T a b l e 1

Estimated per caput annual effective dose equivalent from natural sources in areas of normal background

(Estimates from the UNSCEAR 1982 Report are given in parentheses.)

Source of irradiation	Annual effective dose equivalent (µSv)		
	External irradiation	Internal irradiation	Total
Cosmic rays			
Ionizing component	300 (280)		300 (280)
Neutron component	55 (21)		55 (21)
Cosmogenic radionuclides		15 (15)	15 (15)
Primordial radionuclides			
K-40	150 (120)	180 (180)	330 (300)
Rb-87		6 (6)	6 (6)
U-238 series:			
U-238 → U-234		5 (10)	
Th-230		7 (7)	
Ra-226	100 (90)	7 (7)	1300 (1040)
Rn-222 → Po-214		1100 (800)	
Pb-210 → Po-210		120 (130)	
Th-232 series:			
Th-232		3 (3)	
Ra-228 → Ra-224	160 (140)	13 (13)	340 (330)
Rn-220 → Tl-208		160 (170)	
Total (rounded)	800 (650)	1600 (1340)	2400 (2000)

T a b l e 2

Absorbed dose rates in air derived from exposure rate measurements in the centre of a 12-storey building
[M9]

Level	Dose rate (nGy h^{-1})	Transmission factor
Roof	31.4	1
12	20.2	0.64
10	20.0	0.64
8	18.1	0.58
5	17.4	0.55
4	13.7	0.44
2	11.5	0.37
Basement	8.6	0.27

Table 3

Average activity mass concentrations of potassium-40, uranium-238 and thorium-232 in soil and absorbed dose rate in air 1 m above the ground surface
[B32]

Radionuclide or decay series	Dose rate per unit activity mass concentration in soil (nGy h^{-1} per Bq kg^{-1}) (wet weight)	Average activity mass concentration in soil a/ (Bq kg^{-1}) (wet weight)	Absorbed dose rate in air a/ (nGy h^{-1})
K-40	0.043	370 (100-700)	16 (4-30)
U-238	0.427	25 (10- 50)	11 (4-21)
Th-232	0.662	25 (7- 50)	17 (5-33)

a/ The typical range is given in parentheses.

Radionuclide or decay series	Dose rate per unit specific concentration in soil (nGy h^{-1} per Bq kg^{-1}) (wet weight)	Average specific concentration in soil a/ (Bq kg^{-1}) (wet weight)	Absorbed dose rate in air a/ (nGy h^{-1})
K-40	0.043	370 (100-700)	16 (4-30)
U-238	0.427	25 (10- 50)	11 (4-21)
Th-232	0.662	25 (7- 50)	17 (5-33)

a/ The typical range is given in parentheses.

Table 4

Estimates of outdoor absorbed dose rate in air from terrestrial radiation sources 1 m above ground level obtained in large-scale surveys

Country or area	Year reported	Number of measurements	Absorbed dose rate in air ($nGy\ h^{-1}$) Average	Range	Type of survey and instrumentation used	Ref.
Austria	1980	> 1000	43	20-150	Ground survey in populated areas with Geiger counter	[T9]
Belgium	1987	272	43	13-58	Ground survey with thermoluminescent dosimeters, gamma spectrometer and ionization chamber	[D15]
Canada	1984	33 areas	24	18-44	Aerial survey with a scintillation detector	[G28]
China	1986	38661	80	60-120 a/	Ground survey with ionization chambers and scintillation detectors	[W21]
China (Taiwan Province)	1972	26	69	-	Analysis of soil samples using gamma spectrometry	[W18]
Denmark	1980	14 sites	38	17- 52	Ground survey with ionization chamber and gamma spectrometer	[N16]
Finland	1980	-	65	-	-	[L17, R7]
France	1985	5142	68	10-250	Ground survey with thermoluminescent dosimeters (preliminary results)	[M25, R6]
German Democratic Republic	1969	1005	85 b/	24-270	Ground survey with ionization chamber	[O13]
Germany, Federal Republic of	1978	24739	53	4-350	Ground survey with scintillation detectors	[D9]
Hungary	1987	123 sites	55	20-130	Ground survey with thermoluminescent dosimeters	[N21]
Iceland	1982	-	28	11- 83	-	[E8,R7]
India	1986	2800	55	20-1100 c/	Ground survey with thermoluminescent dosimeters	[N19]
Ireland	1980	264	42	0-180	Ground survey with ionization chamber	[M26]
Italy	1972	1365	57	7-500	Ground survey with ionization chamber	[C17]
Japan	1980	1127	49	5-100	Ground survey with ionization chamber and scintillation detectors	[A15]
Netherlands	1985	1049	32	10- 60	Ground survey with ionization chamber	[V2]
Norway	1977	234	73	20-1200	Ground survey with ionization chamber placed in a car	[S53]
Poland	1980	352 sites	37	15- 90	Ground survey with thermoluminescent dosimeters	[N17]
Romania	1979	2372	81	32-210	Analysis of soil samples using gamma spectrometry	[T10]
Sweden	1979	-	80	18-4000	-	[J18, R7]
Switzerland	1964	-	60 d/	-	Ground survey with ionization chamber	[H19]
United Kingdom	1984	1400	40	0-100	Ground survey with energy-compensated Geiger counters (preliminary results)	[G30]
United States	1972	25 areas e/	46	13-100	Aerial survey with scintillation detectors	[O12]

a/ Range of the means.
b/ A contribution of 1.0 μR per hour from nuclear weapons fallout was subtracted from the total exposure rate.
c/ Range of the arithmetic means for each province.
d/ A contribution of 3.1 μR per hour from nuclear weapons fallout was subtracted from the total exposure rate.
e/ Inhabited by approximately 30% of the country's population.

Table 5

Population-weighted means of absorbed dose rate in air 1 m above ground level obtained in a large-scale survey in China
($nGy\ h^{-1}$)
[W21]

City, province or autonomous region	Number of measurements		Indoors		Outdoors	
	Indoors	Outdoors	Gamma rays	Cosmic rays (ionizing component)	Gamma rays	Cosmic rays (ionizing component)
Beijing	623	576	87.0	28.1	59.7	31.2
Shanghai	442	227	118.7	25.2	69.8	29.7
Tianjin	308	236	117.1	27.0	73.8	30.0
Hebei	292	316	97.0	30.6	66.0	34.0
Shanxi	3454	1842	105.9	30.9	69.7	37.3
Inner Mongolia	1620	1620	106.5	34.9	70.2	38.5
Heilongjiang	2073	2650	109.1	29.6	72.8	32.9
Jilin	1273	1107	109.9	29.0	77.3	32.7
Liaoning	472	481	96.0	29.1	67.0	71.3
Shandong	2149	2149	115.7	29.3	76.1	30.8
Jiangsu	2331	808	107.0	26.7	68.9	29.7
Anhui	1549	1549	104.1	28.0	69.5	30.0
Zhejiang	1312	1312	151.4	27.3	92.3	30.0
Jiangxi	2093	896	144.3	27.0	99.0	29.4
Fujian	6694	1276	161.6	27.6	119.2	29.7
Henan	4077	2236	118.1	27.5	77.2	30.2
Hubei	1462	1439	112.7	27.6	73.0	30.4
Hunan	1677	1534	130.4	28.5	89.1	30.2
Guangdong	1712	1712	158.2	24.7	104.2	29.1
Guangxi	1555	1555	133.6	27.8	93.0	29.8
Shaanxi	894	901	108.3	31.4	67.0	34.7
Ningxia	992	230	121.6	39.2	76.3	45.6
Gansu	850	853	118.6	51.0	81.1	55.9
Qinghai	230	257	113.9	67.7	78.2	76.9
Xinjiang	3250	2510	124.1	36.5	81.9	41.0
Sichuan	6846	4707	116.5	29.7	79.3	32.9
Guizhou	698	682	112.5	36.7	91.9	39.5
Yunnan	2198	2126	120.0	44.5	87.3	46.8
Tibet	803	759	126.4	106.1	94.1	119.0
Total for China	53952	38611	119.5	30.0	80.3	33.0

