

General concepts of Radiation Protection

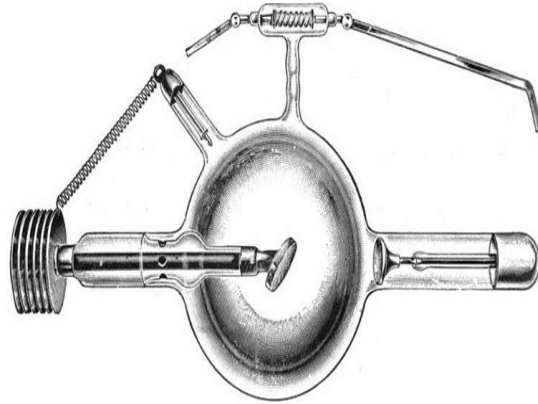
- Radioactivity
- Natural Background
- Industrial applications
- Medical applications
- Tissue reactions
- Stochastic risks
- Legislation

Prof. Romolo Remetti
Radiation Protection Expert
of Sapienza

The beginning of Radiation Protection



Wilhelm
Conrad
Röntgen, X-
Ray tube,
1895



Hand mit Ringen (Hand
with ring)- 22 december
1895. The first
radiographic image (the
left hand of Röntgen's
wife)



The first dental radiography, Otto Walkhoff 1896

Extensive
use of
«Röntgen
Rays»

The first report of a
radiographic mobile unit is
due to Winston Churchill,
(Afghanistan, 1897)



THE STORY OF THE MALAKAND FIELD FORCE

AN EPISODE OF FRONTIER WAR

BY
WINSTON L. SPENCER
CHURCHILL

“They (Frontier Wars) are but the surf that marks the
edge and the advance of the wave of civilisation.”
LORD SALISBURY, Guildhall, 1892

WITH MAPS, PLANS, ETC.

THOMAS NELSON & SONS, LTD.
LONDON, EDINBURGH, AND NEW YORK

First problems

- Dermatitis
 - USA, 1896
 - UK, 1896)
 - Germany, 1896)




A new pathology was discovered “The hand of the radiologist”

1896 First Radiological Protection Advice

In December 1896 Wolfram Fuchs gave the first protection advice:

- make the exposure as short as possible
- do not stand within 12 inches (30 cm) of the x-ray tube
- coat the skin with Vaseline and leave an extra layer on the area most exposed



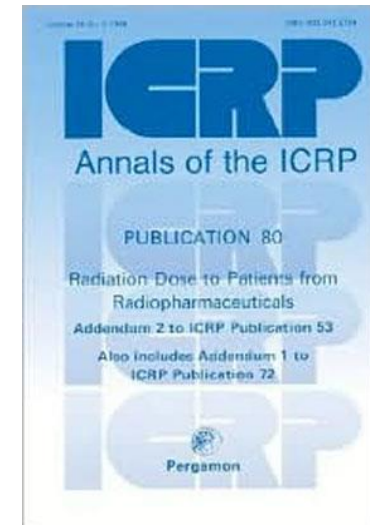
ICRP INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

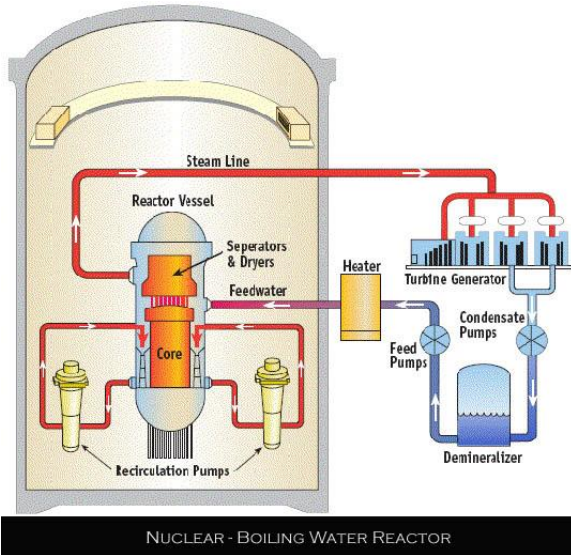
Radiation Protection origins

First international recommendations on on safe use of X rays were given in 1920. In 1925 the first International Congress on Radiology (ICR) was held in London. During the first ICR the **International Commission on Radiation Units and Measurements (ICRU) was created.**

During the second ICR, held in Stockholm in 1928, the **International Commission on Radiological Protection (ICRP) was created.**

- ICRU's duty: ionising radiations metrology;**
- ICRP's duty: giving internationally recognised RP recommendations successively adopted by national laws**

