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Terrestrial Gamma Radiation in Kochi Prefecture, Japan

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Absorbed dose rates in air (dose rate) from terrestrial gamma radiations obtained using a scintillation survey meter ranged from 13.8 to 187 nGy/h depending on the geological features in Kochi Prefecture. Mean dose rates of four geological belts were found in the following order; Alluvial Deposits < Sambagawa Belt = Chichibu Belt < Shimanto Belt. The mean dose rate of the prefecture was about 60 nGy/h, which was 20% higher than that of Japan as a whole. The mean effective dose rate per person in this prefecture was about 0.37 mSv/y, which was the same as the Japanese mean. The ratio of the mean dose rates of ^{40}K, nuclides of the thorium series and the uranium series in the soil determined using a germanium detector were 2 : 2 : 1. The relationship between ^{40}K, ^{208}Tl and ^{214}Bi was positive, and therefore ^{40}K, nuclides of the thorium series and the uranium series were considered to have the same behavior in the soil. ^{137}Cs in the soil ranged from 1.4 to 150 Bq/kg with a mean of 24.5 ± 23.1 (S.D.) Bq/kg, suggesting that we continue to be under the influence of nuclear tests in the atmosphere.

Key words —— absorbed dose rate, effective dose rate, terrestrial gamma radiation, NaI(Tl) scintillation survey meter, germanium detector

INTRODUCTION

Natural sources of external radiation exposure consist of cosmic and terrestrial radiation. Absorbed dose rate in air (dose rate) from cosmic radiation is about 30 nGy/h in Japan,[1] and local dose rates vary with the geological features. Abe[2] and Furukawa[3] performed dose rate measurement outdoors of all of Japan, and Morita *et al.*[4] and others[5–8] performed detailed studies on the dose rates outdoors due to terrestrial background radiation in several prefectures. In this study, we examined the distribution of dose rates outdoors from terrestrial gamma radiation and their effective dose rates, and investigated the relationship between dose rate and concentration of radioactive nuclides in the soil in Kochi Prefecture from February 1997 to March 2000.

MATERIALS AND METHODS

Study Sites —— Measurement sites were selected from the following three factors according to "The Geological and Mineral Spring Resources Map of Kochi Prefecture"[9] (Fig. 1, Fig. 2). (1) Flat and unpaved ground. (2) No structure within a radius of 5 m from the site. (3) No soil brought from another place around the site. Geological features were calculated by the gravimetric method from the above geological map.

Apparatus and Methods —— Dose rates were measured at 511 sites with a NaI(Tl) scintillation survey meter (Aloka TCS-166) fixed with a tripod horizontally 1 m above the ground surface. Five measurements were made for 30 s each, and the results were averaged. When multiple measurement sites were in the same geological feature within a distance of 1 km, their dose rates were averaged. Measurements were performed 24 h or more after rain to avoid the effects of the fallout of radon and its decay products. Presuming that indoor and outdoor dose rates are equivalent in Japan,[10] effective dose rate was calculated by the following formula:

$$\text{Effective dose rate (mSv/y)} = \text{dose rate (nGy/h)} \times 24\ \text{h} \times 365\ \text{d} \times 0.8\ \text{(conversion coefficient)} \times 10^{-6}$$

The number of inhabitants was determined from the national census taken in October 1995.

Nuclides in the soil collected from 373 sites were measured for over 30000 s using a germanium de-

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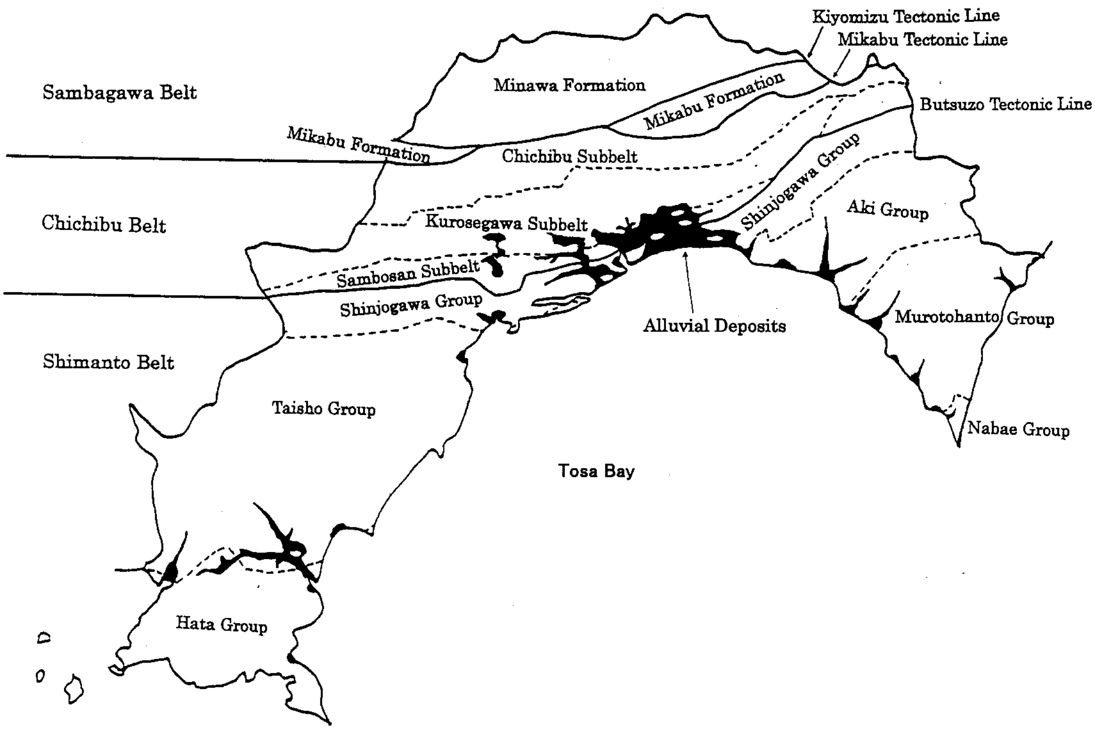

Fig. 1. Tectonic Subdivisions and Boundaries of Kochi Prefecture[a]

a) : Investigated and edited by Katto *et al.* in 1991[9]; The geology of Kochi Prefecture is characterized chiefly by a distinct zonal arrangement of pre-Neogene rocks, which strike East to West and are divided into three; the Sambagawa, Chichibu and Shimanto Belts, from north to south. The areas of alluvial deposits are distributed mainly along the coast.