Table 6

Results of large-scale surveys of indoor absorbed dose rate in air due to gamma terrestrial radiation

Country	Year reported	Number of dwellings	Type of building	Absorbed dose rate in air (nGy h-1)		Comments	Ref.
				Average	Population-weighted a/		
Austria	1980	1900	Brick	110			[T9]
			Concrete	81	71		
			Wood	75			
			Natural stone	110			
China	1986	53952	Various types		120	Range of the means: 90-160 nGy h-1	[W21]
Denmark	1985	82	Brick	60 b/		Pilot study	[S52]
			Concrete	50	60		
			Wood	30			
Finland	1983	-	-	80	(80)	Estimated	[R7]
France	1980	946	Various types	88 b/	(88)		[M22]
	1985	5798	Various types	75	(75)	The study covered 43% of the country and 50% of the population	[R6]
German Democratic Republic	1969	667	Various types		74		[D13]
Germany, Federal Republic of	1978	29996	Solid	70			[D9]
			Frame	71	70		
			Prefabricated	40			
			Wood	45			
Hungary	1987	123	Various types	84	(84)	Range 10-200 nGy h-1	[N21]
Iceland	1982	-	Concrete	23	(23)	Range 14- 23 nGy h-1	[E7,R7]
Ireland	1985	223	Various types	62 b/	(62)	Range 10-140 nGy h-1	[M23]
Japan	1984	135	Various types		50	Calculated from outdoor value of 49 nGy h-1 [A15] and indoor/outdoor ratio of 1.02 [A18]	[A15, A18]
Italy	1984	600	Various types	~60 b/	~60	Range 20-110 nGy h-1 Pilot study	[B33]
Netherlands	1955	399	Various types	64	(64)	Range 30-100 nGy h-1	[J17]
Norway	1965	2026	Brick	120			[S53]
	1977		Concrete	105	95		[S54]
Poland	1984	1351	Coal by-product prefabricate	77-120		The study covered about 10% of the country. Outdoor doses from terrestrial radiation are higher than the country average	[K20]
			Red brick	57-100			
			Gravel-sand prefabricate	54- 68			
			Wood	42- 51			
Sweden	1980	1282	Brick	92			[R7]
	1983		Concrete	120	110		
			Aerated concrete	170			
			Wood	53			
United Kingdom	1985	2300	Various types	60	60	Living areas and bedrooms of dwellings. Standard deviation 24 nGy h-1.	[W22]

a/ The numbers in parentheses are the reported averages, assumed here to be equal to the population-weighted average.
b/ The cosmic-ray contribution has been subtracted from the published value.

Table 7

Intakes of uranium-238, thorium-232, and their decay products in normal areas

Source	Annual intake (Bq) Inhalation	Annual intake (Bq) Ingestion
U-238 series:		
U-238	0.01	5
Th-230	0.01	2
Ra-226	0.01	15
Rn-222	200000	300
Pb-210	4	40
Po-210	0.3	40
Th-232 series:		
Th-232	0.01	2
Ra-228	0.01	15
Rn-220	100000	-

Table 8

Average activity mass concentrations in organs and tissues of uranium-238, thorium-232 and their decay products
[mBq kg-1 (fresh weight)]

Source	Gonads	Breast	Lungs	Cortical bone a/	Trabecular bone a/	Red bone marrow	Thyroid	Kidney	Liver	Other tissues
U-238 series:										
U-238	7	2	15	50	50	2	2	5	3	2
Th-230	0.3	0.3	20	20	70	0.3	0.3	10	7	0.3
Ra-226	2.7	2.7	2.7	170	170	2.7	2.7	2.7	2.7	2.7
Rn-222	-	-	100 b/	-	-	-	-	-	-	-
Pb-210	200	200	200	3000	3000	140	200	200	200	200
Po-210	200	200	100	2400	2400	110	200	200	200	200
Th-232 series:										
Th-232	0.15	0.15	20	6	24	0.15	0.15	3	2	0.15
Ra-228 (Th-228)	0.5	0.5	15	50	50	0.5	0.5	10	5	0.5
Rn-220	-	-	40 c/	-	-	-	-	-	-	-

a/ Dry bone (5 kg dry bone yielding 2.7 kg ash per skeleton).
b/ Radon gas. The radon concentrations in tissues other than that of the lungs are negligible.
c/ Thoron gas. The thoron concentrations in tissues other than that of the lungs are negligible.

Table 9

Annual absorbed doses resulting from internal irradiation by alpha emitters from the uranium-238 and thorium-232 decay series
(μGy)

Source	Gonads	Breast	Lungs	Red bone marrow	Bone lining cells	Thyroid	Kidney	Liver	Other tissues	Effective dose equivalent (μSv)
U-238 series:										
U-238→U-234	0.32	0.09	0.69	0.17	1.2	0.09	0.23	0.14	0.09	5
Th-230	0.007	0.007	0.47	0.56	7.4	0.007	0.24	0.02	0.007	7
Ra-226 a/	0.17	0.17	0.17	0.48	5.4	0.17	0.17	0.17	0.17	7
Rn-222→Po-214			630 b/ 80 c/							850
Pb-210→Po-210	5.4	5.4	2.7	5.1	36	5.4	5.4	5.4	5.4	120
Th-232 series:										
Th-232	0.003	0.003	0.4	0.17	2.0	0.003	0.06	0.04	0.003	3
Ra-228→Ra-224	0.08	0.08	2.4	0.35	4.4	0.08	1.6	0.80	0.09	13
Rn-220→Pb-208	0.3	0.3	44	2.5	28	0.3	19	3.2	0.3	160
Total d/	31	18	970	22	51	4	32	12	22	1160

a/ Including doses resulting from the formation of Rn-222 and its short-lived decay products in the body by decay of Ra-226 (retention factor of one third).
b/ Tracheo-bronchial tree.
c/ Lungs.
d/ Contributions to the annual effective dose equivalent (μSv).

Table 10

Activity concentration of polonium-210 in ground-level air
[W13]

Country and place	Period of measurements	Number of samples	Polonium-210 concentration ($\mu Bq\ m^{-3}$) Mean	Range	Ref.
Finland					
Nurmijarvi	1969	32, daily	30	10- 60	[M11]
Helsinki	1969	32, daily	50	30- 80	[M11]
France					
Toulouse	1965-1968	37, monthly	50	20-100	[M12]
Germany, Federal Rep. of					
Munich-Neuherberg	1976-1979	207, weekly	30	<7- 80	[W13]
United Kingdom					
Harwell	1955-1957	4, daily	20	4- 30	[B6]
Chilton	1962-1965	41, monthly	40	15-140	[P7]
Sutton	1962	5, monthly	30	15- 45	[O5]
United States					
Boulder	1967-1972	15, daily	35	20-120	[P8]
USSR					
Vilnius	1966-1968	?	70(?)	20-120	Quoted in [P9]
Rostov-na-Donu	1971	3, monthly	130	55-220	[L9]

