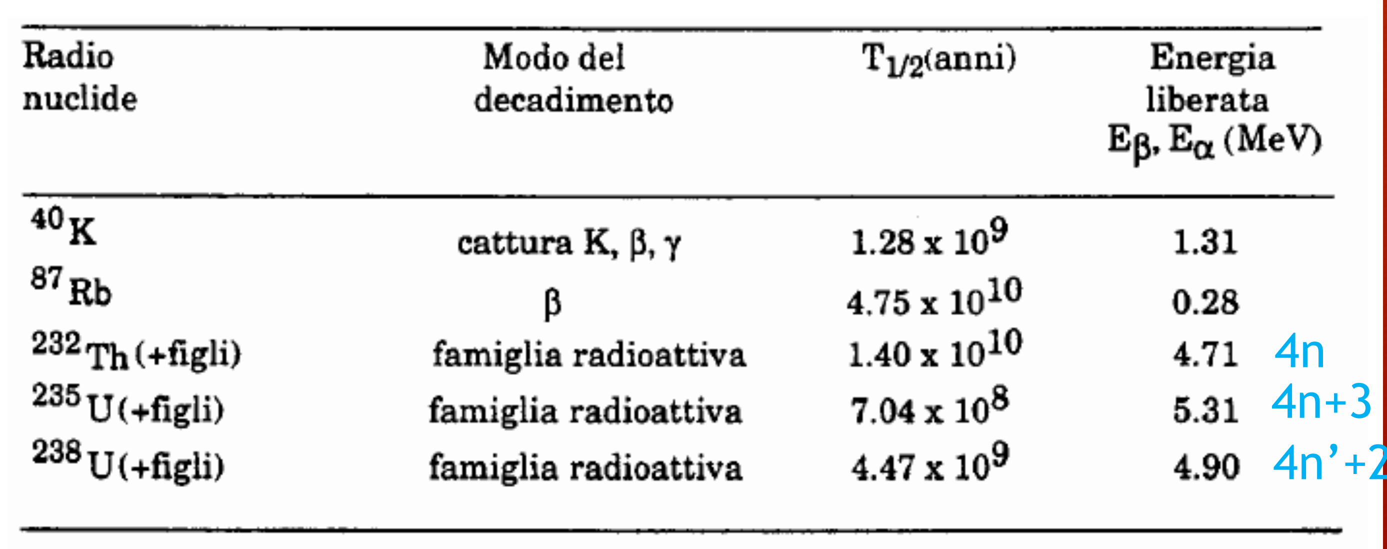
Natural Radiactivity

Corvisioero pag 201-226

Primordial natural radionuclides

Lifetimes >~ earth age or descendants

[secular equilibrium]



Radio nuclide	Modo del decadimento	$T_{1/2}$(anni)	Energia liberata E_β, E_α (MeV)	
^{40}K	cattura K, β, γ	1.28×10^9	1.31	
^{87}Rb	β	4.75×10^{10}	0.28	
^{232}Th (+figli)	famiglia radioattiva	1.40×10^{10}	4.71	4n
^{235}U (+figli)	famiglia radioattiva	7.04×10^8	5.31	4n+3
^{238}U (+figli)	famiglia radioattiva	4.47×10^9	4.90	4n’+2

4n+1 family was ^{237}Np, but «short» lifetime (10^6 yrs)
→ residual: ^{209}Bi

Some have very short chains

- $^{40}K \rightarrow {}^{40}Ca + e^- + \nu$

  Is. Ab. 0,01%
- $^{87}Rb \rightarrow {}^{87}Sr + e^- + \nu$

  Is. Abb. 27,8%

Example: ^{40}K

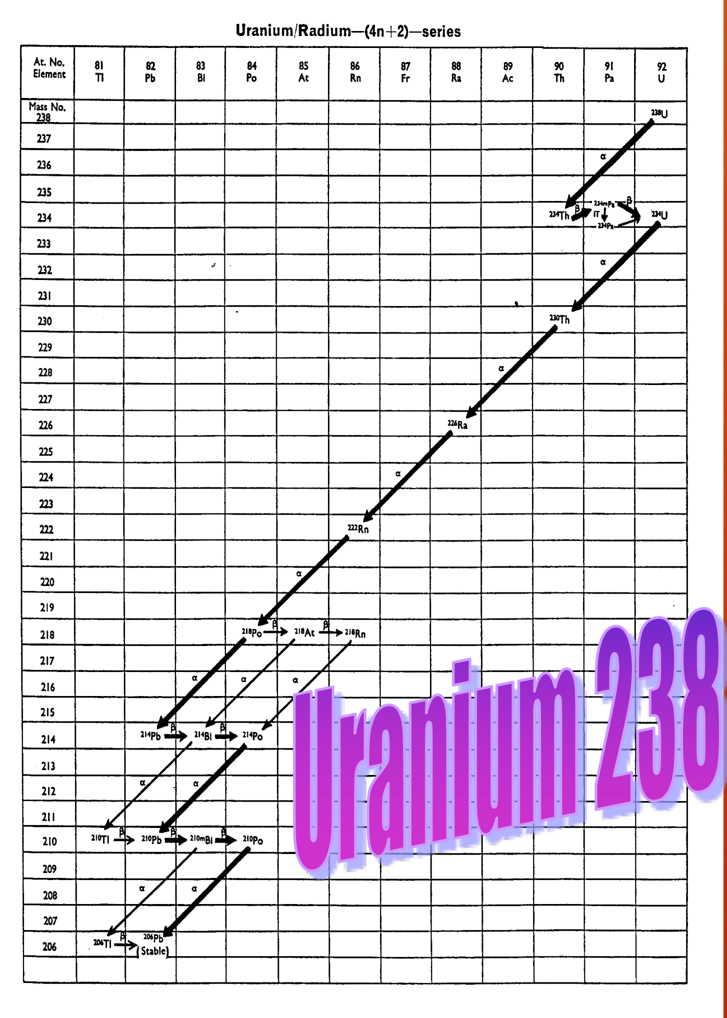
- Potassium fractional mass in human body: $f \sim 3\ 10^{-3}$ → 70kg man has ~210g of potassium
- ^{40}K isotopic fraction today $f_I \sim 1.2\ 10^{-4}$ → 70kg man has ~25 mg of ^{40}K

  → 0.63 mM → $3.8\ 10^{20}$ ^{40}K nuclei
- ^{40}K decays with $\tau = 1.8\ 10^{9}$ y= $5.6\ 10^{16}$s in
  - β^- (EP=1310 MeV) in 90% of the cases
  - γ (E=1460 MeV) in 10 % of the cases