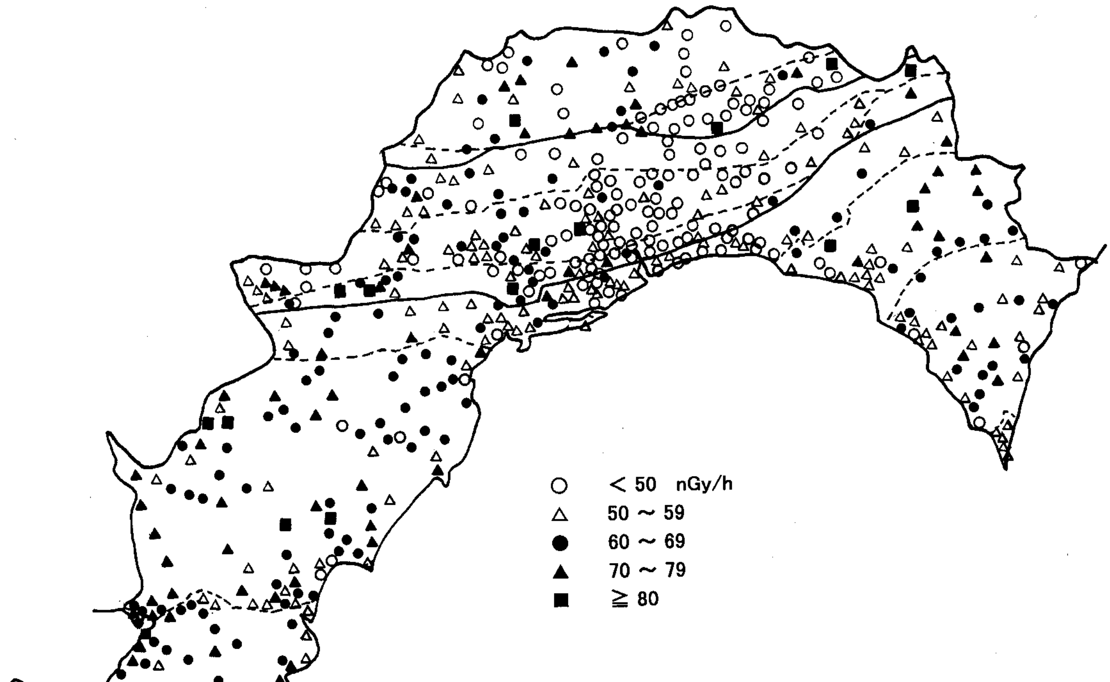

Fig. 2. Absorbed Dose Rates of 511 Sites Examined in Kochi Prefecture from February 1997 to March 2000

tector (Toshiba IGC1619SD). Samples collected from 285 sites using a soil collector were analyzed with regard to ^{40}K, nuclides of the thorium series and uranium series, and ^{137}Cs, while samples collected from 88 sites using a scoop were analyzed for the above nuclides with the exception of ^{137}Cs. If natural radioactive nuclides are uniformly distributed in the ground, dose rates at 1 m above the ground surface were calculated by the following formula:

Dose rate (nGy/h)
= concentration of nuclide (Bq/kg)
× HASL's coefficient[11)]

Preparation of Soil Sample —— Soil was sampled from 0–10 cm depth layers collected with a soil collector (inside diameter: 5.5 cm) at three points within a radius of 5 m from the sites at which dose rates were measured. When a surface layer was hard or covered with pebbles and stones, soil of 0– ca. 2 cm depth layer was collected with a scoop. The soil from which plant materials was removed was dried for 3 h at 105 °C in a oven, and sifted out with a sieve of 2 mm mesh to remove stones and pebbles. Soil samples were preserved in plastic bottles (inside diameter: 5 cm), sealed with two acrylic boards and glue, and left for about 40 d at room temperature.

RESULTS AND DISCUSSION

Absorbed Dose Rate

Dose rates ranged from 13.8 to 187 nGy/h, and variations were dependent on the geological features (Table 1, Fig. 3). Eighteen sites under 30 nGy/h were found mainly in the Mikabu greenstone area of the Sambagawa Belt and serpentinite area of the Chichibu Belt (Fig. 4). In both areas, rocks originating mainly in basalt and peridotite were observed.

Table 1. The Geological Features[a)] and Their Absorbed Dose Rates Examined in 511 Sites in Kochi Prefecture from February 1997 to March 2000

Geological Feature	Number of Sites	Absorbed Dose Rate (nGy/h) Range	Mean ± S.D.	Area (km^2)	Number of Inhabitants
Sambagawa Belt					
Kuma Formation (Terrestrial facies area)	1		50.8	3	0
Minawa Formation					
Pelitic schist area	23	52.2 – 81.2	65.5 ± 8.4	547	4467
Siliceous schist area	3	50.4 – 61.8	56.3 ± 5.7	48	446
Basic schist area	11	28.4 – 47.2	38.4 ± 6.6	175	275
Highly foliated pelitic schist area	8	21.6 – 48.6	37.6 ± 8.8	32	7552
Mikabu Formation					
Mikabu greenstone area	8	16.0 – 45.0	24.9 ± 9.3	144	2591
Pelitic schist area	8	52.8 – 86.1	67.8 ± 12.8	131	4312
Siliceous schist area	5	32.5 – 51.0	40.3 ± 7.3	49	149
Subtotal	67	16.0 – 86.1	54.1	1129	19792
Chichibu Belt					
Chichibu Sub-belt					
Ac area	27	42.2 – 67.0	51.5 ± 7.2	547	11849
Quartz porphyry area	1		36.0	3	0
Chert area	5	61.0 – 85.1	70.6 ± 9.2	33	622
Kurosegawa Sub-belt					
Shelf depositional facies area	23	43.9 – 81.0	56.4 ± 8.2	187	54357
Melange 1 area	8	31.0 – 56.8	44.2 ± 7.4	142	2224
Melange 2 area	30	38.4 – 80.4	57.0 ± 11.4	224	14220
Serpentinites area	12	13.8 – 37.7	24.8 ± 8.7	46	10137
Sambosan Sub-belt					
Shelf depositional facies area	4	49.6 – 65.0	58.4 ± 6.5	29	1102
Ac area	14	57.2 – 85.0	71.4 ± 9.1	266	16124
Melange area	2	60.5 – 68.4	64.4 ± 5.6	31	2211
Limestone area	15	29.2 – 46.6	37.9 ± 5.6	48	9692
Subtotal	141	13.8 – 85.1	55.2	1556	122538