Table 11

Potential alpha energy ratio of thoron and radon decay products in dwellings

Country	Number of dwellings	Potential alpha energy ratio (thoron/radon) Average (mean or median)	Range	Ref.
Austria	12	0.71	0.2-2.7	[S23]
Canada	95	0.3		[G15]
Hungary	22	0.48	0.1-1	[T2]
Germany, Federal	27	0.62	0.1-2.5	[W6]
Republic of	95	0.8	0 -1.9	[U3]
	150	0.51		[K13]
Norway	22	0.48	0.1-0.7	[S24]
United Kingdom	8	0.14	0.1-1.5	[C8]
United States	68	0.62		[S67]

Table 12

Dose factors for indoor and outdoor inhalation of thoron and thoron decay products by members of the public

Organ or tissue	Thoron gas: Dose rate per unit concentration (μGy a^{-1} per Bq m^{-3}) (α)	Thoron decay products: Dose per unit intake (nGy Bq^{-1}) (α)	Thoron decay products: Dose rate per unit concentration, Indoors (μGy a^{-1} per Bq m^{-3}) (α)	Thoron decay products: Dose rate per unit concentration, Outdoors (μGy a^{-1} per Bq m^{-3}) (α)
Lungs	0.25	14	78	25
Red bone marrow	0.02	0.8	4.5	1.4
Bone lining cells	0.18	9	50	16
Liver	0.02	1	5.6	1.8
Kidneys	0.10	6	34	11
Spleen	0.004	0.2	1.1	0.4
Other soft tissues	0.002	0.1	0.6	0.04
Effective	0.96 (μSv a^{-1} per Bq m^{-3})	50 (nSv Bq^{-1})	280 (μSv a^{-1} per Bq m^{-3})	88 (μSv a^{-1} per Bq m^{-3})

Table 13

Range and representative values of parameters for estimating the area exhalation rate of radon-222 from soils
[G2, O1, S1, W1]

Parameter	Symbol	Unit	Reported range	Representative value	Ref.
Emanating power	F_r	-	0.01-0.8	0.2	[O1,S1]
Effective bulk diffusion coefficient	Δ_{eff}	$m^2\ s^{-1}$	10^{-11}-3 10^{-6}	5 10^{-7}	[O1,S1]
Porosity	$P_{soil,ps}$	-	0.01-0.5	0.25	[O1,S1]
Exhalation rate	R	$Bq\ m^{-2}\ s^{-1}$	0.0002-0.07	0.016	[G2,W1]

Table 14

Dimensions and relevant parameters of the reference house

Parameter	Symbol	Value
Volume	(V)	250 m^3
Surface area of floor	(S_F)	100 m^2
Surface area of external walls and ceiling	(S_w)	300 m^2
Total surface area, including internal walls, furniture, etc.	(S)	450 m^2
Air exchange rate	(λ_v)	1 h^{-1}
Thickness of floor and ceiling	(L_F)	0.2 m (concrete)
Thickness of external walls	(L_w)	0.2 m (bricks)

Table 15

Normal content of radium-226 and radon-222 in Swedish soil, measured at 1 m depth
[A10]

Soil type	Radium-226 activity mass concentration ($Bq\ kg^{-1}$)	Radon-222 concentration ($kBq\ m^{-3}$)
Till, normal	15- 62	5- 30
Till, with granitic material	30- 125	10- 60
Till, with uranium-rich granite material	125- 360	10- 200
Esker gravel	30- 75	10- 150
Sand, silt	6- 70	10- 80
Soil containing alum shale	175-2500	50->1000

Table 16

Radon-222 source characteristics for building materials

Material	Country	Number of samples	Radium-226 concentration ($Bq\ kg^{-1}$)	Radon-222 mass exhalation rate ($\mu Bq\ kg^{-1}\ s^{-1}$)	Emanating power	Diffusion length (m)	Ref.
Concrete							
Heavy concrete	USSR	18	66	3.2	0.035	0.13	[K2]
Lightweight concrete	USSR	19	141	4.1	0.021	0.26	[K2]
Ordinary concrete	Sweden	3	40-60	11-31			[P27]
Aerated concrete based on alum shale	Sweden	1	1500	580			[P27]
Alum-shale concrete	Denmark	1	-	440		0.074	[J2]
Fly-ash concrete (4%)	USA	8	19	10	0.26		[I1]
Fly-ash concrete	Greece	4	11-17	6.4-20	0.03-0.09 a/		[S5]
Concrete	Hungary	~100	13	7.8	0.28		[T1]
Concrete	Denmark	4		4.7		0.04	[J2]
Concrete	Norway	137	28		0.01-0.20	0.13	[S6]
Concrete	Greece	-	11-12	2.9-5	0.02-0.03 a/		[S5]
Concrete	USA	50	9-32	2.5-20	0.13-0.25		[I1]
Concrete	USA	1				0.13	[Z1]
Concrete	USA	1				0.17	[Z1]
(Adopted reference value)			(25)	(10)	(0.20)	(0.15)	
Brick							
Red brick	USSR	12	50	1.6	0.017	0.15	[K2]
Red brick	Hungary	~200	55	3.9	0.036		[T1]
Red brick	Poland	3	18		0.02-0.05		[P1]
Red brick	USA	6	45	1.0	0.01		[I1]
Brick	Denmark	2		0.17			[J2]
Brick	Norway	18	63		0.01	0.15	[S6]
Brick	Greece	5	45	0.3-7.5	0.02		[S5]
Silicon brick	Poland	3	7-15		0.008-0.16		[P1]
Adobe brick	USA	2	30	3.5	0.06		
(Adopted reference value)			(50)	(2)	(0.02)	(0.15)	
Gypsum							
Gypsum	USA	12	12	6.3	0.28		[I1]
Gypsum board	Denmark	1		0.23			[J2]
By-product gypsum (apatite)	Poland	1	26		0.035		[P1]
By-product gypsum (phosphorite)	Poland	3	580-740		0.13-0.20		[P1]
Lightweight expanded clay aggregate	Norway	12	52		0.01-0.20	0.20	[S6]
Storage rock	USA	9	55	5	0.04		[I1]
Wood	USA	2		0.2			[I1]
Fly ash	Poland	33	100		0.005		[P1]
Slag	Poland	11	70		0.007		[P1]
Cement	Poland	4	> 9-25		0.008-0.08		[P1]
	USA	4	50	1.0	0.01		[I1]
Sand	USA	2	34	12	0.16		[I1]
	USA	2	10	3	0.12		[I1]
Gravel	USA	4	14	2.2	0.07		[I1]

a/ Calculated from data given in the reference, assuming a diffusion length of 0.2 m.

Table 17

Sources of radon entry rates in the reference house

Source	Radon entry rate ($Bq\ m^{-3}\ h^{-1}$)	
	Estimated arithmetic mean	Typical range
Underlying soil		
Diffusion	1.7	0.1-200
Pressure-driven flow	40	
Building materials	6.4	1- 20 a/
Outdoor air	5	1- 10
Water	0.1	0.001-100
Natural gas	0.3	0- 1
Total (rounded)	50	2-200

a/ Excluding alum shale; a radon entry rate of 80 $Bq\ m^{-3}\ h^{-1}$ is estimated if aerated concrete based on alum shale is used.

