Natural Radiation Environment

- Cosmic sources

- Terrestrial sources

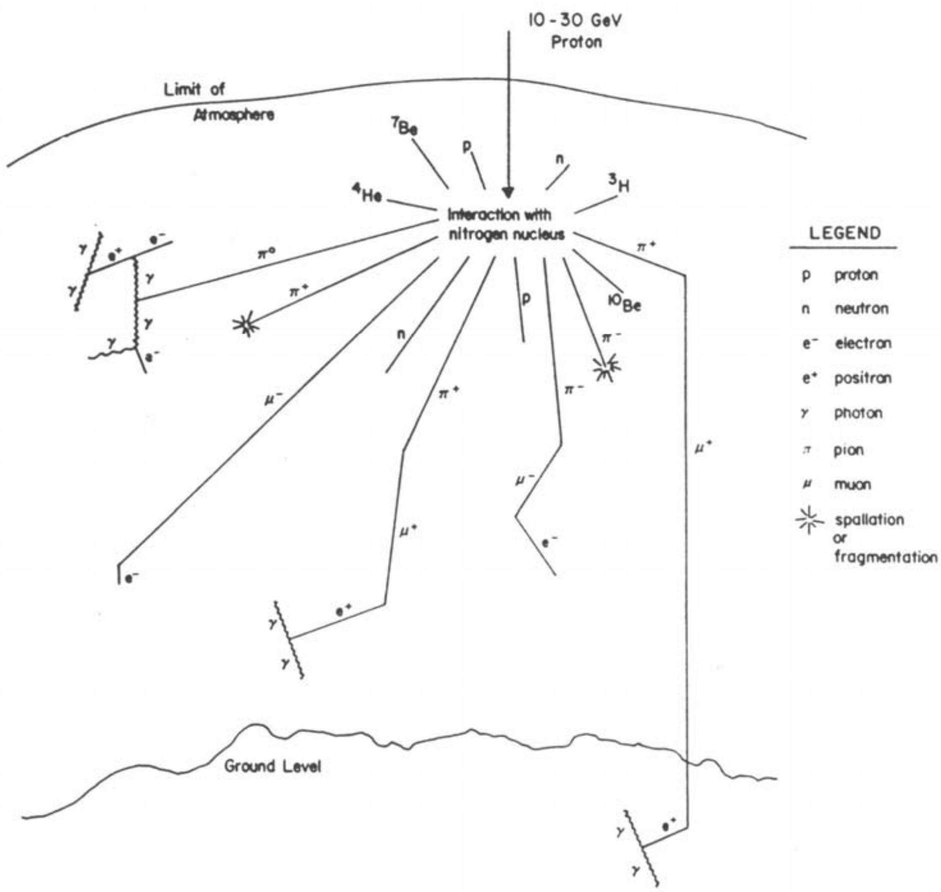
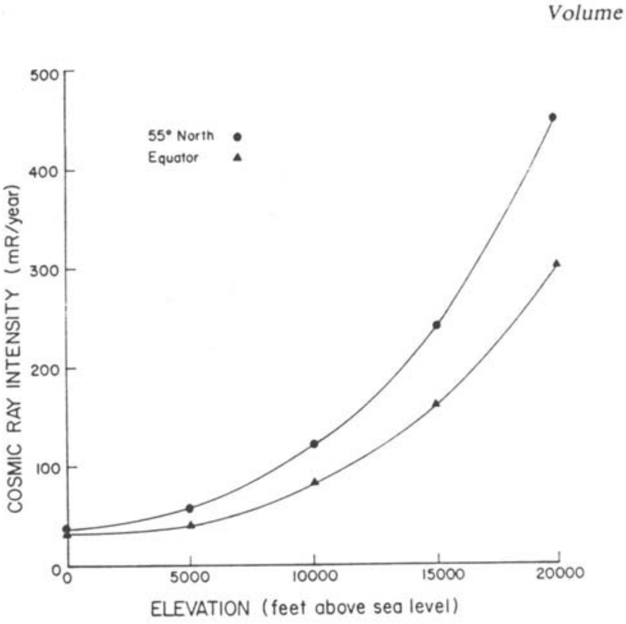


FIGURE 1. Schematic diagram showing the interaction of a primary cosmic proton with an atom in the earth's atmosphere to form numerous secondary particles. Decay products and some interaction possibilities of secondaries are also shown.