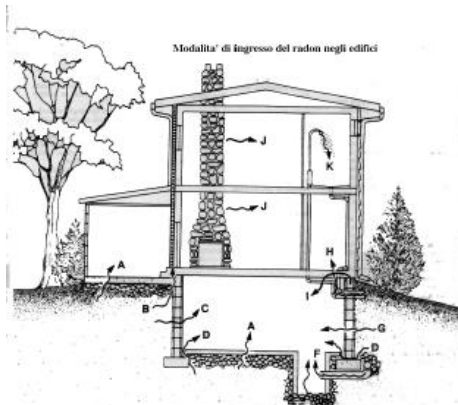




RP today

To protect mankind and environment (including flora and fauna) from harmful effects and/or risks caused by radiation fields originated by

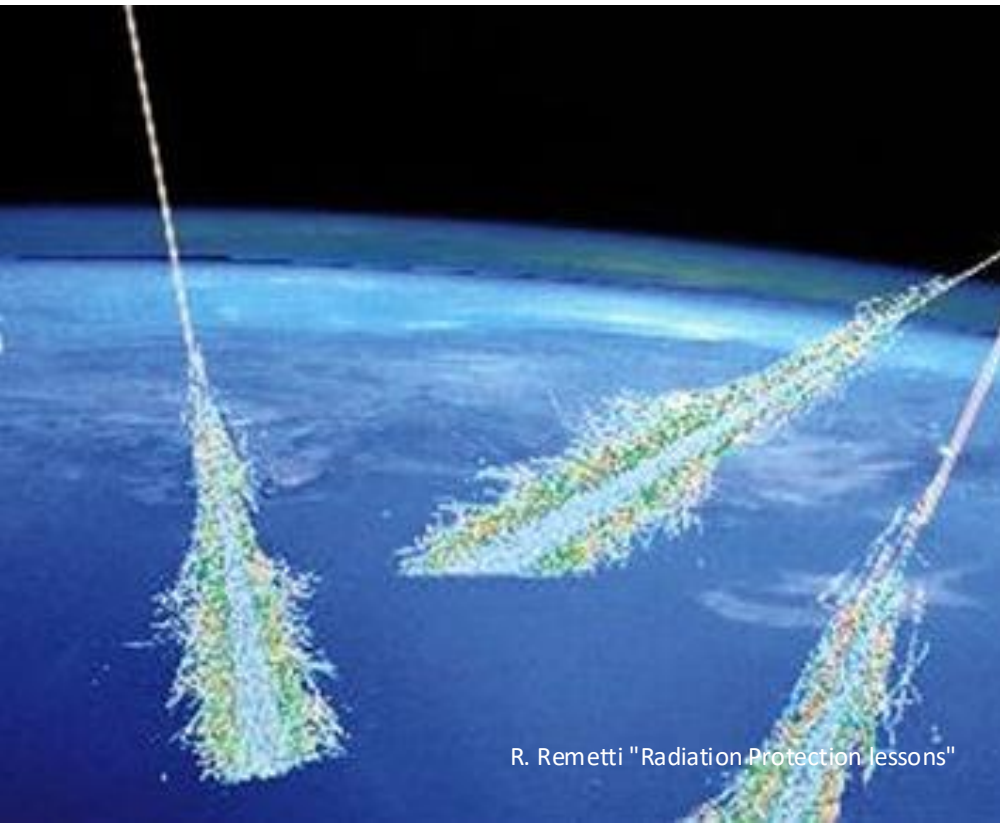
- Natural phenomena;
- Antropic activities.