Table 18

Equilibrium factor F for radon daughters

Country	Number of dwellings	Equilibrium factor F: Average	Equilibrium factor F: Range	Ref.
Canada				
March Township	-	0.38		[L4]
13 cities	9118	0.52 a/	0.19-0.67 b/	[M6]
	56	0.41 c/		[S44]
Finland	35	0.47	0.30-0.63	[M5]
Germany, Federal Republic of	38	0.37	0.25-0.65	[W5]
	200	0.30		[K6]
Italy	500	0.8 d/		[S14]
	50	0.7		[S14]
Netherlands	80	0.3		[P13]
Norway	25	0.5	0.3 -0.8	[S13]
Sweden	225	0.44	0.1 -0.8	[S12]
United Kingdom	130	0.30 e/		[W22]
United States				
New Jersey	21	0.52 f/	0.26-0.76	[G11]
		0.63 g/	0.33-0.82	[G11]

a/ Arithmetic mean of the ratio of the geometric means of the equilibrium equivalent concentration and of the radon concentration in 13 cities.
b/ Range for the 13 cities.
c/ Arithmetic mean; Gaussian distribution with $\sigma = 0.22$.
d/ Ratio of the medians of equilibrium equivalent concentration and of radon concentration.
e/ At mean ventilation rate of 2 air changes h^{-1}. Calculated to be 0.40 at 1 air change h^{-1}.
f/ Cellars.
g/ First and second floors.

Table 19

Radon and equilibrium equivalent concentrations obtained in recent large-scale indoor surveys

Country or area	Number of dwellings	Type of dwelling	Type of sampling	Purpose of the survey	Date of completion	Average value ($Bq\ m^{-3}$)		Distribution or range	Ref.
						Radon	Radon EEC		
Argentina	112	Homes	Radon, passive	Population exposure	1985	37 (median)		Log-normal σ_g = 2.0	[P21]
Austria									
Salzburg	729	Homes	Radon and radon daughters, grab sampling, usually 4 times a year	Population exposure	1980?	15 (median)	9 (median)	Log-normal ? range <15-190 $Bq\ m^{-3}$ (Rn)	[S16] [S17]
Belgium	79	73 houses and 6 apartments	Radon, passive, one-year exposure	Nation-wide population exposure (preliminary survey)	1984	41 (median)		Log-normal σ_g = 1.6	[P19]
Canada	13413	Houses	Radon and radon daughters, grab samplings, preferably in basements	Nation-wide variability of exposures	1980	33 (mean)	7 (median)	Log-normal	[L5] [G7] [U1]
Port Hope	2960	Homes	Radon, grab samples in basements	Remedial of industrial contamination	1976	36 (median)	11 (median)	Log-normal	[K8] [L5]
Uranium City	632	Homes in uranium mining communities	Radon and radon daughters, grab sampling, basements and living areas	Causes of increased radon levels in homes	1976		48 (median)	Log-normal σ_g = 4.1	[L5]
Elliot Lake	1921				1976		30 (median)	Log-normal σ_g = 2.9	[L5]
Bancroft	1162		Radon daughters, grab sampling, basements and living areas		1977		26 (median)	Log-normal σ_g = 3.1	[L5]
Saskatchewan	155	Homes	Radon daughters, grab sampling	Index map of radon problem areas	1980		11 (median)	Log-normal	[L5]
	74							47 (median)	
	438						28 (median)		
	175						65 (median)		
	770						13 (median)		
	961						16 (median)		
China	896		-	Population exposure	1983	120 (mean)	80 (mean)	-	[H18]
Beijing	537	364 houses 173 apartments		Population exposure	1987	30 (mean)		Range 0.6-259 $Bq\ m^{-3}$ (Rn)	[P22]
Denmark	400	Homes	Radon, passive 3-month exposure in summer and in winter	Nation-wide population exposure (pilot survey)	1985	50 (median)		Range 50-700 $Bq\ m^{-3}$	[S62]
Germany, Federal Republic of	5970	Homes	Radon, passive, 3-month exposure, 1 in bedroom, 1 in living room	Nation-wide population exposure	1984	40 (median) 49 (mean)	13 (median)	Log-normal σ_g = 1.8	[W7, W15, S61]
Finland	8150	Homes	Radon, passive, 1-month exposure in living room	Nation-wide population exposure	1982	64 (median) 90 (mean)		Log-normal σ_g = 3.1	[C5] [C21] [C23]
France	765	Houses	Radon, passive and and RnDP, active, one-month exposure	Nation-wide population exposure (preliminary results)	1985	44 (median) 76 (mean)		Log-normal	[R6]
Hungary	833	Houses	Radon daughters, grab sampling, living areas, data reduced to 1 h^{-1} ventilation rate	Population exposure	1972		12	Log-normal	[T6]
Ireland	736	Houses	Radon, passive 6-month exposure	Nation-wide population exposure (preliminary results)	1987	37 (median)		3-1700 $Bq\ m^{-3}$	[M23] [C22]
Italy	1000	Houses	Radon, passive, 3-12 month exposures,	Nation-wide population exposure (partial results)	1984	43 (median)		Log-normal	[S14]
Japan	250	Houses	Radon, electrostatic integrating, 2 months; total 1.5 year exposure	Nation-wide population exposure	1988	10 (mean)			[N23]
Netherlands	1000	Houses	Radon, passive, exposure for 4 months in the living room	Nation-wide population exposure	1985	24 (median) 29 (mean)	10 (median) 12 (mean)	Log-normal σ_g = 1.6	[H1, P13, C22, P20]
Norway	1500	Houses	Radon, passive, 1 week exposure	Assessment of geographical variation	1985	90 (mean)		30-5000 $Bq\ m^{-3}$	[S66]

Table 19, continued

Country or area	Number of dwellings	Type of dwelling	Type of sampling	Purpose of the survey	Date of completion	Average value (Bq m^{-3}) Radon	Radon EEC	Distribution or range	Ref.
Poland	201	Apartments	Radon and radon daughters, grab sampling in the worst ventilation conditions	Nation-wide population exposure	1978	9 (mean)	4 (mean)	Log-normal ? range 0.4-17 Bq m-3 (EEC)	[G13]
Sweden	315	Detached houses built before 1975				122 (mean) 65 (median)		Log-normal	[S8, S42]
	191	Apartments built before 1975	Radon, passive 2-week exposure, 1 in bedroom, 1 in living room	Nation-wide population exposure	1982	85 (mean) 46 (median)	105 (mean)	Log-normal	
	96	Detached houses built 1978-1980				59 (mean)		Log-normal	
	38260	Detached houses built before 1982	Various	Search for dwellings with high radon levels	1986		Median of about 100	143 houses exceeding 2000 Bq m-3	[S70, S71, S72]
	8008	Apartments built before 1982							
Switzerland	123	Homes	Radon, passive, detectors, 1 in basement, 1 in living room, 1 in bedroom	Nation-wide population exposure	1982	60 (median) 150 (mean)		Log-normal ?	[B4]
	105	Homes	-	Comparison of weatherproofed and conventional houses	1983			22-5500 Bq m-3 (Rn)	[B29]
United Kingdom	2300	Homes	Radon, passive, 1-year exposure in living room and in main bedroom	Nation-wide population exposure	1985	17 (median) in living-rooms 12 (median) in bedrooms		Log-normal σ_g = 2.4 in living-rooms σ_g = 2.2 in bedrooms	[W22]
Cornwall and other uraniferous regions	700	Homes	Grab sampling of radon and radon daughters plus ventilation rate plus 1-year exposure with passive radon detectors	Search for problem areas	1985?	140 (median) in living-rooms	14 (median) in living-rooms	Log-normal σ_g = 3.2 (Rn) σ_g = 5.2 (EEC)	[W8, B27, O9]
United States	552	Single-family homes	Various	Nation-wide population exposure	1984	35 (median) 61 (mean)		Log-normal σ_g = 2.8	[N11]

Table 20

Variability of radon daughter bronchial dose range as a per cent change from nominal annual dose for males
[N14]

Factor	Variability	Comments
Unattached polonium-218 from 4% to 20%	-10 +30	4% unattached polonium-218 20% unattached polonium-218
Daughter product equilibrium (1/0.9/0.7/0.7 to 1/0.9/0.6/0.4)	-20	
Particle deposition models		A few percent
Particle size (change in median size from 0.125 μm or 0.17 μm)	+100 -20	For 0.05 μm particles) For 0.17 μm particles)
Calculated physical dose to a given site in epithelium		A few percent
Breathing pattern (entirely active pattern to entirely resting) (Mouth versus nose breathing)	+20 -25 (+35)	Active pattern Resting pattern
Bronchial morphometry (child versus adult)	+60	
Mucociliary clearance (normal to complete stasis)	+10	
Mucus thickness (none to twice normal)	+20 -30	No mucus Twice normal mucus thickness
Location of target cell (shallow -22 μm to average -45 μm)	-80	

Table 21

Dose and effective dose equivalent factors per unit concentration of radon (or its decay products) in air (or water)

(Applicable only to adults in the general population.)