RADIONUCLIDES PRODUCED FROM COSMIC RAYS

Radionuclide	Half-life	Primary production mode	Atmospheric production rate (atoms/cm²-sec)	Detected and measured in
^{10}Be	2.7×10^6 year	Spallation	4.5×10^{-2}	Deep sea sediments
^{36}Cl	3.1×10^5 year	$^{35}Cl(n,\gamma)^{36}Cl$	1.1×10^{-3}	Rocks, rain
^{14}C	5568 year	$^{14}N(n,p)^{14}C$	1.8	Organic material, CO_2
^{32}Si	500 year	Spallation	1.6×10^{-4}	Marine sponges, sea water
^{3}H	12.3 year	Spallation $^{14}N(n,^{3}H)^{12}C$	0.25	Water, air
^{22}Na	2.6 year	Spallation	5.6×10^{-5}	Rain, air, organic material
^{35}S	88 day	Spallation	1.4×10^{-3}	Rain, air, organic material
^{7}Be	53 day	Spallation	8.1×10^{-2}	Rain, air
^{33}P	25 day	Spallation	6.8×10^{-4}	Rain, air, organic material
^{32}P	14.3 day	Spallation	8.1×10^{-4}	Rain, air, organic material
^{27}Na	15.1 hr	Spallation		Rain
^{38}S	2.9 hr	Spallation		Rain
^{39}Cl	55 min	$^{40}A(\mu^-,n)\,^{39}Cl$	1.6×10^{-3}	Rain
^{38}Cl	37 min	Spallation		Rain



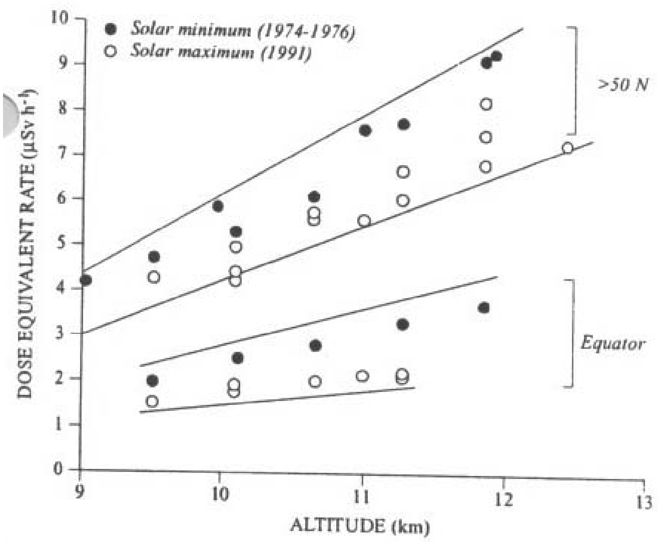


Figure III. Measurement results of cosmic ray exposure rate at aircraft altitudes [E1].

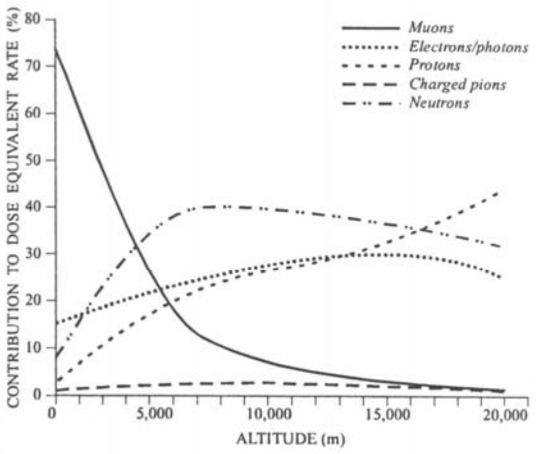


Figure I. Components of the dose equivalent rate from cosmic rays in the atmosphere [O4].