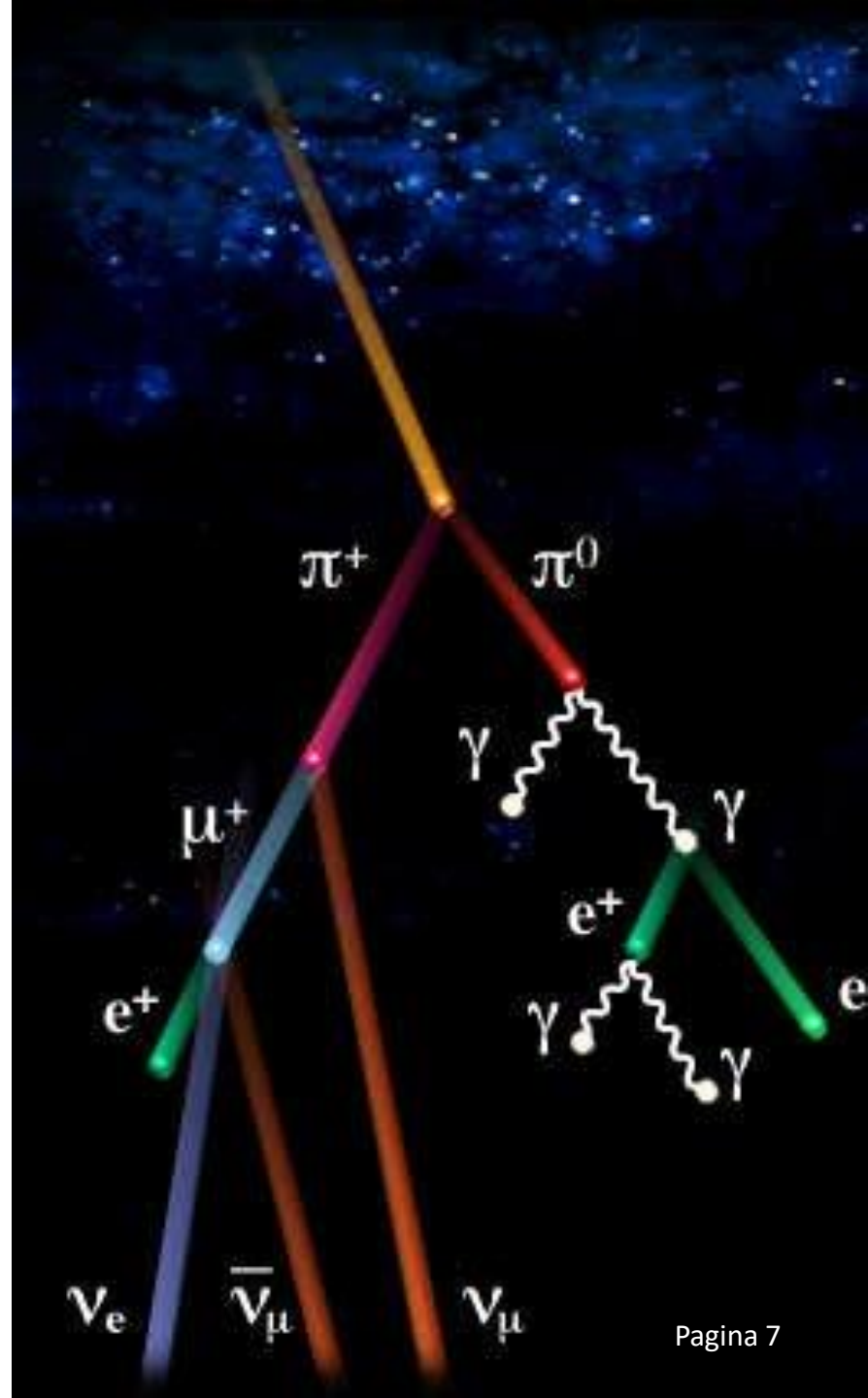
- MAJOR RADON ENTRY ROUTES**
- A. Cracks in concrete slabs
 - B. Spaces behind brick veneer walls that rest on unengaged hollow-block foundation
 - C. Holes and cracks in concrete blocks
 - D. Floor-wall joints
 - E. Sump used, as in a sump
 - F. Bleeding (drain) line, if drained to open sump
 - G. Mortar joints
 - H. Loose fitting pipe penetrations
 - I. Open tops of block walls
 - J. Building materials such as some rock
 - K. Water (from some wells)

Natural background— Cosmic rays

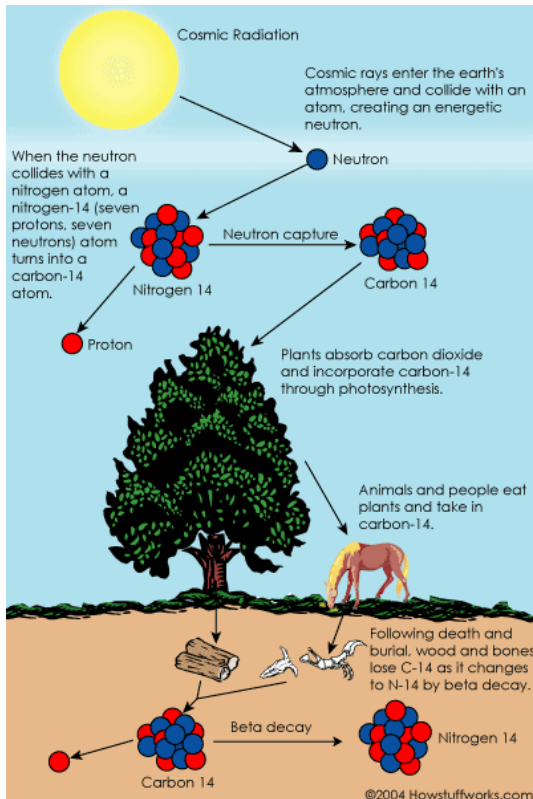
- Cosmic radiation, in its galactic component, is formed by particles generated by supernovae explosions in practice protons, alpha particles, electrons and heavy nuclei; solar component, otherwise said, *solar wind*, is formed by protons. All these particles, will have extremely high energy (up to 10^{20} eV, i.e. 100 billion of billions electronvolt). Interacting with the Earth's atmosphere they generate a secondary cosmic radiation, or swarms of particles, such electrons, neutrons, neutrinos, positrons, muons and gamma radiation.