Pathway	Dose factor ($nGy\ h^{-1}$ per $Bq\ m^{-3}$)			Effective dose equivalent factor ($nSv\ h^{-1}$ per $Bq\ m^{-3}$)	Main assumptions
	Stomach	Tracheo-bronchial tree	Lungs		
Inhalation					
Radon gas	0.005		0.04	0.2	Decay of radon and decay products in the same tissue; solubility factor of 0.4
Radon decay products (EEC)					D_{T-B}/I_{pot} = 1.5 Gy J^{-1} $D_P\ /I_{pot}$ = 0.2 Gy J^{-1} I_{ih} = 0.8 $m^3\ h^{-1}$
Indoors		7	0.9	10	
Outdoors		7	0.9	10	Same dosimetric coefficients for indoor and outdoor conditions
Ingestion					
Radon gas	0.0001			0.0001	D_{St}/A = 5 nGy Bq^{-1} Water consumption rate = 0.5 l d^{-1}

Table 22

Production of coal and reported activity mass concentrations of natural radionuclides

	Production of hard coal 1985 [U15]		Activity mass concentration (Bq kg^{-1})			Ref.
	Coal equivalent (10^9 kg)	% of the world production	U-238	Th-232	K-40	
Australia	118	4	30- 48	30	40	[B10,F5]
Austria	-		11-363	7-11	7-59	[B9]
Brazil	8	0.3	100	67	370	[S25]
Canada	34	1	12	7	26	[T4,T7]
Czechoslovakia	26	0.8	4-13			[J12]
China	810	26	7	16	30	[F5,J12]
Germany, Fed.Rep.						
Bituminous coal	88	3	20	< 20		[J13]
Brown coal			10	< 7		[J13]
Greece (lignite)			120-1300	0.7-0.9		[P10,P11]
Hungary	3	0.1	1.5			[J12]
India						
Average	150	5	24	38	83	[L12]
Range			10-70	20-90	15-440	[L12]
Italy (lignite)						
Central Italy			15-25		120-200	[D1,G16]
Sardinia			250			[D1,G16]
Poland						
Average	192	6	38	30	290	[T3]
Range			2-140	7-110	40-800	[T3]
South Africa	173	6	30	20	110	[S25]
USSR						
Average	494	16	28	25	120	[L11]
United Kingdom						
Yorkshire area			20	20	240	[B7]
Country range			7-94	2.4-19		[C9]
Country average	94	3	15	13	150	[S29]
United States						
Average	741	24	18	21	52	[B8]
Range			1-540	2-320	1-710	[B8]
Venezuela	0.04	0.001	< 20	< 20	110	[S25]
Yugoslavia	0.4	0.01	12-530	21-50		[B9]
World	3100	100				

Table 23

Uses of hard coal in OECD countries, 1985 [U15]

	OECD		Japan	United Kingdom	United States
	(10^9 kg)	(%)	(%)	(%)	(%)
Domestic	20	1.6	0.4	8.1	0.4
Commercial/public service	7	0.6	-	1.6	0.6
Power stations	835	67.8	22.9	71.7	84.4
Coke ovens	211	17.1	63.3	12.3	5.4
Iron and steel industry	5	0.4	0.3	0.03	0.3
Chemical industries	22	1.8	1.1	0.6	2.3
Other industries	77	6.2	8.3	4.9	5.5
Rail transport	0.2	0.02	-	-	-
Other	55	4.5	3.7	0.8	1.1
Total	1232	100.0	100.0	100.0	100.0

Table 24

Radon and radon decay products in coal mines

(Mean values with range in parentheses.)

Country or area	Year	Radon concentration (Bq m^{-3})	Potential alpha energy concentration of radon a/ (μJ m^{-3})	Annual potential alpha energy exposure (mJ)	Ref.
European Communities	1981		0.09	0.2	[B19]
b/	1981		0.2	0.5	[B19]
	1981		0.5	1.2	[B19]
Germany, Federal Republic of	1976	105 (up to 400)			[E6]
India	1981		0.02 (0.01-0.04)		[N9]
Poland	1981		<2 c/		[D4]
United Kingdom	1968	(20-500)	0.4		[D3]
	1976			(up to 2)	[O10]
	1981			0.5 d/	[O11]

a/ 1 μJ m^{-3} corresponds to an equilibrium equivalent concentration of radon of 180 Bq m^{-3}.
b/ Radon decay product concentrations and annual exposures derived from two-month measurements; log-normal distributions.
c/ Less than 2 μJ m^{-3} for 94% of the measurements.
d/ Mean annual exposure in nationalized mines, employing 185,200 miners; the mean annual exposure in private mines, employing 1,500 miners, was 1.0 mJ.

Table 25

Ash production in the United Kingdom
[C11]

Source	Coal consumption (10^9 kg)	Ash content (%)	Ash production (10^9 kg)	Ash production (% of total)
Domestic and manufactured fuels	15.0	4.7	0.7	4.5
Power stations	73.1	17.1	12.5	80.1
Carbonization (coke, ...)	17.5	6.0	1.1	7.1
Other industry	12.1	9.6	1.2	7.7
Other, including export	1.5	6.3	0.1	0.6
Total	119.2	Weighted average 13.2	15.6	100.0

Table 26

Total emissions of respirable particulates in the United Kingdom
[C11]

Origin	Total emissions 10^6 kg	Total emissions % of total
Domestic	337	74
Commercial/public service	12	3
Power stations	28	6
Other industry	68	15
Rail transport	10	2
Total	455	100

Table 27

Coal-fired power plants: estimates of annual atmospheric discharges per unit energy generated
(MBq per GW a)

Site	Fly-ash removal efficiency (%)	K-40	U-238 decay series				Th-232 decay series		Reference
			U-238	Ra-226	Pb-210	Po-210	Th-232	Th-228	
Canada a/									
Nanticoke, 4000 MW	99.5	350	100	100	300	300	70		[T4]
France	?	3500	7000	7000			6000		[A5]
Germany, Federal Rep. of									
Brown coal			100	70	200	400	40	40	[J14,S26]
Bituminous coal			500	500	4000	8000	200	200	[J14]
Bituminous dry ash removal	99		300	200	200	300	100	100	[H12]
Bituminous liquid ash removal	99		500	300	2000	6000	200	200	[H12]
India	95	31000		6400			10000		[L12]
Italy									
Lignite, 250 MW	95	42000	5500	5500	3500		22000		[D1,G16]
Lignite, 70 MW	95	120000	23000	23000	34000		34000		[D1,G16]
Coal, 1280 MW	99.5	3300	2500	2500			3300		[D1,G16]
USSR									
Zaporozhje b/ 1200 MW (old)	90	200000		20000	81000	74000	20000		[I6]
1000 MW (modern)	97.5	50000		5000	20000	18000	5000		[I6]
United Kingdom, 2000 MW	99.5	1000	1000	1000	1000	1000	1000	1000	[C9]
	99.5	4000	800	800	8000	8000	400	400	[C14]
United States	99		300	300	300	300	200	200	[M14]
			4900	5600			6300	6300	[N7]
M-1, 510 MW c/	99.3		2700	590	3200	7600	90	80	[U5]
M-2, 450 MW c/	99.3		720	520	1900	1800	190	220	[U5]
M-3, 125 MW c/	99.4		350	100	620	510	90	140	[U5]
M-4, 12.5 MW c/	99.7		450	100	830	720	220	230	[U5]
Milliken, 270 MW	99.7	550	70	70	100		60		[K14]
Model plant (modern)	99		1600	1200	3900	3900	670	670	[U5]
Model plant (1970)	80		16000	16000	32000	32000	14000	14000	[U5]
Model plant (modern)	98-99	1100	1000	780	2600	2600	410	410	[B8]
Model plant (1972)	90	10000	4700	4700	9300	9300	3800	3800	[B8]
UNSCEAR 1982 Report	97.5	4000	1500	1500	5000	5000	1500	1500	[U1]
This Annex									
modern	99.5	600	250	250	750	750	250	250	
old	90	12000	5000	5000	15000	15000	5000	5000	