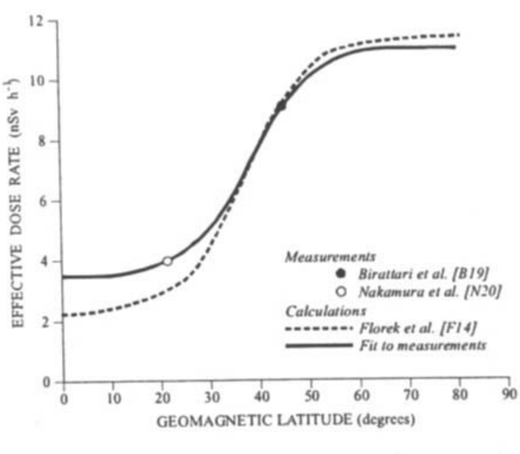


Figure II. Latitude variation in dose rate from cosmic ray neutrons at sea level.

Table 3
SINGLY OCCURRING PRIMORDIAL RADIONUCLIDES•

Radionuclide	Half-life (year)	Radiation
^{40}K	1.26×10^{9}	β,γ
^{50}V	6×10^{15}	β,γ
^{87}Rb	4.8×10^{10}	β
^{115}In	6×10^{14}	β
^{123}Te	1.2×10^{13}	EC•
^{138}La	1.1×10^{11}	β,γ
^{142}Ce	$> 5 \times 10^{16}$	α
^{144}Nd	2.4×10^{15}	α
^{147}Sm	1.1×10^{11}	α
^{149}Sm	$> 1 \times 10^{15}$	α
^{152}Gd	1.1×10^{14}	α
^{174}Hf	2×10^{15}	α
^{176}Lu	2.2×10^{10}	β,γ
^{180}Ta	$>1 \times 10^{12}$	β
^{187}Re	4.3×10^{10}	β
^{190}Pt	6.9×10^{11}	α

• Electron capture.

From Eisenbud, M., *Environmental Radioactivity*, 2nd ed., Academic Press, New York, 1973. With permission.

TABLE 6-3

Thorium Series[a]

Nuclide	Historical name	Half-life	Major radiations
^{232}Th	Thorium	1.4×10^{10} y	α, <1% γ
^{228}Ra	Mesothorium I	5.75 y	β, <1% γ
^{228}Ac	Mesothorium II	6.13 h	β, γ
^{228}Th	Radiothorium	1.91 h	α, γ
^{224}Ra	Thorium X	3.66 d	α, γ
^{220}Rn	Emanation thoron	55.6 s	α, <1% γ
^{216}Po	Thorium A	0.15 s	α, <1% γ
^{212}Pb	Thorium B	10.64 h	β, γ
^{212}Bi	Thorium C	60.55 m	α, γ
^{212}Po (64%)	Thorium C′	0.305 μs	α
^{208}Tl (36%)	Thorium C″	3.07 m	β, γ
^{208}Pb	Thorium D	Stable	None

[a] Adapted from Bureau of Radiological Health (1970).

Actinium Series[a]

Nuclide	Historical name	Half-life	Major radiations
^{235}U	Actinouranium	7.038×10^{8} y	α, γ
^{231}Th	Uranium Y	25.5 h	β, γ
^{231}Pa	Protoactinium	2.276×10^{4} y	α, γ
^{227}Ac	Actinium	21.77 y	β, <1% γ
^{227}Th (98.62%)	Radioactinium	18.72 y	α, γ
^{223}Fr (1.38%)	Actinium K	21.8 m	β, γ
^{223}Ra	Actinium X	11.43 d	α, γ
^{219}Rn	Emanation actinon	3.96 s	α, γ
^{215}Po	Actinium A	1.78 ms	α, <1% γ
^{211}Pb (~100%)	Actinium B	36.1 m	β, γ
^{215}At (0.00023%)	Astatine	~0.1 ms	α, <1% γ
^{211}Bi	Actinium C	2.14 m	α, γ
^{211}Po (0.273%)	Actinium C′	0.516 s	α, γ
^{207}Tl (99.73%)	Actinium C″	4.77 m	β, <1% γ
^{207}Pb	Actinium D	Stable	None

[a] Adapted from Bureau of Radiological Health (1970).