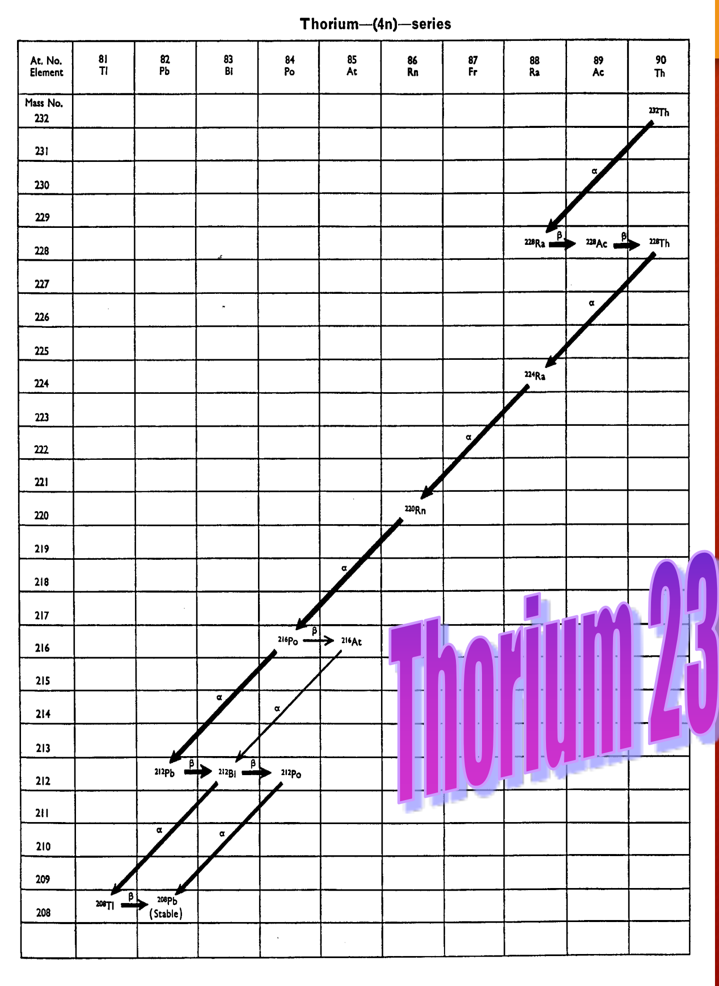
A(man)~6 kBq!!! →

600 cps of 1460 MeV Photons
5400 cpf of 1310 MeV β-

Chains



Uranium 238



Thorium 232

Decay laws in decay chains

Quantification of the decay law in the case

$$A \xrightarrow{\lambda_1} B \xrightarrow{\lambda_2} C \;\ldots\ldots\ldots\ldots \xrightarrow{\lambda_{n-1}} X \quad (stabile)$$

Differential equation system, (Bateman Equations) :

$$\begin{aligned}
\frac{dN_1(t)}{dt} &= -\lambda_1 N_1(t) \\
\frac{dN_2(t)}{dt} &= -\lambda_2 N_2(t) + \lambda_1 N_1(t) \\
&\ldots\ldots\ldots\ldots \\
\frac{dN_i(t)}{dt} &= -\lambda_i N_i(t) + \lambda_{i-1} N_{i-1}(t) \\
&\ldots\ldots\ldots\ldots \\
\frac{dN_N(t)}{dt} &= \lambda_{N-1} N_{N-1}(t)
\end{aligned}$$

$N_i(t)$ is the number of nuclides attime t and λ_i is the corresponding disintegration constant

Nell’ipotesi che $N_{0i} = 0$ per i = 2,3, ... N le soluzioni sono:

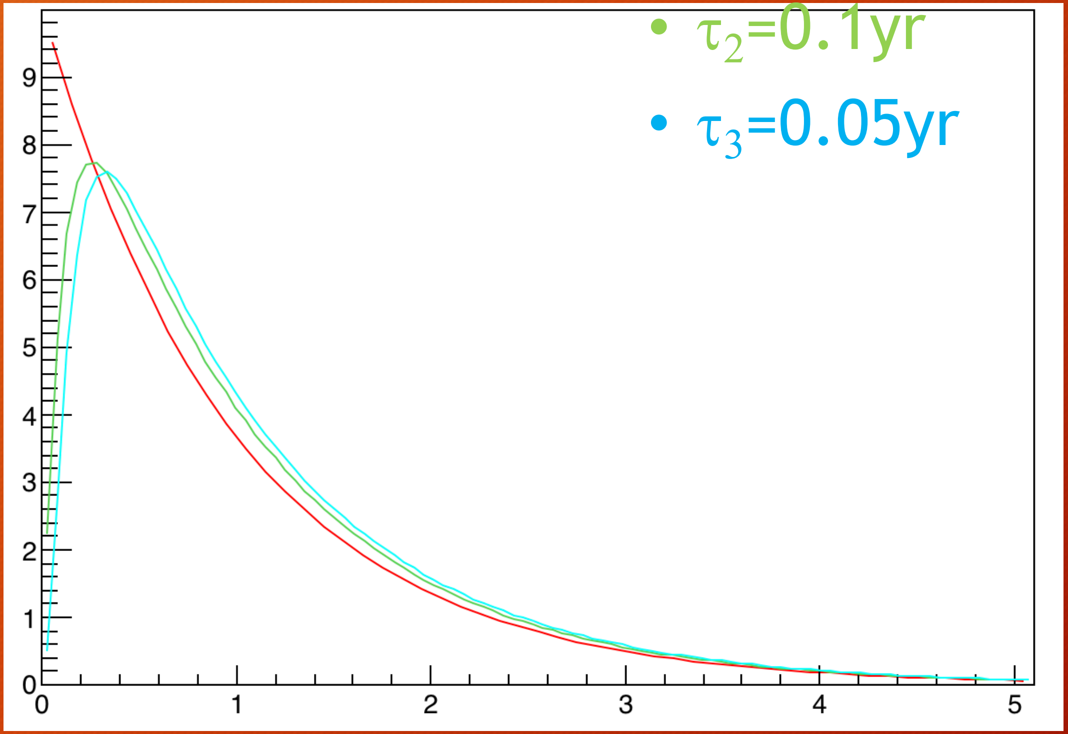
$$
\begin{aligned}
N_1(t) &= N_{01}\exp(-\lambda_1 t) \\
N_2(t) &= N_{01}\frac{\lambda_1}{\lambda_2-\lambda_1}[\exp(-\lambda_1 t)-\exp(-\lambda_2 t)] \\
&\ldots\ldots\ldots \\
N_i(t) &= N_{01}\lambda_1..\lambda_{i-1}[\frac{\exp(-\lambda_1 t)}{(\lambda_2-\lambda_1)\ldots(\lambda_i-\lambda_1)}+\ldots.+\frac{\exp(-\lambda_k t)}{(\lambda_1-\lambda_k)\ldots(\lambda_{k-1}-\lambda_k)(\lambda_{k+1}-\lambda_k)\ldots(\lambda_i-\lambda_k)}+.. \\
&\quad ..+\frac{\exp(-\lambda_i t)}{(\lambda_1-\lambda_i)\ldots(\lambda_{i-1}-\lambda_i)}] \\
&\ldots\ldots\ldots \\
N_N(t) &= N_{01}\lambda_1..\lambda_{N-1}[-\frac{\exp(-\lambda_1 t)}{\lambda_1(\lambda_2-\lambda_1)\ldots(\lambda_{N-1}-\lambda_1)}-\ldots.-\frac{\exp(-\lambda_{N-1} t)}{\lambda_{N+1}(\lambda_1-\lambda_{N-1})\ldots(\lambda_{N-2}-\lambda_{N-1})}]+N_{01}
\end{aligned}
$$