Table 1. Continued

Geological Feature	Number of Sites	Absorbed Dose Rate (nGy/h) Range	Mean ± S.D.	Area (km^2)	Number of Inhabitants
Shimanto Belt					
Shinjogawa Group					
Td area	14	50.5 – 65.7	57.2 ± 4.6	172	13174
Td/Sl area	24	49.8 – 75.4	60.5 ± 7.3	550	44984
Aki and Taisho Groups					
Td area	57	49.8 – 83.4	66.1 ± 7.8	1548	42814
Td/Sl area	8	52.4 – 75.0	70.4 ± 7.7	258	2287
Sl area	15	57.4 – 77.4	66.6 ± 6.0	137	12824
Melange area	16	53.2 – 102	70.6 ± 13.3	253	4954
Terrestrial facies area	3	43.6 – 55.8	49.9 ± 6.1	8	538
Murotohanto and Hata Groups					
Td area	45	52.0 – 80.8	64.7 ± 6.9	1001	33476
Sl area	4	62.3 – 83.0	75.0 ± 8.9	20	6600
Melange area	6	32.8 – 70.8	56.9 ± 13.3	57	2578
Shelf depositional facies area	8	55.0 – 73.7	62.9 ± 7.3	61	10254
Granite area	8	89.6 – 187	127 ± 35.5	32	3294
Nabae Group (Td/Sl area)	4	52.6 – 58.8	55.4 ± 2.6	26	8435
Subtotal	212	32.8 – 187	65.3	4123	186212
Alluvial Deposits					
The plains in the eastern part of Kochi Pref.	17	48.2 – 62.4	54.7 ± 4.5	33	40880
The plains in the central part of Kochi Pref.	43	31.6 – 69.0	48.0 ± 7.0	187	359206
The plains in the western part of Kochi Pref.	10	52.8 – 72.9	61.3 ± 6.2	33	26716
The coastal plains from the western part of Aki City to Okata Town	19	31.9 – 56.0	42.4 ± 7.3	41	60921
The Ohkinohama coastal plain	2	62.6 – 69.8	66.2 ± 5.1	2	439
Subtotal	91	31.6 – 72.9	49.6	296	488162
Total	511	13.8 – 187	60.7	7104	816704

a) Investigated and edited by Katto *et al.* in 1991[9]; Ac: undivided accretionary prism composed of seamount materials and pelagic sediments; Melange 1: Melange mainly composed of limestone; Melange 2: Melange mainly composed of tuff; Sl: slope depositional facies; Td: accretionary prism mainly composed of trench deposits; Td/Sl: coexistence of Td with Sl.

The lowest dose rate (13.8 nGy/h) was found in the serpentinite area. Values ranging from 30 to 49 nGy/h were found in 127 sites mainly in the basic schist area of the Sambagawa Belt, limestone and melange areas of the Chichibu Belt, and alluvial deposits. Values ranging from 50 to 69 nGy/h were found in 274 sites of most sites other than granite and low dose rate areas. Values ranging from 70 to 79 nGy/h were found in 67 sites mainly in the Ac area of the Chichibu Belt, and Td area of the Shimanto Belt. Twenty-five sites with values over 80 nGy/h were found mainly in the pelitic schist area of the Sambagawa Belt, melange and granite areas of the Shimanto Belt, where granite, chert and shale, and their mixtures were recognized. The highest dose rate (187 nGy/h) was found in the granite area.

The mean dose rate of the Sambagawa Belt was 54.1 nGy/h. Mikabu greenstone, highly foliated pelitic schist and basic schist areas had lower mean dose rates of under 40 nGy/h, while pelitic schist areas had higher mean dose rates of over 60 nGy/h. The mean dose rate of the Chichibu Belt was 55.2 nGy/h. Serpentinite and limestone areas were lower mean dose rates under 40 nGy/h, while the Ac area of the Sambosan Sub-belt and chert area were higher mean dose rates over 70 nGy/h. The mean dose rates of the Sambagawa and Chichibu Belts were the same as those (56 nGy/h) of the districts from the western part of the Itoigawa–Shizuoka Tectonic Line.[12] The mean dose rate (65.3 nGy/h) was comparatively high in the Shimanto Belt, and was higher than 120 nGy/h in the granite area. The mean dose rate of the alluvial deposits was the same as the mean of Japan as a whole (50 nGy/h).[1] The mean dose rates of plains in the central part of the prefecture and the coastal plains except Ohkinohama