Bildung natürlicher Radionuklide aus künstlichen RN:
^{235}U aus ^{239}Pu, ^{232}Th aus ^{252}Cf

Nuklid	Name		Zerfall	HWZ
^{239}Pu			α	$2.41 \cdot 10^{4}$ a
^{235}U	AcU	Actin Uranium	α	$7.04 \cdot 10^{8}$ a
^{252}Cf			α	2.645 a
^{248}Cm			α	3.4×10^{5} a
^{244}Pu			α	8×10^{7} a
^{240}U			β^-	14.1 h
^{240}Np			β^-	1.032 h
^{240}Pu			α	6561 a
^{236}U			α	$2.3 \cdot 10^{7}$ a
^{232}Th	Th	Thorium	α	$1.405 \cdot 10^{10}$ a

TABLE 6-2

Uranium Series[a]

Nuclide	Historical name	Half-life	Major radiations
^{238}U	Uranium I	4.47×10^{9} y	α, <1% γ
^{234}Th	Uranium X_1	24.1 d	β, γ
^{234m}Pa	Uranium X_2	1.17 m	β, <1% γ
^{234}Pa	Uranium Z	21.8 y	β, γ
^{234}U	Uranium II	244,500 y	α, <1% γ
^{230}Th	Ionium	7.7×10^{4} y	α, <1% γ
^{226}Ra	Radium	1600 y	α, γ
^{222}Rn	Emanation radon	3.8 d	α, <1% γ
^{218}Po	Radium A	3.05 m	α, <1% γ
^{214}Pb (99.98%)	Radium B	26.8 m	β, γ
^{218}At (0.02%)	Astatine	2 s	α, γ
^{214}Bi	Radium C	19.9 m	β, γ
^{214}Po (99.98%)	Radium C′	164 μs	α, <1% γ
^{210}Tl (0.02%)	Radium C″	1.3 m	β, γ
^{210}Pb	Radium D	22.3 y	β, γ
^{210}Bi	Radium E	5.01 d	β
^{210}Po (~100%)	Radium F	138.4 d	α, <1% γ
^{206}Tl (0.00013%)	Radium E″	4.20 m	β, <1% γ
^{206}Pb	Radium G	Stable	None

[a] Adapted from Bureau of Radiological Health (1970).

Table 11
Areas of high natural radiation background

Country	*Area*	*Characteristics of area*	*Approximate population*	*Absorbed dose rate in air [a] (nGy h⁻¹)*	*Ref.*
Brazil	Guarapari Mineas Gerais and Goias Pocos de Caldas Araxá	Monazite sands; coastal areas Volcanic intrusives	73 000 350	90-170 (streets) 90-90 000 (beaches) 110-1 300 340 average 2 800 average	[P4, V5] [A17, P4] [V5]
China	Yangjiang Quangdong	Monazite particles	80 000	370 average	[W14]
Egypt	Nile delta	Monazite sands		20-400	[E3]
France	Central region Southwest	Granitic, schistous, sandstone area Uranium minerals	7 000 000	20-400 10-10 000	[J3] [D10]
India	Kerala and Madras Ganges delta	Monazite sands, coastal areas 200 km long, 0.5 km wide	100 000	200-4 000 1 800 average 260-440	[S19, S20] [M13]
Iran (Islamic Rep. of)	Ramsar Mahallat	Spring waters	2 000	70-17 000 800-4 000	[S21] [S58]
Italy	Lazio Campania Orvieto town South Toscana	Volcanic soil	5 100 000 5 600 000 21 000 ~100 000	180 average 200 average 560 average 150-200	[C12] [C12] [C20] [B21]
Niue Island	Pacific	Volcanic soil	4 500	1 100 maximum	[M14]
Switzerland	Tessin, Alps, Jura	Gneiss, verucano, ^{226}Ra in karst soils	300 000	100-200	[S51]

a Includes cosmic and terrestrial radiation.