The i-th element, absent at t = 0 is produced by the decay of the previous nuclides. Once the equilibrium is reached asymptotycally reaches the same lifetime as the initial nucleus, assuming $\lambda_1 << \lambda_i$ (i>1)

Example with three nuclides

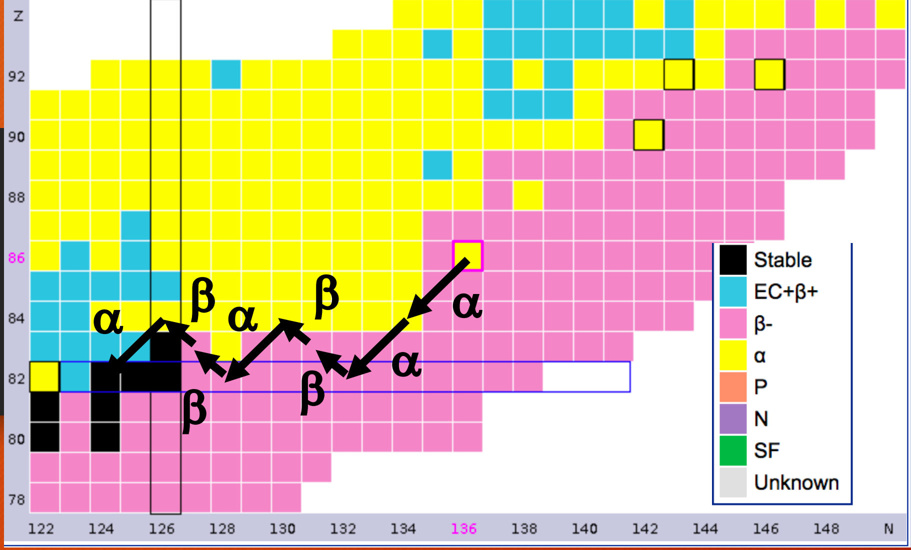
- τ_1=1yr
- τ_2=0.1yr
- τ_3=0.05yr

A



t(yr)

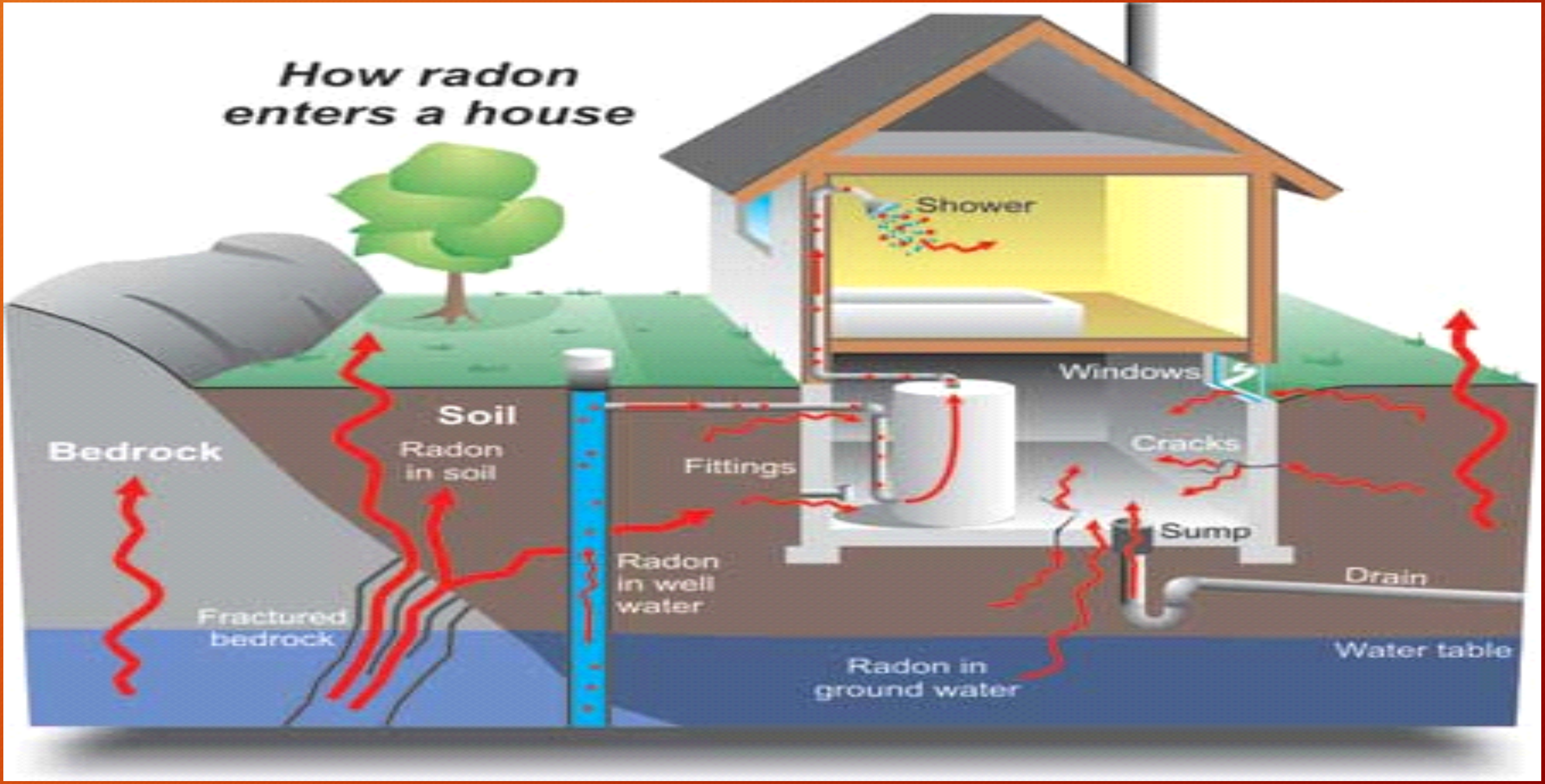
Rn-222



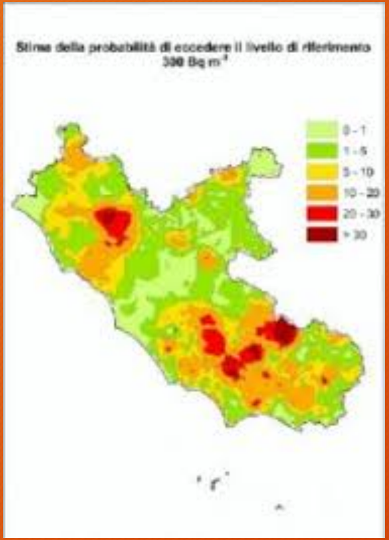
- Particularly important is the noble gas ^{222}Rn, which is a member of the ^{238}U series.
- It decays by α-emission with a half life of t1/2=3.82 days. Because of its gaseous character it can diffuse out of the rock and mix into the air where it can be inhaled. Outside its concentration is low because of the dilution in air, but in closed rooms like basements its concentration can be quite large.
- Once inhaled, the majority of the dose is deposited in the trachea-bronchial region by the decay of the short-lived daughters, 218Po and 214Po, which are both α-emitters.

