data for every radionuclide and latest numerical data for mass energy-transfer coefficient. That is the reason why, according to the authors opinion, obtained values for $\Gamma_{\delta,}$ listed in the table 1, are the most accurate data that can be found in the literature available at present.

It has to be pointed out that to calculate the absorbed dose to soft tissue the air kerma rate has to be multiplied by the ratio of the mass energy-absorption coefficient of soft tissue to that of air, which can be taken as 1,11 between 2 and 0,1 MeV and drops to 1,04 at 0,02 MeV. Also, since the radiation-waiting factor for gamma rays and X rays is 1, by multiplying air kerma rate constants by a factor 1,11, the soft tissue-equivalent dose constant can be obtained.

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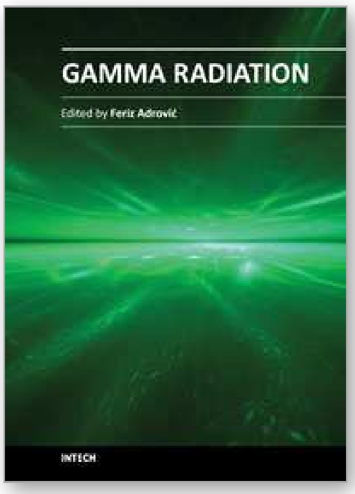

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This book brings new research insights on the properties and behavior of gamma radiation, studies from a wide range of options of gamma radiation applications in Nuclear Physics, industrial processes, Environmental Science, Radiation Biology, Radiation Chemistry, Agriculture and Forestry, sterilization, food industry, as well as the review of both advantages and problems that are present in these applications. The book is primarily intended for scientific workers who have contacts with gamma radiation, such as staff working in nuclear power plants, manufacturing industries and civil engineers, medical equipment manufacturers, oncologists, radiation therapists, dental professionals, universities and the military, as well as those who intend to enter the world of applications and problems of gamma radiation. Because of the global importance of gamma radiation, the content of this book will be interesting for the wider audience as well.