Table 31
Average worldwide exposure to natural radiation sources

Source of exposure	*Annual effective dose (mSv)*	
	Average	*Typical range*
Cosmic radiation		
Directly ionizing and photon component	0.28 (0.30) [a]	
Neutron component	0.10 (0.08)	
Cosmogenic radionuclides	0.01 (0.01)	
Total cosmic and cosmogenic	0.39	0.3-1.0 [b]
External terrestrial radiation		
Outdoors	0.07 (0.07)	
Indoors	0.41 (0.39)	
Total external terrestrial radiation	0.48	0.3-0.6 [c]
Inhalation exposure		
Uranium and thorium series	0.006 (0.01)	
Radon (^{222}Rn)	1.15 (1.2)	
Thoron (^{220}Rn)	0.10 (0.07)	
Total inhalation exposure	1.26	0.2-10 [d]
Ingestion exposure		
^{40}K	0.17 (0.17)	
Uranium and thorium series	0.12 (0.06)	
Total ingestion exposure	0.29	0.2-0.8 [e]
Total	2.4	1-10

a Result of previous assessment [U3] in parentheses.
b Range from sea level to high ground elevation.
c Depending on radionuclide composition of soil and building materials.
d Depending on indoor accumulation of radon gas.
e Depending on radionuclide composition of foods and drinking water.

Uranium/Radium—(4n+2)—series

Isotope	Half-life	α-energies MeV	β-energies MeV	γ-energies MeV	IC
Uranium-238	$4{\cdot}5 \times 10^9$ y	~4·2 — 100%	—	0·048 — 0%	23%
Thorium-234 (UX₁)	24·1 d	—	0·10 — 35% 0·19 — 65%	0·029 0·063 0·091	α — 10 α — 0·2 α — 2·5
Protactinium-234m (UX₂)	1·18 m	—	IT — 1% 0·58 — ~ 1% 1·50 — ~ 9% 2·31 — ~90%	0·75, 1·00 } most abundant others	—
Protactinium-234 (UZ)	6·66 h	—	1·13 others	0·043 0·80 others	—
Uranium-234 (U II)	$2{\cdot}5 \times 10^5$ y	4·717 — 28% 4·768 — 72%	—	0·051 — 0%	28%
Thorium-230 (Ionium)	$8{\cdot}0 \times 10^4$ y	4·615 — 24% 4·682 — 76%	—	0·068 — 0·6% others —very weak	23·4%
Radium-226	1620 y	4·589 — 5·7% 4·777 — 94·3%	—	0·188 — ~4%	~2%
Radon-222	3·825 d	5·48 — ~ 100%	—	—	—
Polonium-218 (Radium A)	3·05 m	6·00 — ~ 100%	? — 0·02%	—	—
Astatine-218	1·3 s	6·70 — ~0·02% 6·65 — ~0·001%	? —very weak	—	—
Radon-218	$1{\cdot}9 \times 10^{-2}$ s	7·13 — very weak	—	0·61 —very weak	—
Lead-214 (Radium B)	26·8 m	—	0·59 — ~ 56% 0·65 — ~ 44%	0·24 0·30 0·35 others — weak	—
Bismuth-214 (Radium C)	19·9 m	~5·5 — 0·04%	— 0·4 — 9% 1·0 — 23% 1·51 — 40% 1·88 — 9% 3·26 — 19%	— 0·61, 1·12, 1·76 } most abundant 14 others to 2·43 MeV	— —
Polonium-214 (Radium C′)	$1{\cdot}6 \times 10^{-4}$ s	7·68 — ~100%	—	—	—
Thallium-210 (Radium C″)	1·3 m	—	1·96 — 0·04%	several —very weak	—
Lead-210 (Radium D)	22 y	—	0·017— 85% 0·063— 15%	0·047 — ~ 5%	~ 80%
Bismuth-210 (Radium E)	5·01 d	5·06 — $1{\cdot}7 \times 10^{-4}$%	— 1·17 —~100%	— —	— —
Polonium-210 (Radium F)	138·4 d	5·305 — ~100%	—	0·8 — $1{\cdot}2 \times 10^{-3}$%	—
Thallium-206 (Radium E″)	4·2 m	—	1·51—$1{\cdot}7 \times 10^{-4}$%	—	—
Lead-206	Stable	—	—	—	—

All percentages relate to disintegrations of Uranium-238