Radon in Buildings

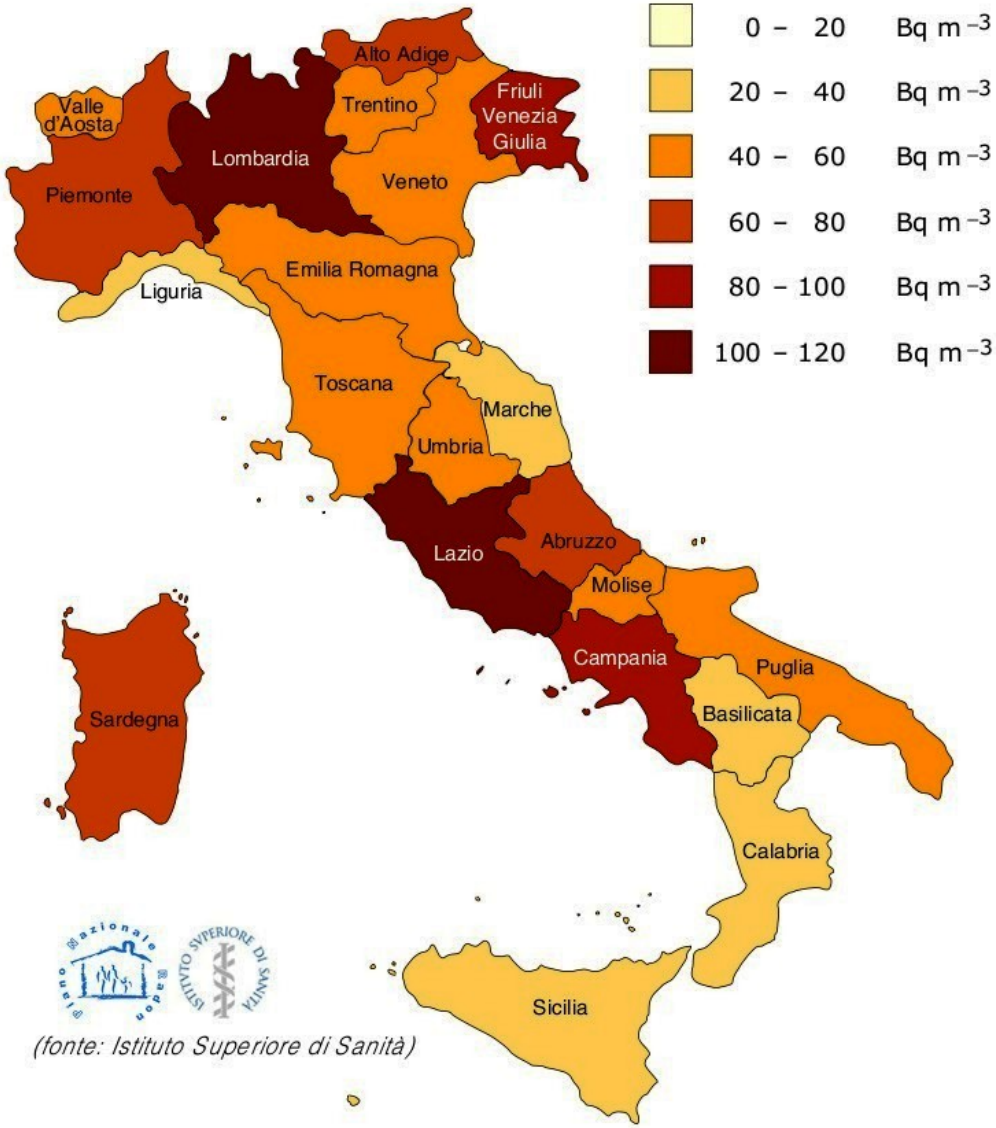
There are two main sources for the radon in home's indoor air, soil and water supply.



Radon MAP (Italy)



Stima della probabilità di eccedere il livello di riferimento 300 Bq m^{-3}



(fonte: Istituto Superiore di Sanità)

ATTENZIONE: il valore di concentrazione medio regionale, ricavabile dalla mappa, non dà nessuna indicazione riguardo al livello di radon della propria abitazione.
Per conoscere la concentrazione di radon nella propria casa è necessario effettuare una misura con dispositivi adeguati.

Po-210

- Within the 238U chain, ^{210}Po is present in tobacco. It emits 5.3 MeV α particles with an half life of $T_{1/2}$=138.4 days.

When smoking cigarettes
lungs are exposed to α radiation!

Exercize

- Find alla the radionuclides in the ^{238}U chain, following only the most probable decay. For each, report:
  - Decay type
  - Lifetime
- Determine the age of the earth assuming that originally all isotopes of Uranium where equally present and that:
  - The half lives are: 4.5 10^9 y (^{238}U) and 7.1 10^8 y (^{235}U)
  - The present abundances are: 99.3% (^{238}U) and 0.7%(^{235}U)

Other sources of natural radiactivity

- Spontaneous fission

- Nuclear fall-out and nuclear plants:
  - Direct production of fission

    ^{90}Sr ($T_{1/2}$=28y)

    ^{137}Cs ($T_{1/2}$=30y)

    ^{131}I ($T_{1/2}$=8.1d)
  - Neutron induced production

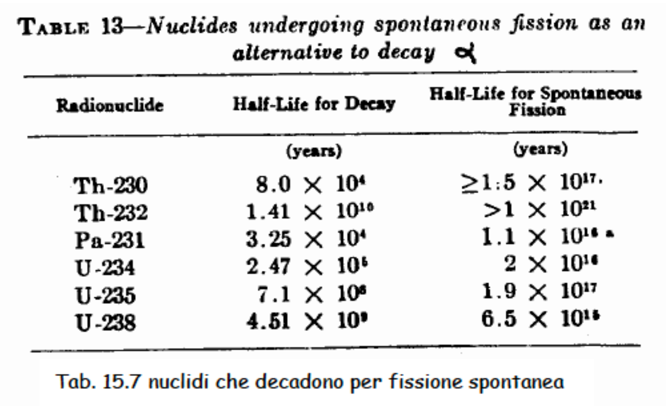
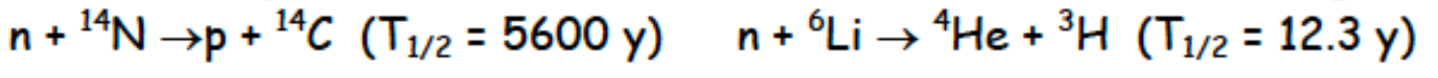