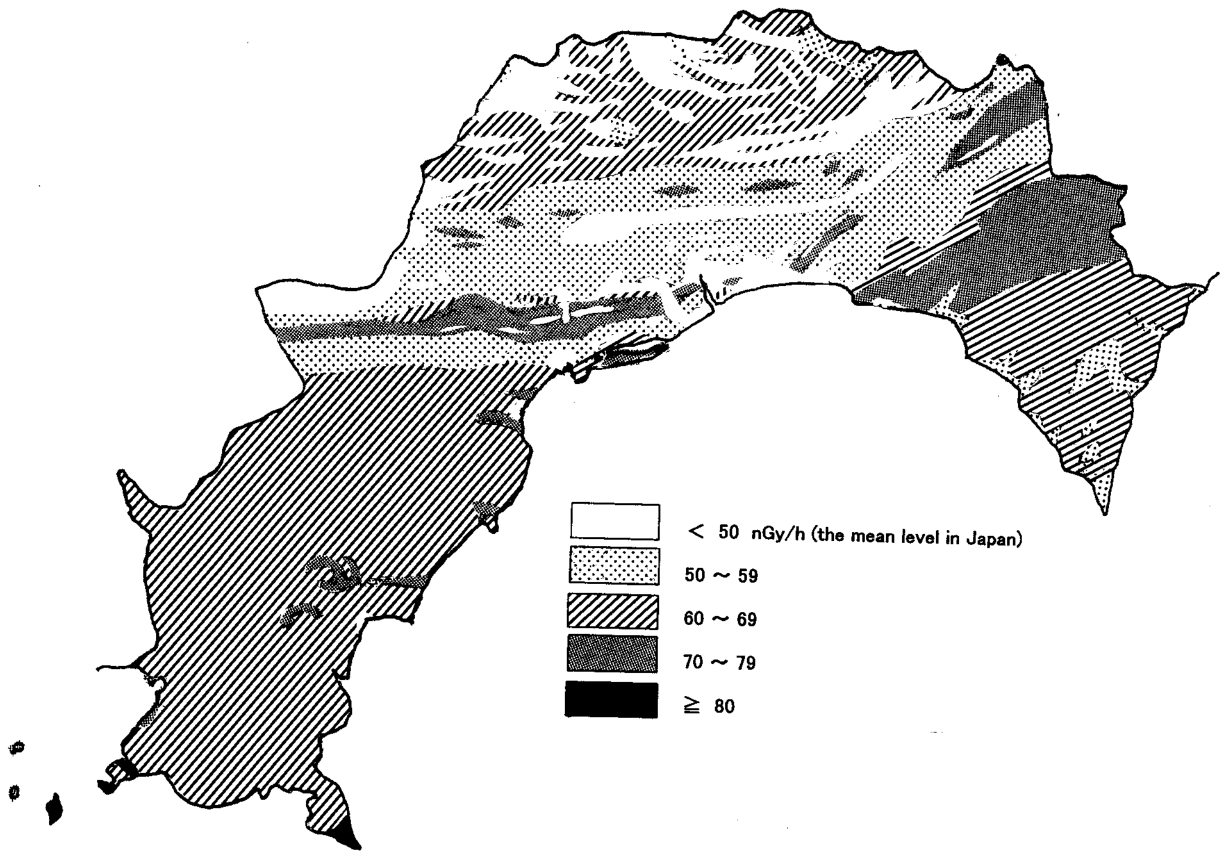

Fig. 3. Absorbed Dose Rates Map of Kochi Prefecture Based on the Geological Features[a]
a) : Investigated and edited by Katto *et al.* in 1991.[9]

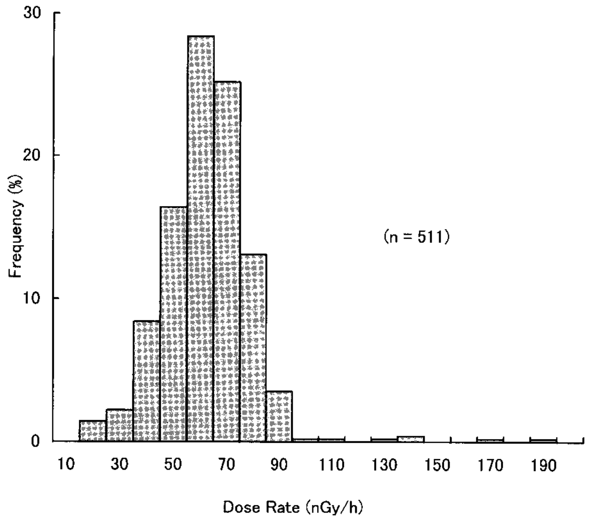

Fig. 4. Frequency (%) of Absorbed Dose Rates in 511 Sites in Kochi Prefecture
The minimum and maximum values were found in serpentinite and granite areas with values of 13.8 and 187 nGy/h, respectively, and the main frequency lay between 50 and 70 nGy/h.

were less than 50 nGy/h.

The mean dose rates of four geological belts were in the order of Alluvial Deposits < Sambagawa Belt = Chichibu Belt < Shimanto Belt. The mean dose rate of the whole prefecture was about 60 nGy/h, which was 20% higher than that in Japan as a whole.

Measured spots were classified into the following four groups based on the surface conditions: A: Bare or sandy land; B: Land with weeds; C: Farmland; D: Withered leaves-rich land (Table 2, Fig. 5). Dose rates in A and B groups were distributed irregularity ranging from 13.8 to 187 nGy/h and from 22.6 to 161 nGy/h, respectively, and both groups seemed to be influenced directly by radioactivity of the surface layer. In contrast, the distributions of dose rates in C and D groups were almost normal ranging from 33.0 to 70.8 nGy/h and from 17.5 to 85.0 nGy/h, respectively, lower than the prefectural mean. These results suggested that terrestrial radiation was shielded by humus.

Table 2. Absorbed Dose Rates Classified into Four Groups Based on the Surface Conditions in Kochi Prefecture

Surface Conditions	Number of Spots	Absorbed Dose Rate (nGy/h) Range	Mean ± S.D.	Skewness	Kurtosis
Bare or Sandy Land	174	13.8 – 187	60.9 ± 22.8	1.12	5.55
Land with Weeds	149	22.6 – 161	56.0 ± 14.2	2.48	19.4
Farmland	59	33.0 – 70.8	55.1 ± 7.1	−0.46	0.90
Withered Leaves-rich Land	129	17.5 – 85.0	56.2 ± 12.2	−0.53	0.85
Total	511	13.8 – 187	57.6 ± 16.8	1.57	10.8