a/ Assuming a coal consumption of 3 Tg per GW a.
b/ Ash content of the coal of 30-39% (Donety, Kuznets coal field); annual coal consumption of 5 Tg.
c/ Derived from the ratio of emission rate to activity feed rate for U-238.

Table 28

Estimates of collective effective dose equivalent commitments per unit energy generated resulting from atmospheric releases from a typical "old" coal-fired power plant a/ (10^{-2} man Sv per GW a)

Radionuclide	Inhalation during the cloud passage	Internal irradiation due to deposited activity	External irradiation due to deposited activity	Total
U-238	15	2		
U-234	17	2		
Th-230	60	3		
Ra-226	1.3	3	12	215
Rn-222 + daughters	0.1	20		
Pb-210 → Po-210	14	66		
Th-232	290	1		
Ra-228 + daughters	60	6.7	18	405
Rn-220 + daughters	-	30		
Total (rounded)	455	135	30	620

a/ Releasing about 10% of the fly-ash produced.

Table 29

Estimates of collective effective dose equivalent commitments per unit energy generated resulting from atmospheric releases from a typical modern coal-fired power plant a/ (10^{-2} man Sv per GW a)

Radionuclide	Inhalation during the cloud passage	Internal irradiation due to deposited activity	External irradiation due to deposited activity	Total
U-238	0.75	0.1		
U-234	0.9	0.1		
Th-230	3	0.15		
Ra-226	0.07	0.15	0.6	30
Rn-222 + daughters	0.1	20		
Pb-210 → Po-210	0.7	3.3		
Th-232	14	0.05		
Ra-228 + daughters	3	0.3	0.9	20
Rn-220 + daughters	-	1.5		
Total (rounded)	23	26	1.5	50

a/ Using emission control devices that allow only about 0.5% of the fly-ash produced to escape.

Table 30

Estimates of collective effective dose equivalent commitments per year of practice in the coal fuel cycle

Source	Collective effective dose equivalent commitment per year of practice (man Sv)	
	Public	Workers
Coal mining	0.5-10	2000
Use of coal		
Electrical energy production	2000	60
Domestic use	2000-40000	-
Coke ovens	Not estimated	Not estimated
Use of fuel ash	50000	Not estimated

Table 31

Use of oil in the OECD countries, 1978 [O6]

Use	Type of fuel	Mass (10^9 kg)
Domestic	Gas/diesel oil	200
	Liquefied gases	33
Commercial/public service	Gas/diesel oil	26
Power stations	Residual fuel oil	200
Iron and steel industry	Residual fuel oil	22
Chemicals industry	Residual fuel oil	30
Other industries	Residual fuel oil	120
Air transport	Jet fuel	76
Road transport	Motor gasoline	490
Railways	Gas/diesel oil	20

Table 32

Uses of natural gas in OECD countries, 1985 [U15]

Use	OECD (total)		Japan	United Kingdom	United States
	Energy (PJ)	Share (%)	(%)	(%)	(%)
Domestic	7980	24.4	-	47.1	24.9
Commercial/public service	4310	13.2	-	5.8	13.7
Power stations	5850	17.9	75.1	1.1	17.1
Natural gas extraction	2340	7.2	1.5	5.6	8.6
Petroleum refineries	670	2.0	-	-	2.8
Iron and steel industry]	]	]	2.0	2.2	]
Chemicals industry]	10000	] 30.6	1.7	10.7	] 30.5
Other industries]	]	]	0.2	15.2	]
Other	1550	4.7	19.5	12.3	2.4
Total	32700	100	100	100	100

Table 33

Collective effective dose equivalent commitment to members of the public attributable to various systems of electricity production

Type of plant	Collective effective dose equivalent commitment per year of practice (man Sv)	Normalized collective effective dose equivalent commitment (man Sv per GW a)
Coal-fired	2000	4
Oil-fired	100	0.5
Natural gas	3	0.03
Geothermal	3	2
Peat	-	2

Table 34

Estimated atmospheric discharges from phosphate industrial plants

Type of plant and location	Annual input of phosphate rock (10^6 t)	Radionuclide discharges (GBq a^{-1})						Ref.
		U-238	Th-230	Ra-226	Rn-222 a/	Pb-210	Po-210	
Ore drying and grinding								
United States, reference plant	2.7	0.6	0.6	0.6	4000	0.6	0.6	[U9]
Elemental phosphorus plant								
Vlissingen, Netherlands	0.75					150	350	[B31]
United States								
Pocatello, Idaho]		0.15	0.15	0.15	1500	4	330	[U9]
Soda Springs, Idaho]		0.2	0.2	0.2	1100	210	780	[U9]
Silver Bow, Montana]	~4	0.02	0.02	0.02	2000	4	26	[U9]
Mt. Pleasant, Tenn.]		0.007	0.007	0.007	40	2	4	[U9]
Columbia, Tenn.]		0.07	0.07	0.07	300	15	22	[U9]
Columbia, Tenn.]		0.007	0.007	0.007	40	2	4	[U9]
Wet-process fertilizer plant								
United States, reference plant	1	0.25	0.25	0.036		0.13	0.13	[U9]

a/ Atmospheric discharges of Rn-222 estimated by UNSCEAR.

Table 35

Estimates of collective dose commitments per unit mass of phosphate ore resulting from atmospheric releases from phosphate industrial plants