TABLE 13—*Nuclides undergoing spontaneous fission as an alternative to decay* α

Radionuclide	**Half-Life for Decay**	**Half-Life for Spontaneous Fission**
	(years)	(years)
Th-230	8.0×10^4	$\geq 1.5 \times 10^{17}$
Th-232	1.41×10^{10}	$> 1 \times 10^{21}$
Pa-231	3.25×10^4	1.1×10^{16} [a]
U-234	2.47×10^5	2×10^{16}
U-235	7.1×10^8	1.9×10^{17}
U-238	4.51×10^9	6.5×10^{15}

Tab. 15.7 nuclidi che decadono per fissione spontanea



$n + {}^{14}N \rightarrow p + {}^{14}C \quad (T_{1/2} = 5600\ y) \qquad n + {}^{6}Li \rightarrow {}^{4}He + {}^{3}H \quad (T_{1/2} = 12.3\ y)$

Cosmic rays

Cosmic rays-a long story

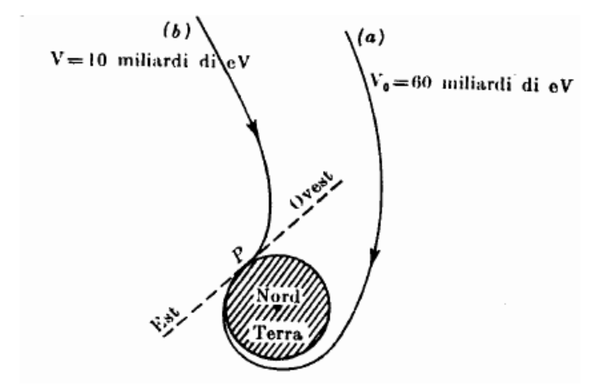
- C.T.R Wilson discovered in 1900 the continuous atmospheric ionization. It was believed to be due to the natural radiation of the Earth. In other words, from the ground up.
- Wilson noticed the reappearance of drops of condensation in expanded dust free gas, the first cloud chamber.
- At the beginning of the 20th century scientists were puzzled by the fact that more radiation existed in the environment than could be explained by natural background radiation
- The debate was solved on a balloon flight in 1912 from the University of Vienna.

Victor Hess

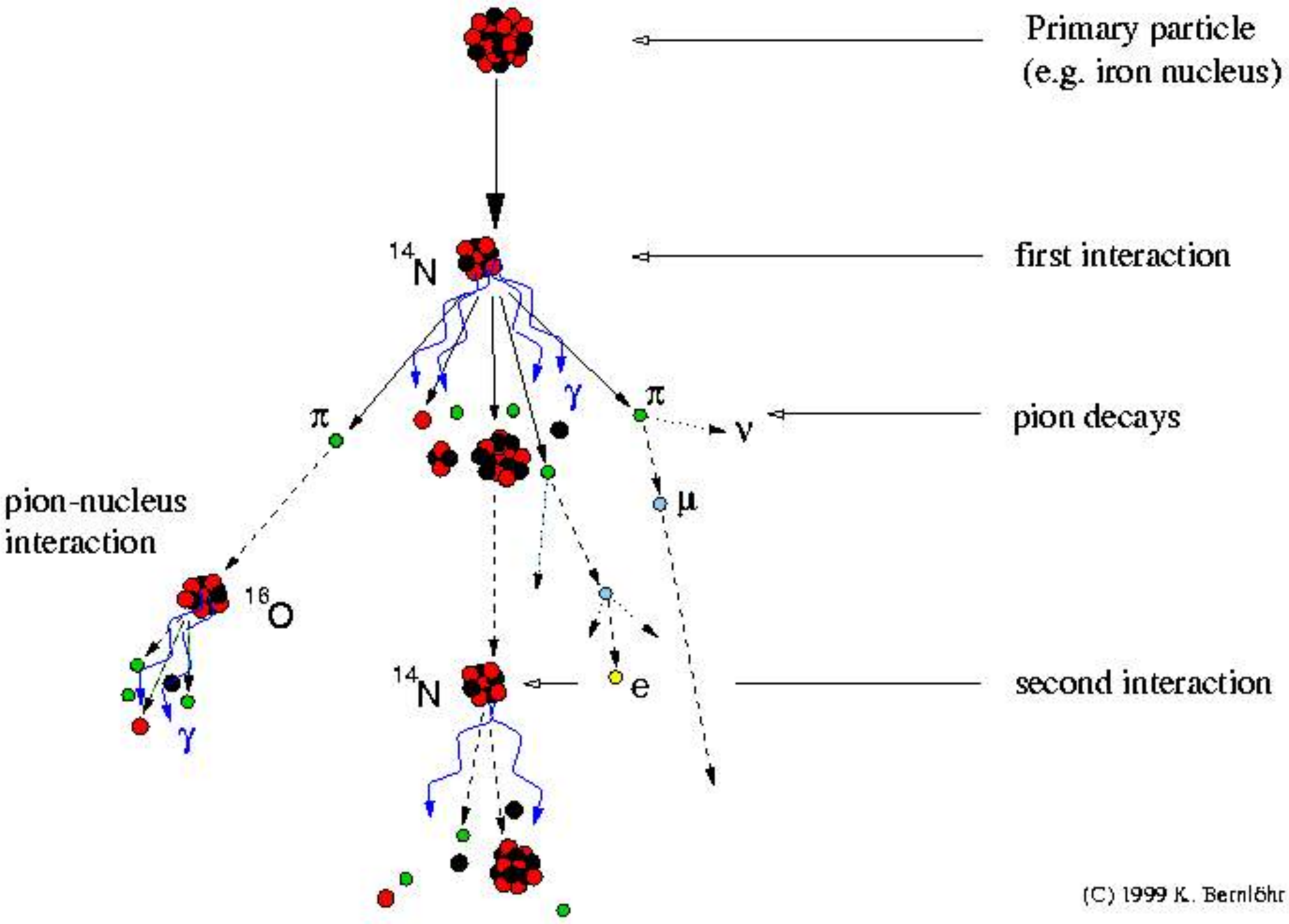
- In 1912 a Victor Hess, a German scientist, took a radiation counter (a simple gold leaf electroscope) on a balloon flight.
- He rose to 17, 500 feet (without oxygen) and measured the amount of radiation increase as the balloon climbed.
- Victor discovered that up to about 700 m the ionization rate decreased but then increased with altitude showing an outer space origin for ionization.

Not From The Sun

- During subsequent flights Hess determined that the ionizing radiation was not of solar origin since it was similar for day and night.
- It was initially believed that the radiation consisted of gamma rays only.
- Seth Nedermeyer and Carl Anderson discover muons in cosmic rays.
- T.H. Johnson discovered that the ionization rate increased from east to west viewing angle indicating they were positively charged particles (protons). The increase occurs because the rays are deflected by the earths magnetic field, which changes in its strength with latitude.