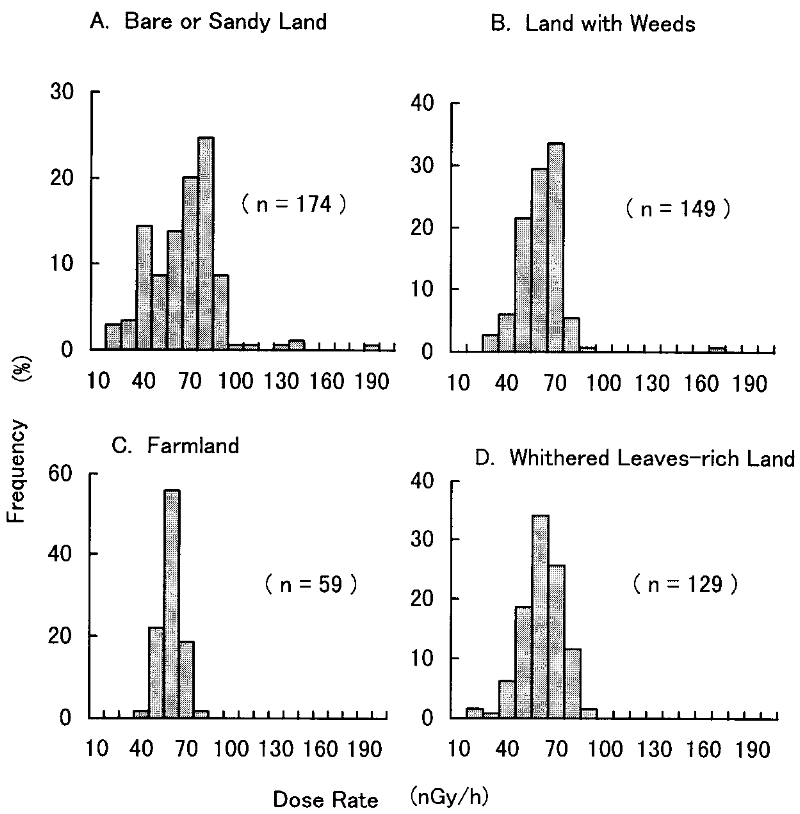

Fig. 5. Frequency (%) of Absorbed Dose Rates Classified into Four Groups Based on the Surface Conditions in Kochi Prefecture

Effective Dose Rate

Low and high effective dose rates were detected in the central and western parts of the prefecture, respectively (Table 3, Fig. 6). The lowest dose rate (0.26 mSv/y) was detected in Tosa Town where most people lived in highly foliated pelitic schist area of the Sambagawa Belt, while the highest (0.54 mSv/y) was detected in Otsuki Town where most people lived in the Hata Group of the Shimanto Belt. Levels under 0.38 mSv/y (the mean level in Japan) were found in the districts where most people lived mainly in the alluvial deposits. Dose rates ranging from 0.39 to 0.44 mSv/y were found in the districts where most people lived mainly in the Chichibu Belt or Shimanto Belt. Levels over 0.45 mSv/y were found in the districts where most people lived mainly in the Shimanto Belt. The mean effective dose rate (0.37 mSv/y) of the prefecture was the same as the mean of Japan as a whole, because about 60% of the people in the prefecture lived in the alluvial deposits, which accounted for 4% of the prefectural area.

Concentrations of Radioactive Nuclides in the Soil

Concentrations of ^{40}K, ^{208}Tl and ^{214}Bi in the soil ranged from 16.6 to 1300 Bq/kg dry weight with a mean of 581 ± 214 Bq/kg dry weight, from 1.3 to 82.8 Bq/kg dry weight with a mean of 14.8 ± 6.8 Bq/kg dry weight, and from n.d. to 100 Bq/kg dry weight

Table 3. Effective Dose Rate per Person Divided into 53 Municipalities in Kochi Prefecture in October 1995

Names of Cities, Towns and Villages	Effective Dose Rate (mSv/y)	Main Geological Feature	(Subgeological Feature)	Number of Inhabitants
Tosa. T.	0.26	Sambagawa Belt		5292
Geisei V.	0.30	Alluvial Deposit		4383
Yoshikawa V.	0.31	Alluvial Deposit		2095
Akaoka T.	0.31	Alluvial Deposit		3599
Motoyama T.	0.31	Sambagawa Belt		4901
Tosayama V.	0.33	Chichibu Belt		1347
Kochi C.	0.34	Alluvial Deposit	(Chichibu Belt)	321999
Nankoku C.	0.34	Alluvial Deposit	(Chichibu Belt)	48192
Haruno T.	0.35	Alluvial Deposit	(Shimanto Belt)	14806
Ochi T.	0.35	Alluvial Deposit	(Chichibu Belt)	7803
Nakatosa T.	0.35	Alluvial Deposit	(Shimanto Belt)	7516
Tosayamada T.	0.35	Alluvial Deposit	(Chichibu Belt)	21951
Susaki C.	0.36	Alluvial Deposit	(Shimanto Belt)	28742
Tosa C.	0.36	Alluvial Deposit	(Shimanto Belt)	30723
Kagami V.	0.36	Chichibu Belt		1712
Noichi T.	0.36	Alluvial Deposit		15102
Hidaka V.	0.37	Alluvial Deposit	(Chichibu Belt)	6105
Kagami T.	0.37	Sambagawa Belt	(Alluvial Deposit)	6227
Sakawa T.	0.37	Alluvial Deposit	(Chichibu Belt)	15148
Gohoku V.	0.38	Chichibu Belt	(Sambagawa Belt)	3705
Tano T.	0.38	Alluvial Deposit		3575
Ino T.	0.38	Alluvial Deposit	(Chichibu Belt)	25444
Agawa V.	0.38	Chichibu Belt		3371
Otovo T.	0.39	Sambagawa Belt		6979
Aki C.	0.39	Alluvial Deposit		22377
Muroto C.	0.39	Alluvial Deposit	(Shimanto Belt)	21430
Ikegawa T.	0.39	Chichibu Belt	(Sambagawa Belt)	2641
Kahoku T.	0.39	Chichibu Belt		5733
Niyodo V.	0.39	Chichibu Belt		2907
Yasuda T.	0.40	Alluvial Deposit	(Shimanto Belt)	3826
Nahari T.	0.40	Alluvial Deposit	(Shimanto Belt)	4291
Okata T.	0.40	Shimanto Belt	(Alluvial Deposit)	10395
Monobe V.	0.40	Shimanto Belt	(Chichibu Belt)	3392
Hayama V.	0.40	Shimanto Belt		4630
Yusuhara T.	0.40	Shimanto Belt	(Chichibu Belt)	4998
Toyo T.	0.41	Alluvial Deposit	(Shimanto Belt)	4068
Kitagawa V.	0.42	Shimanto Belt		1650
Yasu T.	0.42	Shimanto Belt	(Alluvial Deposit)	4458
Okawa V.	0.42	Sambagawa Belt		680
Higashitsuno V.	0.44	Shimanto Belt	(Chichibu Belt)	2924
Nakamura C.	0.44	Alluvial Deposit	(Shimanto Belt)	34930
Onomi V.	0.45	Shimanto Belt		1805
Mihara V.	0.45	Shimanto Belt		1986
Sukumo C.	0.45	Shimanto Belt	(Alluvial Deposit)	25919
Umaji V.	0.46	Sambagawa Belt		1242
Hongawa V.	0.46	Shimanto Belt		930
Towa V.	0.46	Shimanto Belt		3862
Nishitosa V.	0.46	Shimanto Belt		4061
Kubokawa T.	0.46	Shimanto Belt		15606