Radionuclide	Airborne discharge ($Bq\ t^{-1}$)	Collective dose commitment (10^{-9} man Gy t^{-1})							
		Lungs	Bone surfaces	Red bone marrow	Liver	Kidneys	Spleen	Gastro-intestinal tract	Other soft tissues
Ore drying and grinding									
U-238	200	2.6	0.4	0.05	0.03	0.2	0.03	0.03	0.03
U-234	200	3.1	0.3	0.04	0.01	0.2	0.01	0.01	0.01
Th-230	200	2.9	23	1.7	0.04	0.04	0.006	0.006	0.006
Ra-226	200	0.2	1	0.1	0.03	0.03	0.03	0.03	0.03
Rn-222	$1.5\ 10^{6}$	17 a/ 2.2 b/							
Pb-210	200	0.3	3.1	0.5	0.5	0.5	0.4	0.4	0.4
Po-210	200	0.2	0.004	0.004	0.004	0.1	0.2	0.003	0.004
External irradiation		4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Total		22 a/ 16 b/	33	7.1	5.3	6.0	5.4	5.2	5.2
Elemental phosphorus plant									
U-238	100	1.3	0.2	0.03	0.01	0.1	0.01	0.01	0.01
U-234	100	1.5	0.2	0.02	0.007	0.1	0.007	0.007	0.007
Th-230	100	1.4	11	0.8	0.02	0.02	0.003	0.003	0.003
Ra-226	100	0.1	0.5	0.05	0.01	0.01	0.01	0.001	0.001
Rn-222	$1.2\ 10^{6}$	14 a/ 1.8 b/							
Pb-210	$5.9\ 10^{4}$	8.8	920	140	160	140	120	120	120
Po-210	$2.9\ 10^{5}$	340	5.8	5.8	5.8	170	300	4.1	5.8
External irradiation		2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Total		16 a/ 360 b/	940	150	170	310	420	130	130
Wet process fertilizer plant									
U-238	250	3.2	0.5	0.07	0.03	0.3	0.01	0.01	0.01
U-234	250	3.8	0.4	0.05	0.02	0.3	0.02	0.02	0.02
Th-230	250	3.6	28	2.1	0.05	0.06	0.007	0.007	0.007
Ra-226	40	0.04	0.2	0.02	0.005	0.005	0.005	0.005	0.005
Pb-210	100	0.1	1.6	0.2	0.3	0.2	0.2	0.2	0.2
Po-210	100	0.1	1.002	0.002	0.002	0.06	0.1	0.001	0.002
External irradiation		0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Total		12	32	3.3	1.3	1.8	1.3	1.2	1.2

a/ Tracheo-bronchial basal cell layer.
b/ Pulmonary epithelium.

Table 36

Estimates of collective dose commitments resulting from world-wide annual atmospheric releases from phosphate industrial plants

Radionuclide	Airborne discharge (Bq t^{-1})	Collective dose commitment (10^{-3} man Gy)							
		Lungs	Bone surfaces	Red bone marrow	Liver	Kidneys	Spleen	Gastro-intestinal tract	Other soft tissues
Ore drying and grinding									
U-238	20	260	37	5.5	2.6	23	2.6	2.6	2.6
U-234	20	310	35	4.1	1.4	20	1.4	1.4	1.4
Th-230	20	21	9.9	10	2.6	2.6	2.6	2.6	2.6
Ra-226	200	0.2	1	0.1	0.03	0.03	0.03	0.03	0.03
Rn-222	130000	1700 a/ 200 b/							
Pb-210	20	30	310	48	55	47	40	39	39
Po-210	20	23	0.4	0.4	0.4	12	21	0.3	0.4
External irradiation		470	470	470	470	470	470	470	470
Total		2000 a/ 600 b/	3200	710	540	580	540	520	520
Elemental phosphorus plant									
U-238	1.5	19	2.8	0.4	0.2	1.7	0.2	0.2	0.2
U-234	1.5	23	2.6	0.3	0.1	1.5	0.1	0.1	0.1
Th-230	1.5	22	170	12.7	0.3	0.3	0.05	0.05	0.05
Ra-226	1.5	1.6	7.4	0.8	0.2	0.2	0.2	0.2	0.2
Rn-222	16000	180 a/ 24 b/							
Pb-210	800	1200	12000	1900	2200	1900	1600	1600	1600
Po-210	4000	4600	80	80	80	2300	4200	56	80
External irradiation		35	35	35	35	35	35	35	35
Total		220 a/ 5900 b/	12000	2000	2300	4200	5800	1700	1700
Wet process fertilizer plant									
U-238	10	130	19	2.7	11	1.3	0.01	1.3	1.3
U-234	10	150	17	2.1	0.7	10	0.7	0.7	0.7
Th-230	10	140	1100	85	2	2.2	0.3	0.3	0.3
Ra-226	2	2.1	1	1	0.3	0.3	0.3	0.3	0.3
Pb-210	6	9	94	15	16	14	12	12	12
Po-210	6	7	0.1	0.1	0.1	3.5	6.2	0.008	0.1
External irradiation		47	47	47	47	47	47	47	47
Total		490	1300	150	67	88	68	62	62

a/ Tracheo-bronchial basal cell layer.
b/ Pulmonary epithelium.

Table 37

Average activity mass concentrations of uranium-238 and radium-226 per unit mass of P_2O_5 in phosphate fertilizer

Country	Bq/kg P_2O_5 U-238	Bq/kg P_2O_5 Ra-226	Ref.
Finland	1700	480	[M21]
Germany, Fed.Rep.of	2600	1700	[P15]
United States	9200	1300	[U13]
Union of Soviet Socialist Republics		930	[D8]

Table 38

Estimated collective dose commitment per mass of phosphate rock resulting from the use of phosphate fertilizers

Organ or tissue	Collective dose commitment (10^{-7} man Gy t^{-1})						
	U-238	U-234	Th-230	Ra-226	Rn-222	Pb-210	Total
Internal irradiation							
Lungs	1	1	4	0.4	300 a/ 40 b/		300 a/
Bone surfaces	20	20	60	10		100	300
Red bone marrow	3	2	4	1		20	30
Liver	1	1	0.07	0.4		10	10
Kidneys	10	10	2	0.4		10	30
Other tissues	1	1	0.07	0.4		10	10
External irradiation							
All tissues			2				2

a/ Tracheo-bronchial basal cell layer.
b/ Pulmonary epithelium.

Table 39

Estimates of collective effective dose equivalent commitment to the world population arising from one year of exploitation of phosphate rock

Source of exposure	Collective effective dose equivalent commitment (man Sv): Members of the public	Workers
Phosphate industrial operations	60 a/	20 b/
Use of phosphate fertilizers	10000	50 b/
Use of by-products and waste	300000	Not estimated

a/ An additional 170 man Sv to the Dutch population is estimated to result from dumping phosphogypsum into the Rhine.
b/ From external irradiation only.