Development of cosmic-ray air showers



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What are cosmic rays?

- Primaries are particles with energies from 10^9 eV to 10^{21} eV.
- An eV is a unit of energy. A 40 W reading light uses about 10^{34} eV of energy in one hour.

(from James Pinfoli,

Pinfold@phys.ualberta.ca)

Cosmic rays within the range of 10^{12} eV to 10^{15} eV have been determined to be:

50% protons

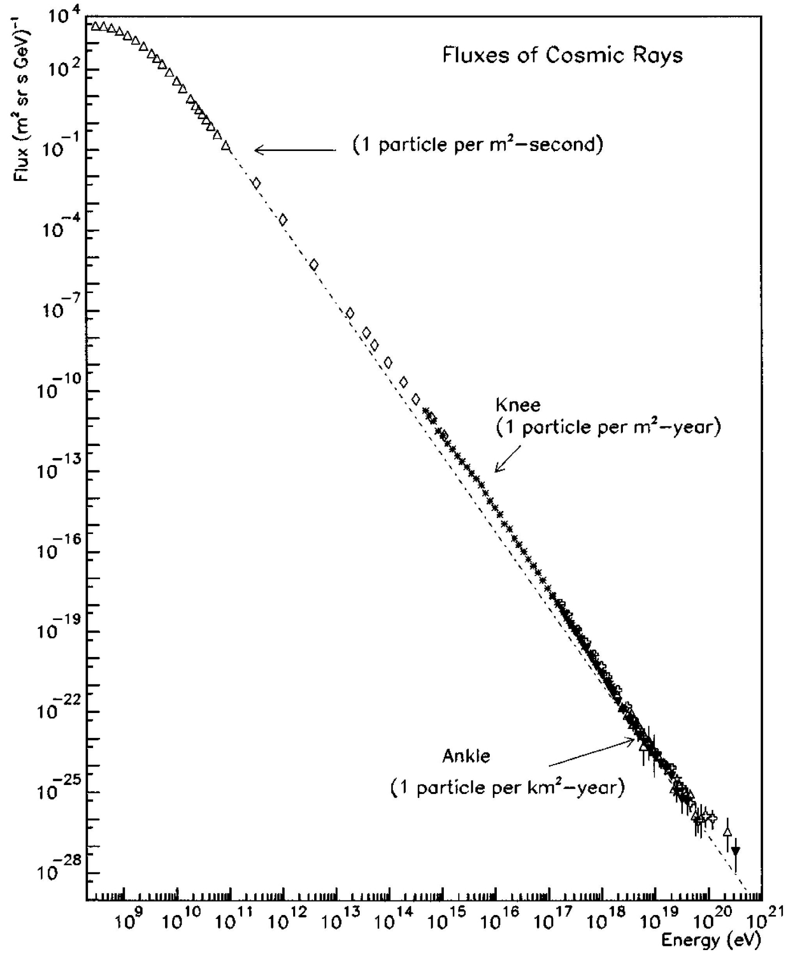
25% alpha particles

13% C, N, and O nuclei

<1% electrons

<0.1% gammas

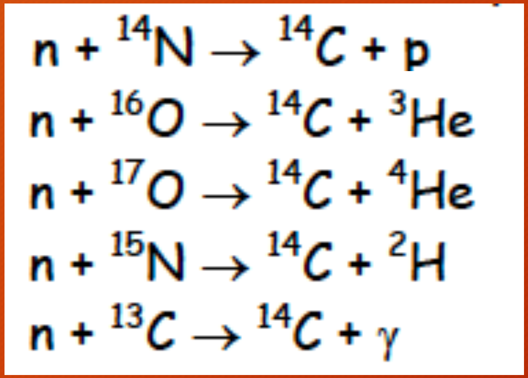
The Energy Spectrum



- Low energy rays (less than 10 GeV) come from the sun.
- Supernovae may be the source of particles up to 10^{15} eV.
- The sources for ultrahigh cosmic rays are probably, active galactic nuclei and gamma ray bursts.

C-14

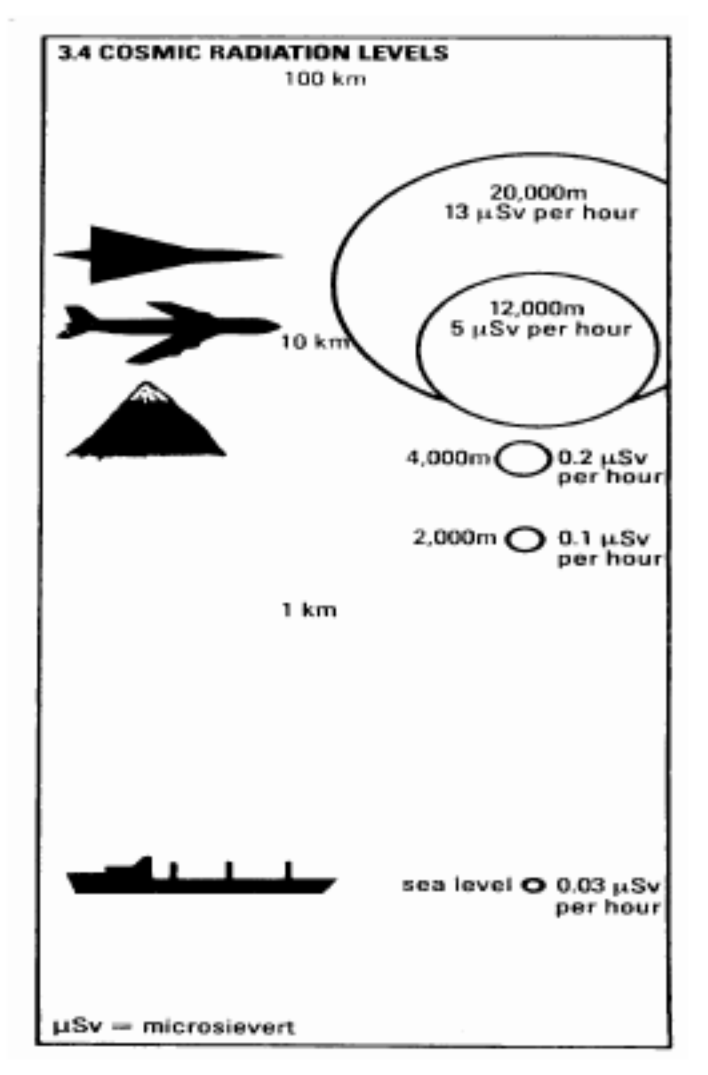
- Cosmic rays are also responbile of the constant rate of ^{14}C in air



$$n + {}^{14}N \rightarrow {}^{14}C + p$$
$$n + {}^{16}O \rightarrow {}^{14}C + {}^{3}He$$
$$n + {}^{17}O \rightarrow {}^{14}C + {}^{4}He$$
$$n + {}^{15}N \rightarrow {}^{14}C + {}^{2}H$$
$$n + {}^{13}C \rightarrow {}^{14}C + \gamma$$