Table 3. Continued

Names of Cities, Towns and Villages	Effective Dose Rate (mSv/y)	Main Geological Feature	(Subgeological Feature)	Number of Inhabitants
Saga T.	0.46	Shimanto Belt		4629
Taisho T.	0.47	Shimanto Belt		3613
Tosashimizu C.	0.48	Shimanto Belt		19582
Otsuki T.	0.54	Shimanto Belt		7422
Total	0.37	Alluvial Deposit	(Shimanto Belt)	816704

C: City; T: Town; V: Village

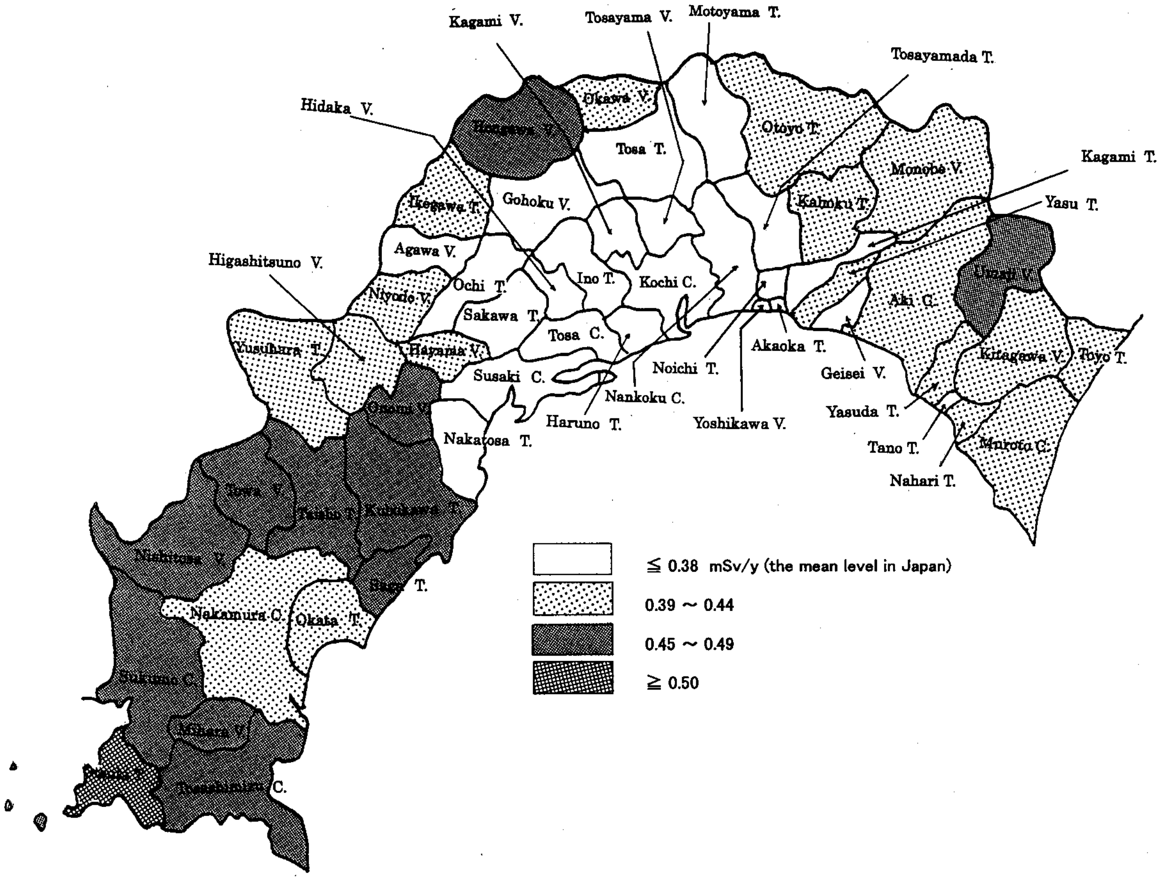

Fig. 6. Effective Dose Rates Map of Kochi Prefecture Divided into 53 Municipalities in October 1995

with a mean of 26.4 ± 10.5 Bq/kg dry weight, respectively. The minimum and maximum values were found in serpentinite and granite areas, respectively (Table 4).

The mean dose rates calculated from concentrations of ^{40}K, nuclides of the thorium series and the uranium series in the soil were 24.2 ± 8.9 nGy/h, 24.8 ± 11.4 nGy/h and 12.2 ± 4.8 nGy/h, respectively. The total calculated mean dose rate (61.3 ± 22.4 nGy/h) was the same as the mean dose rate (58.8 ± 18.8 nGy/h) determined with a scintillation survey meter at the same sites, and also the relationship between total calculated dose rates and dose rates in the same sites showed a high correlation coefficient (r = 0.899) (Fig. 7). However, differences of over 20 nGy/h between total calculated dose rates and dose rates were found at 19 sites. These observations might be explained as follows: (1) The soil samples were analyzed after removal of pebbles and stones; (2) Natural radioactive nuclides may not be distributed uniformly in the soil; (3) Radon and its decay products in the atmosphere may affect dose rates; (4) Soil moisture of the surface layer may affect dose rates[13]; (5) The scintillation

Table 4. Concentrations of Radioactive Nuclides in 373 Soil Samples Collected in Kochi Prefecture from February 1997 to March 2000 and Their Calculated Dose Rates

	Nuclide	Number of Samples	Range	Mean ± S.D.
Concentration (Bq/kg·dry)	^{40}K	373	16.6 – 1300	581 ± 214
	^{208}Tl	373	1.3 – 82.8	14.8 ± 6.8
	^{214}Bi	373	n.d. – 100	26.4 ± 10.5
	^{137}Cs	285	1.4 – 150	24.5 ± 23.1
Calculated Dose Rate$^{a)}$ (nGy/h)	^{40}K	373	0.7 – 54.2	24.2 ± 8.9
	Thorium series	373	2.2 – 139	24.8 ± 11.4
	Uranium series	373	0.0 – 46.2	12.2 ± 4.8
	Total	373	2.9 – 226	61.3 ± 22.4
Dose Rate$^{b)}$ (nGy/h)		373	10.0 – 198	58.8 ± 18.8

n.d.: not detected; *a*): dose rates calculated from concentrations of ^{40}K, ^{208}Tl and ^{214}Bi in the soil; *b*): dose rates obtained using a scintillation survey meter at the same sites.