Table 40

Radon and radon decay products in non-uranium mines

Country	Year	Radon concentration ($Bq\ m^{-3}$)	Potential alpha energy concentration of radon ($\mu J\ m^{-3}$)	Annual potential alpha energy exposure (mJ)	Type of mine	Ref.
China	1975-1978	9000-20000 a/	40-330 a/		Tin, copper, and tungsten	[S33]
Germany, Federal Rep. of	1984		1	3	Lead and zinc	[K15]
	1984	280	1	3	Iron	[K15]
	1984	20	0.2	0.4	Pyrite, zinc, barite	[K15]
	1984	110	0.4	1	Barite	[K15]
	1984		0.4; 6	0.9; 14	Fluorspan, barite	[K15]
	1984	4100	10	25	Fluorspan	[K15]
	1984	6600	20	60	Graphite	[K15]
		1200 b/	2 b/	5 b/		
	1984	120	0.2	0.4	Clay	[K15]
	1984	29000	80	200	Feldspar	[K15]
	1984	730	1	3	Slate	[K15]
	1984	460	0.8	2	Oil shale	[K15]
	1984	170	0.4	0.8	Rock salt	[K15]
	1984	8	0.02	0.04	Salt saline	[K15]
India	1981		0.04-0.3		Gold	[N9]
	1981		1.4 -3.5		Copper	[N9]
	1987	1200	4.8		Copper	[M29]
		19	0.07		Gold	[M29]
		190	0.7		Lead/Zinc	[M29]
		39	0.15		Manganese	[M29]
		79	0.3		Mica	[M29]
Italy	1981		0.04		Amianthinite	[S36]
	1981		1.2		Barite	[S36]
	1981		2.5		Bauxite	[S36]
	1981		0.2		Chalcopyrite	[S36]
	1981		0.04; 0.2		Feldspar	[S36]
	1981		1.5; 5.6		Fluorspar	[S36]
	1981		0.08-11.4 a/		Fluorspar	[S36]
	1981		4.8		Magnetite	[S36]
	1981		0.04- 5.4 a/		Siderite	[S36]
	1981		0.03- 0.7 a/		Steatite	[S36]
	1981		0.5; 3.4		Sulphur	[S36]
	1984	100-2800	0.4 - 10 c/		Not indicated	[S37]
Poland	1966-1970		1.9		Iron	[D4]
	1966-1970		3.1		Pyrite	[D4]
	1966-1970		0.6		Barite	[D4]
	1966-1970		2.2		Zinc-lead, copper	[D4]
	1972-1976		2.5 - 3.1 a/		Zinc-lead, copper	[D4]
	1977-1978		2.5		Zinc-lead, copper	[C15]
Sweden	1970-1980			3-20 d/	50 mines	[S35]
	1982			5	Iron, zinc, copper	[S58]
United Kingdom	1973-1975		1.5 - 90	4-240 a/	Tin	[S34]
	1973-1975		0.4 - 20 a/	0.6-30 a/	Haematite	[S34]
	1973		2	4	Iron	[S34]
	1973-1975		0.08-160 a/	0.4-120	Fluorspar	[S34]
	1973-1975		0.2 - 14 a/	0.7- 30	Limestone	[S34]
	1973		0.2; 1	0.4; 2	Calcspar	[S34]
	1973		0.6; 6	0.4; 15	Homestone	[S34]
	1973-1975		0.2 - 10	0.4- 20	Fireclay	[S34]
	1973		0.1; 1	0.4 - 5	Ballclay	[S34]
	1973-1975		6; 30	10; 55	Lead	[S34]
	1973		1.5	3	Slate	[S34]
	1973		15	40	Barite	[S34]
	1973-1975		0.06; 0.4	0.4; 1	Salt	[S34]
	1975		2	4	Silica sand	[S34]
	1981			11	Other than coal	[O11]
United States	1978	2600	5 - 8		Zinc	[S32]
	1978	280	3		Iron	[S32]
	1978	1000	5		Fireclay	[S32]
	1978	50	0.8		Fluorspar	[S32]
	1978	160			Copper	[S32]
	1978	20	0.04-0.1		Limestone	[S32]

a/ Range of means.
b/ Winter measurements.
c/ Assuming an average equilibrium factor of 0.7.
d/ Average exposures decreasing with time from 20 mJ in 1970 to 3 mJ in 1980.

Table 41

Environmental radiation fields and occupational exposures in non-uranium mines of the United Kingdom
(Based on [D5])

RADIATION CHARACTERISTICS

Mine	^{238}U activity per unit mass (Bq kg^{-1})	^{232}Th activity per unit mass (Bq kg^{-1})	Potential alpha energy concentration of radon daughters (µJ m^{-3})	Potential alpha energy concentration of thoron daughters (µJ m^{-3})
1: sedimentary	66	53	0.06	0.04
2: sedimentary	65	56	0.15	0.11
3: sedimentary	<10	<10	0.94	0.96
4: igneous	60	2	29.5	0.1
5: sedimentary	18	6	1.9	0.51
6: igneous	180	90	9.4	0.64
7: sedimentary	35	44	0.89	0.41
8: igneous	270	65	29	1.4

OCCUPATIONAL DOSES

Mine	Average annual effective dose equivalent (mSv)	Contribution (per cent of the total)			
		External irradiation a/	Inhalation of radon daughters	Inhalation of thoron daughters	Inhalation of ore dust b/
1	0.7	25	51	10	14
2	1.4	13	66	13	7
3	7	<1	78	22	<1
4	180	<1	100	<1	<1
5	12	<1	93	7	<1
6	58	<1	97	2	<1
7	6	2	86	11	1
8	180	<1	98	1	<1

a/ Assuming a 4π geometry.
b/ Assuming an ore dust concentration of 3.8 mg m^{-3}.

Table 42

Estimated atmospheric releases of natural radionuclides from zinc mining and processing facilities
[A7, U8]

Radio-nuclide	Annual atmospheric releases (MBq)		
	Mine	Mill	Smelter
U-238	0.004	0.06	10
U-234	0.004	0.06	10
Th-230	0.004	0.05	5
Ra-226	0.003	0.03	7
Rn-222	8500000	40000	
Pb-210	0.01	0.05	20
Po-210	0.006	0.07	2
Th-232	0.002	0.02	3
Ra-228			3

Table 43

Atmospheric releases of natural radionuclides from a fireclay mine and refractory plant
[A6]

Radio-nuclide	Annual atmospheric emissions (MBq)	
	Mines	Kilns
U-238	< 0.1	5
U-234	< 0.1	5
Th-230	< 0.1	< 6
Ra-226	< 2	< 8
Rn-222	1200000	
Pb-210	<10	< 200
Po-210	< 7	130
Th-232	< 0.1	< 1

Table 44

Radionuclide activities per unit mass in surveyed alumina plant process samples
[A9, U8]

Sample	Activity per unit mass ($Bq\ kg^{-1}$)	
	^{238}U	^{232}Th
Bauxite ore	250	200
Alumina kiln feed	2	2
Alumina product	10	7
Red mud	280	180
Brown mud	200	460

Table 45

Estimated atmospheric releases of natural radionuclides from the surveyed alumina plant and aluminium reduction plant
[A9, U8]

Radio-nuclide	Annual atmospheric releases (MBq)		
	Alumina kilns	Red mud kilns	Aluminium reduction plant
U-238	2.5		
U-234	2.5		
Ra-226	2		
Rn-222		70000	
Pb-210		300	1200
Po-210		340	1000

Table 46

Radionuclide activities per unit mass in surveyed copper mine and mill process samples [A9, U8]

Sample	Underground mine and mill		Open pit mine and mill	
	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})
Ore	30	23	80	110
Concentrate	24	3	50	40

Table 47

Estimated atmospheric releases of natural radionuclides from copper ore mining and processing facilities [A7, U8]

Radionuclide	Annual atmospheric releases (MBq)		
	Mine	Mill	Smelter
U-238		10	400
U-234		14	400
Th-230			700
Ra-226		7	60
Rn-222	240000	70000	
Pb-210		30	7000
Po-210		0.07	7000
Th-232			500
Ra-228			500
Th-228			500

Table 48

Estimates of per caput annual effective dose equivalents and of ranges, excluding extreme values, for the most important natural sources of radiation

Source of irradiation	Annual effective dose equivalent (μSv)	
	Mean	Typical range
External		
Cosmic rays	360	300-2000
Terrestrial sources	410	200-1000
Internal		
K-40	180	100- 200
U-238 → Ra-226	20	10- 50
Rn-222 → Po-214	1100	300-5000
Pb-210 → Po-210	120	50- 200
Th-232 → Ra-224	20	10- 50
Rn-220 → Tl-208	160	50- 500
Total (rounded)	2400	1500-6000 a/

a/ The 90th, 95th and 99th percentiles are estimated to be 2300, 3300 and 6100 μSv, respectively, assuming a log-normal distribution with a geometric standard deviation of 2.5.

Table 49

Estimates of collective effective dose equivalent commitments per year of practice for various industrial activities

Source	Collective effective dose equivalent commitment (man Sv)	
	Public	Workers
Coal combustion		
Power plants	2000	60
Domestic homes	2000-40000	
Coal mining	0.5-10	2000
Use of coal ash in the building industry	50000	
Geothermal energy production	3	
Oil combustion in power plants	100	
Natural gas combustion in power plants	3	
Phosphate industrial operations	60	20
Use of phosphate fertilizers	10000	50
Use of phosphogypsum in houses	300000	
Non-uranium mining	small	20000

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