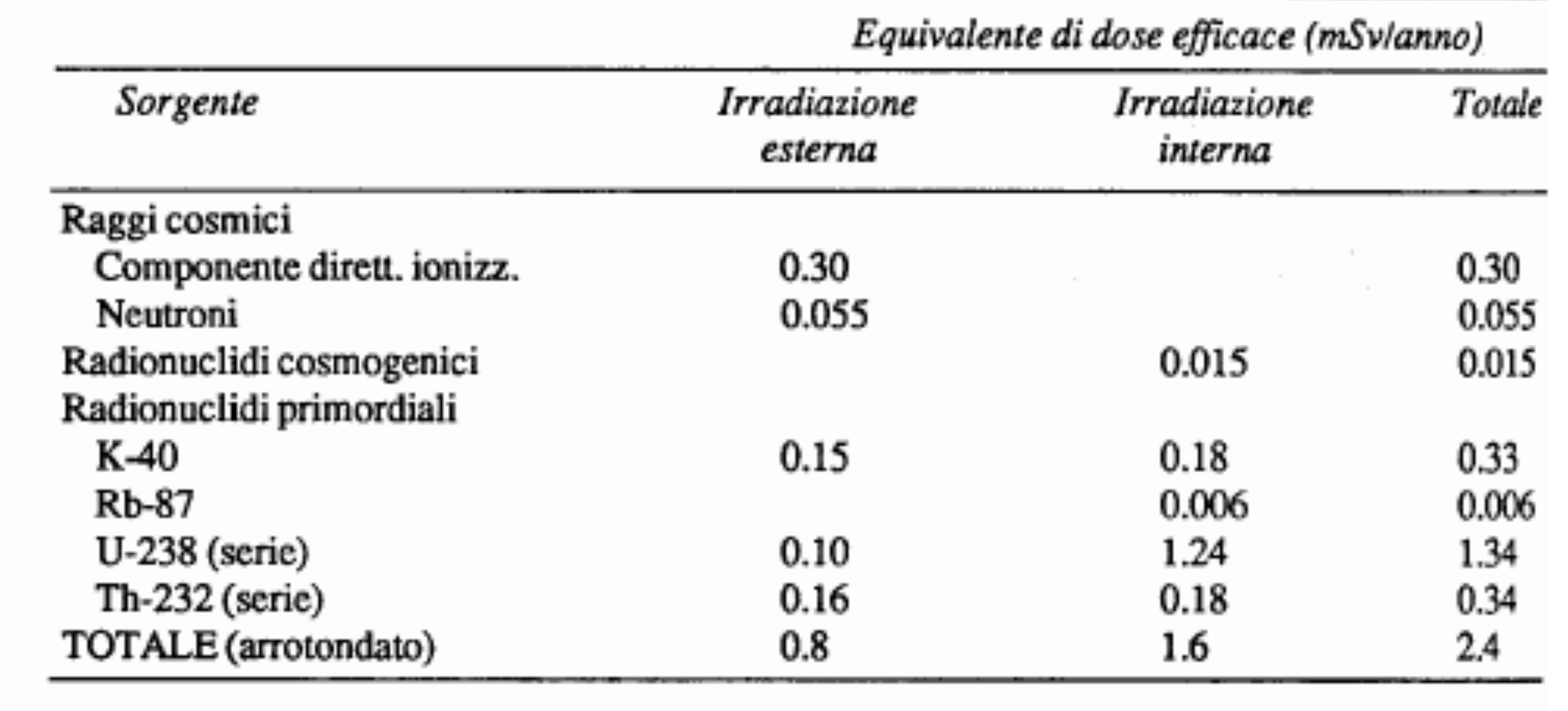
- $^{14}C/^{12}C \sim 1.2\ 10^{-12}$

Radiation from cosmic rays



3.4 COSMIC RADIATION LEVELS

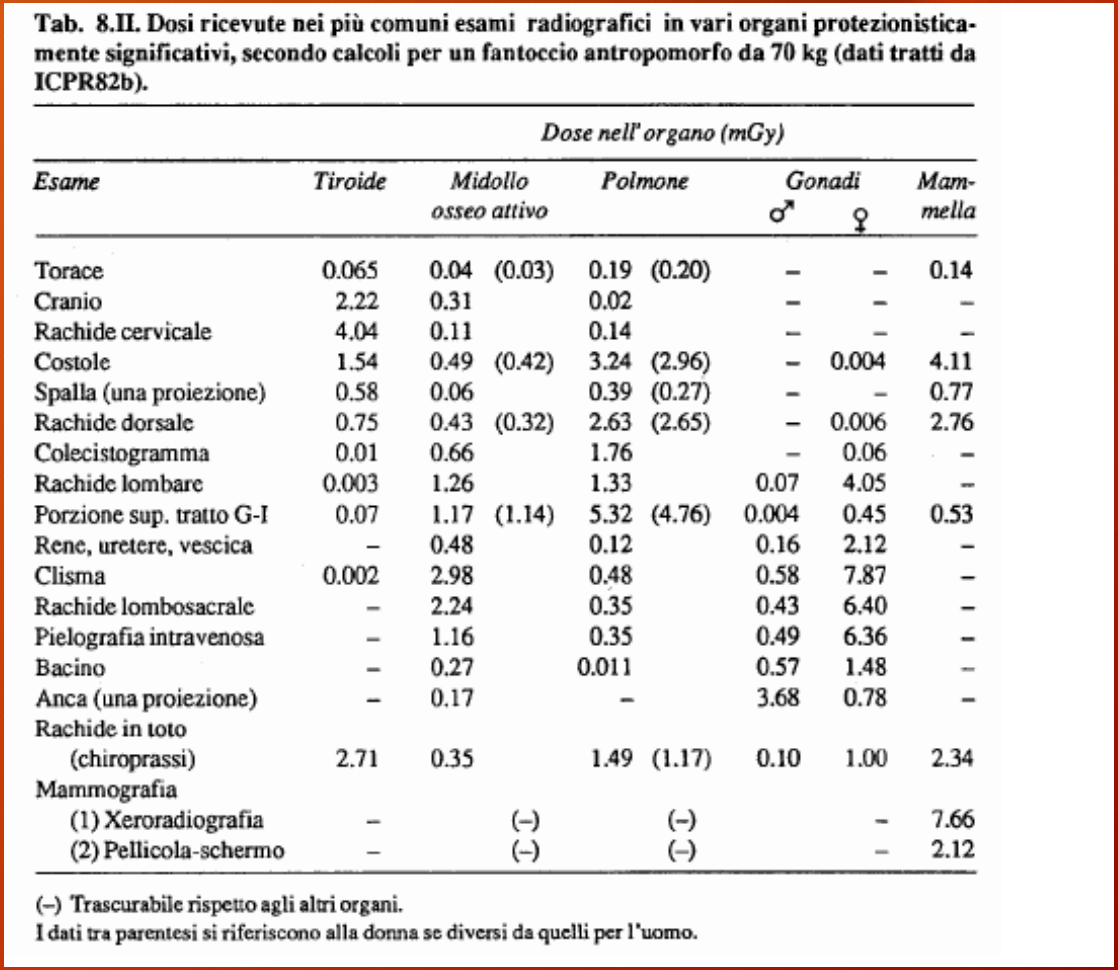
Yearly Dose from Natural Radiactivity



Sorgente	*Equivalente di dose efficace (mSv/anno)* *Irradiazione esterna*	*Irradiazione interna*	*Totale*
Raggi cosmici			
Componente dirett. ionizz.	0.30		0.30
Neutroni	0.055		0.055
Radionuclidi cosmogenici		0.015	0.015
Radionuclidi primordiali			
K-40	0.15	0.18	0.33
Rb-87		0.006	0.006
U-238 (serie)	0.10	1.24	1.34
Th-232 (serie)	0.16	0.18	0.34
TOTALE (arrotondato)	0.8	1.6	2.4

Tab. 18.5 Equivalente di dose annuale dovuto al fondo naturale

Compared with radiation from medical treatments

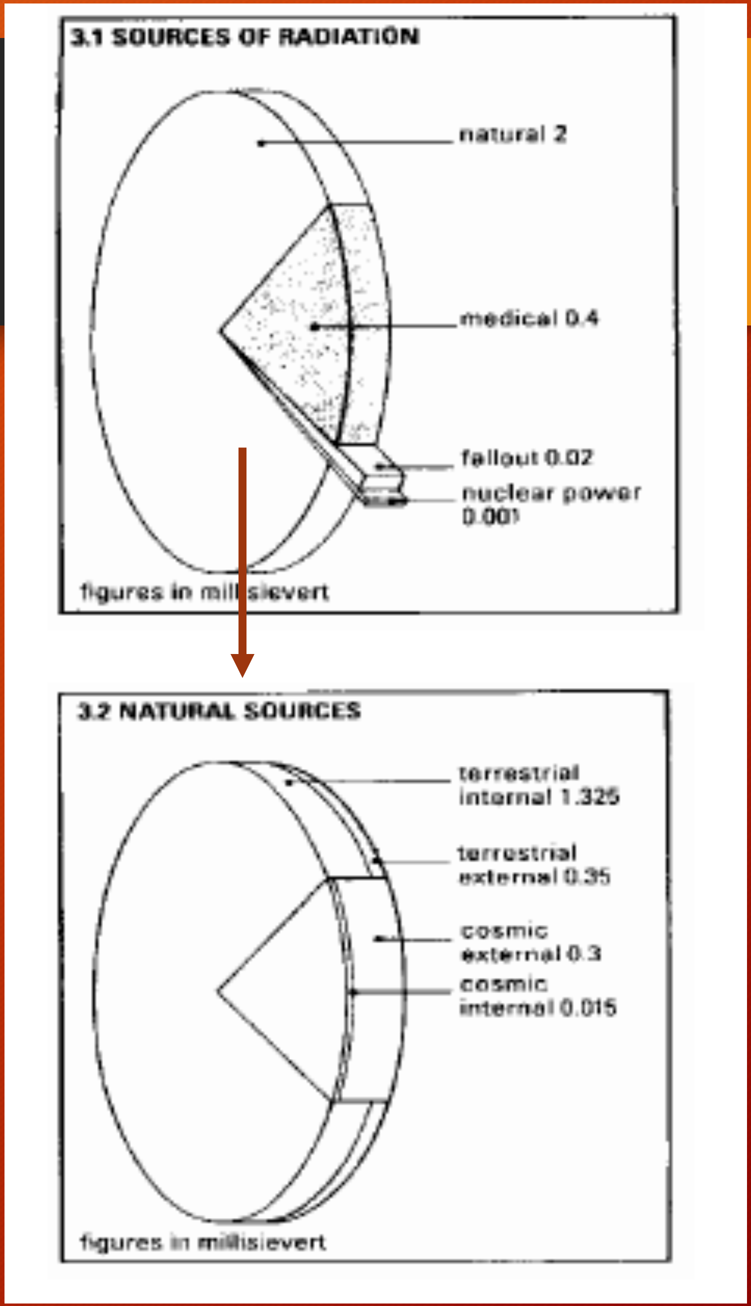


Tab. 8.II. Dosi ricevute nei più comuni esami radiografici in vari organi protezionisticamente significativi, secondo calcoli per un fantoccio antropomorfo da 70 kg (dati tratti da ICPR82b).

		Dose nell' organo (mGy)						
Esame	*Tiroide*	*Midollo osseo attivo*		*Polmone*		*Gonadi*		*Mammella*
						♂	♀	
Torace	0.065	0.04	(0.03)	0.19	(0.20)	–	–	0.14
Cranio	2.22	0.31		0.02		–	–	–
Rachide cervicale	4.04	0.11		0.14		–	–	–
Costole	1.54	0.49	(0.42)	3.24	(2.96)	–	0.004	4.11