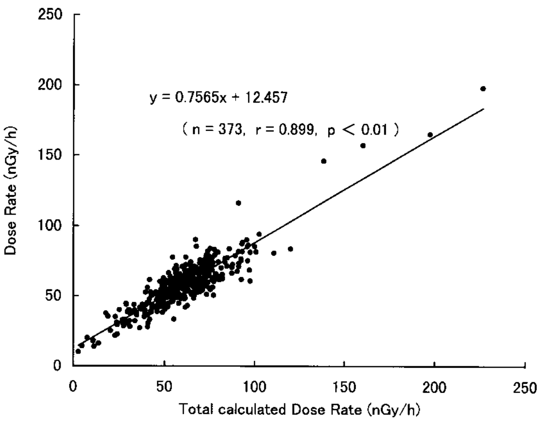

Fig. 7. Relationship between Total Dose Rates Calculated from Concentrations of ^{40}K, ^{208}Tl and ^{214}Bi in 373 Soil Samples of Kochi Prefecture and Dose Rates Obtained Using a Scintillation Survey Meter at the Same Sites

survey meter may be influenced by cosmic rays.[14)]

The correlation between total calculated dose rates and concentrations of nuclides was in the order of ^{40}K (r = 0.834) < ^{214}Bi (r = 0.881) < ^{208}Tl (r = 0.939) with a high correlation coefficients. The correlation of three nuclides was in the order of ^{40}K–^{214}Bi (r = 0.570) < ^{40}K–^{208}Tl (r = 0.613) < ^{208}Tl–^{214}Bi (r = 0.861) with positive correlation coefficients (Table 5). From these results, it seemed that ^{40}K, nuclides of the thorium and the uranium series showed the same behavior in the soil in this prefecture.

Concentrations of ^{137}Cs in the soil ranged from 1.4 to 150 Bq/kg dry weight with a mean of 24.5 ± 23.1 Bq/kg dry weight, suggesting that we continue to be under the influence of nuclear tests

Table 5. Correlation between Concentrations of Nuclides in the Soil of Kochi Prefecture and Their Total Calculated Dose Rates

	^{208}Tl$^{a)}$	^{214}Bi$^{a)}$	T-Dose$^{b)}$
^{40}K$^{a)}$	0.613**	0.570**	0.834**
^{208}Tl$^{a)}$		0.861**	0.939**
^{214}Bi$^{a)}$			0.881**

a) : concentration (Bq/kg); *b*) : total dose rates calculated from concentrations of ^{40}K, ^{208}Tl and ^{214}Bi in the soil; ** : $p < 0.01$.

in the atmosphere. The minimum and maximum values were found at the sites where rocks and pebbles were exposed on the surface, and in sites where the surface was covered by withered leaves, respectively.

Spots were classified into the following four groups based on the surface conditions: A: Bare or sandy land; B: Land with weeds; C: Farmland; D: Withered leaves-rich land (Table 6). The ratio of ^{40}K in group C seemed to be higher than the others, because potassium fertilizer was applied to farmland. However, the ratios of ^{40}K in groups B and D were lower than the others, because potassium in the soil was absorbed by plants. Concentrations of ^{137}Cs in groups C and D rich in humus were higher than the others, while that in group A poor in humus was lower than in the other groups (Fig. 8). This result suggested that ^{137}Cs was combined with organic matter in the soil and remained in the surface layer for long periods.

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Table 6. Concentrations of Nuclides in the Soil of Kochi Prefecture Based on the Surface Conditions and Their Calculated Dose Rates

A : Bare or Sandy Land

	Nuclide	Number of Samples	Range	Mean ± S.D.
Concentration (Bq/kg·dry)	^{40}K	116	16.6 – 1300	639 ± 252
	^{208}Tl	116	1.3 – 82.8	15.8 ± 9.2
	^{214}Bi	116	n.d. – 82.9	27.3 ± 12.2
	^{137}Cs	54	1.4 – 30.9	7.2 ± 5.1
Calculated Dose Rate (nGy/h)	^{40}K	116	0.7 – 54.2	26.6 ± 10.5
	Thorium series	116	2.2 – 139	26.5 ± 15.4
	Uranium series	116	0.0 – 38.3	12.6 ± 5.7
	Total	116	2.9 – 226	65.8 ± 29.2
Ratio (%)	^{40}K	116	18.7 – 52.4	41.0 ± 7.1
	Thorium series	116	27.0 – 75.9	39.8 ± 6.9
	Uranium series	116	0.0 – 41.6	19.2 ± 4.5

B : Land with Weeds

	Nuclide	Number of Samples	Range	Mean ± S.D.
Concentration (Bq/kg·dry)	^{40}K	102	81.2 – 1130	523 ± 174
	^{208}Tl	102	3.2 – 62.0	14.0 ± 6.5
	^{214}Bi	102	5.6 – 100	25.5 ± 11.2
	^{137}Cs	87	2.4 – 68.2	15.6 ± 11.0
Calculated Dose Rate (nGy/h)	^{40}K	102	3.4 – 47.1	21.8 ± 7.2
	Thorium series	102	5.4 – 104	23.5 ± 10.9
	Uranium series	102	2.6 – 46.2	11.8 ± 5.2
	Total	102	11.4 – 197	57.1 ± 20.1
Ratio (%)	^{40}K	102	18.7 – 55.1	38.8 ± 8.7
	Thorium series	102	28.1 – 55.0	40.6 ± 6.3
	Uranium series	102	13.1 – 30.2	20.6 ± 4.0

C : Farmland

	Nuclide	Number of Samples	Range	Mean ± S.D.
Concentration (Bq/kg·dry)	^{40}K	35	359 – 863	647 ± 138
	^{208}Tl	35	7.0 – 24.5	13.7 ± 3.6
	^{214}Bi	35	14.5 – 36.7	25.3 ± 6.0
	^{137}Cs	31	3.3 – 60.8	25.3 ± 17.5
Calculated Dose Rate (nGy/h)	^{40}K	35	15.0 – 36.0	27.0 ± 5.8
	Thorium series	35	11.8 – 41.1	23.0 ± 6.1
	Uranium series	35	6.7 – 17.0	11.7 ± 2.8
	Total	35	33.8 – 91.2	61.7 ± 12.6
Ratio (%)	^{40}K	35	31.5 – 55.9	43.9 ± 5.3
	Thorium series	35	25.5 – 50.0	37.1 ± 4.2
	Uranium series	35	14.3 – 28.7	19.1 ± 3.4

Table 6. Continued

D : Withered Leaves-rich Land

	Nuclide	Number of Samples	Range	Mean ± S.D.
	^{40}K	120	60.7 – 1070	555 ± 206
Concentration	^{208}Tl	120	3.1 – 29.1	14.9 ± 4.5
(Bq/kg·dry)	^{214}Bi	120	n.d. – 52.8	26.7 ± 8.8
	^{137}Cs	113	7.7 – 150	39.4 ± 27.1
Calculated	^{40}K	120	2.5 – 44.6	23.1 ± 8.6
Dose Rate	Thorium series	120	5.2 – 48.8	24.9 ± 7.6
(nGy/h)	Uranium series	120	0.0 – 24.4	12.3 ± 4.1
	Total	120	7.7 – 111	60.4 ± 17.8
	^{40}K	120	13.7 – 59.5	37.7 ± 7.8
Ratio (%)	Thorium series	120	25.9 – 67.1	41.8 ± 6.3
	Uranium series	120	0.0 – 34.0	20.4 ± 4.7

n.d. : not detected

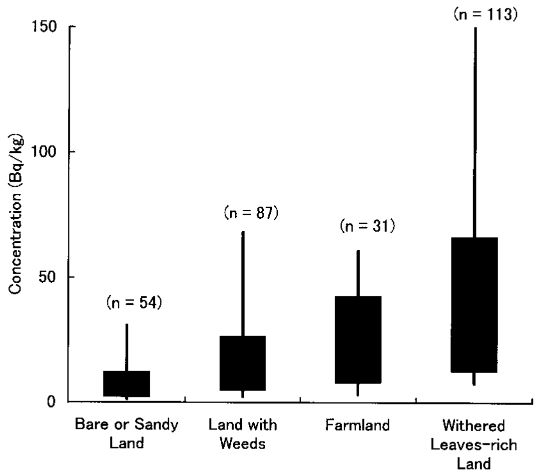

Fig. 8. Concentrations of ^{137}Cs in 285 Soil Samples Classified into Four Groups Based on the Surface Conditions in Kochi Prefecture

Vertical lines and boxes indicate ranges and mean ± S.D. of concentrations of ^{137}Cs in the soil.

REFERENCES

1) Furukawa, M. (1998) Chikyu Kibo no Shizen Hoshasen (2). *Chikyu Monthly*, **22**, 55–62.
2) Abe, S. (1982) Efforts to obtain Japanese Profile of Ambient Natural Radiation Exposure. *Health Phys.*, **17**, 169–193.
3) Furukawa, M. (1993) Natural Radiation Level in Japan Islands. *J. Geography*, **102**, 868–877.
4) Morita, S., Kikuchi, N., Hirai, N., Ejiri, T., Hashimoto, K., Miyoshi, T., Ishikawa, Y. and Takie, N. (1985) Distribution of Ambient Natural Radiation Exposure in Ibaragi Prefecture. *Ann. Rep. Ibaragi Pref. Inst. Environ. Sci.*, **23**, 181–189.
5) Shimozono, S., Shitanda, S., Imamura, H., Fukuda, D., Matsudome, M. and Koriyama, M. (1987) Insitu Measurement of the Environmental Gamma Rays by Portable Ge Detector (2). *Ann. Rep. Kagoshima Pref. Inst. Environ. Sci.*, **3**, 129–135.
6) Shimozono, S., Shitanda, S., Imamura, H. and Fukuda, D. (1989) Distribution of Natural Radiation Exposure in Kagoshima Prefecture. *Ann. Rep. Kagoshima Pref. Inst. Environ. Sci.*, **5**, 101–110.
7) Sugiyama, H., Michihiro, K., Shimizu, M., Kataoka, T., Yunoki, E. and Mori, T. (1996) Survey on Ambient Natural Radiation in Okayama Prefecture, *Ann. Rep. Okayama Pref. Inst. Environ. Sci. and Pub. Health*, **20**, 49–53.
8) Ehime Pref. Gov. (1996) *Report on Natural Radiation Level in Ehime Prefecture*.
9) Katto, J., Hada, S., Tashiro, M., Taira, A. and Terado, T. (1991) *The Geological and Mineral Spring Resources Map of Kochi Prefecture*, Kochi Pref. Gov.
10) United Nations (1995) Sources and Effects of Ionizing Radiation. In *UNSCEAR 1993 Report* (Japanese Edition), pp. 47–73.
11) Saito K. and Jacob, P. (1995) Gamma Ray Fields in the Air Due to Sources in the Ground. *Radiat. Prot. Dosim.*, **58**, 29–45.
12) Furukawa, M. (1998) Chikyu Kibo no Shizen Hoshasen (1). *Chikyu Monthly*, **22**, 48–54.
13) Yoshioka, K. (1994) Study of Time Variation of Terrestrial Gamma Radiation Due to Depth Distribution of Soil Moisture Content. *Radioisotopes*, **43**, 183–189.
14) Nagaoka, K., Honda, K. and Miyano, K. (1996) Cosmic-ray Contribution in Measurement of Environmental Gamma-ray Dose, *Radioisotopes*, **45**, 665–674.