Spalla (una proiezione)	0.58	0.06		0.39	(0.27)	–	–	0.77
Rachide dorsale	0.75	0.43	(0.32)	2.63	(2.65)	–	0.006	2.76
Colecistogramma	0.01	0.66		1.76		–	0.06	–
Rachide lombare	0.003	1.26		1.33		0.07	4.05	–
Porzione sup. tratto G-I	0.07	1.17	(1.14)	5.32	(4.76)	0.004	0.45	0.53
Rene, uretere, vescica	–	0.48		0.12		0.16	2.12	–
Clisma	0.002	2.98		0.48		0.58	7.87	–
Rachide lombosacrale	–	2.24		0.35		0.43	6.40	–
Pielografia intravenosa	–	1.16		0.35		0.49	6.36	–
Bacino	–	0.27		0.011		0.57	1.48	–
Anca (una proiezione)	–	0.17		–		3.68	0.78	–
Rachide in toto (chiroprassi)	2.71	0.35		1.49	(1.17)	0.10	1.00	2.34
Mammografia								
(1) Xeroradiografia	–		(–)		(–)		–	7.66
(2) Pellicola-schermo	–		(–)		(–)		–	2.12

(–) Trascurabile rispetto agli altri organi.
I dati tra parentesi si riferiscono alla donna se diversi da quelli per l'uomo.

Sources of radiation



ICRP Recommended Annual Dose Limits

Body Part	Occupational	General Public
Whole body (HE)	20mSv	1mSv
Eye lens (HT)	150mSv	15mSv
Skin (HT)	500mSv	50mSv
Hands & Feet (HT)	500mSv	----------

Note these recommended limits EXCLUDE any medical or natural background radiation doses.

ICRP= International Commission in Radiation Protection
www.icrp.org/