R. Remetti "Radiation Protection lessons"



Natural background – Cosmogenic Radionuclides



- Neutrons generated by cosmic radiation, interacting with the Earth atmosphere produce the so-called cosmogenic radiation, or radioactive elements (more properly we should talk about *radionuclides*) such as carbon - 14, sodium -22, tritium and beryllium-7.

Natural background – Natural radionuclides



Periodic Table of the Elements

atomic number atomic weight

symbol: black solid blue liquid red gas white synthetically prepared most stable isotope

name

- alkali metals
- alkaline earth metals
- transitional metals
- other metals
- nonmetals
- noble gases

1 1.01 H Hydrogen																	2 4.003 He Helium	
3 6.94 Li Lithium	4 9.01 Be Beryllium																	10 20.18 Ne Neon
11 22.99 Na Sodium	12 24.31 Mg Magnesium																	18 39.95 Ar Argon
19 39.10 K Potassium	20 40.08 Ca Calcium	21 44.96 Sc Scandium	22 47.90 Ti Titanium	23 50.94 V Vanadium	24 51.996 Cr Chromium	25 54.94 Mn Manganese	26 55.85 Fe Iron	27 58.93 Co Cobalt	28 58.70 Ni Nickel	29 63.55 Cu Copper	30 65.37 Zn Zinc	31 69.72 Ga Gallium	32 72.59 Ge Germanium	33 74.92 As Arsenic	34 78.96 Se Selenium	35 79.90 Br Bromine	36 83.80 Kr Krypton	
37 85.47 Rb Rubidium	38 87.62 Sr Strontium	39 88.91 Y Yttrium	40 91.22 Zr Zirconium	41 92.91 Nb Niobium	42 95.94 Mo Molybdenum	43 (98) Tc Technetium	44 101.07 Ru Ruthenium	45 102.91 Rh Rhodium	46 106.40 Pd Palladium	47 107.87 Ag Silver	48 112.41 Cd Cadmium	49 114.82 In Indium	50 118.69 Sn Tin	51 121.75 Sb Antimony	52 127.60 Te Tellurium	53 126.90 I Iodine	54 131.30 Xe Xenon	
55 132.91 Cs Cesium	56 137.33 Ba Barium	57 138.91 La Lanthanum	72 178.49 Hf Hafnium	73 180.95 Ta Tantalum	74 183.85 W Tungsten	75 186.21 Re Rhenium	76 190.20 Os Osmium	77 192.22 Ir Iridium	78 195.09 Pt Platinum	79 196.97 Au Gold	80 200.59 Hg Mercury	81 204.37 Tl Thallium	82 207.19 Pb Lead	83 208.98 Bi Bismuth	84 (209) Po Polonium	85 (210) At Astatine	86 (210) Rn Radon	
87 (223) Fr Francium	88 226.03 Ra Radium	89 227.03 Ac Actinium	104 (261) Rf Rutherfordium	105 (262) Ha Hahnium	106 (266) Sg Seaborgium	107 (262) Bh Bohrium	108 (265) Hs Hassium	109 (266) Mt Meitnerium	110 (271) Uu Ununennium	111 (272) Uub Unbibium	112 (277) Uuq Unquennium	113 (285) Uuq Unquennium	114 (285) Uuq Unquennium	115 (285) Uuq Unquennium	116 (289) Uuq Unquennium	117 (285) Uuq Unquennium	118 (293) Uuo Ununoctium	

58 140.12 Ce Cerium	59 140.91 Pr Praseodymium	60 144.24 Nd Neodymium	61 (145) Pm Promethium	62 150.40 Sm Samarium	63 151.96 Eu Europium	64 157.25 Gd Gadolinium	65 158.93 Tb Terbium	66 162.50 Dy Dysprosium	67 164.93 Ho Holmium	68 167.26 Er Erbium	69 168.93 Tm Thulium	70 173.04 Yb Ytterbium	71 174.97 Lu Lutetium
90 238.03 Th Thorium	91 231.04 Pa Protactinium	92 238.03 U Uranium	93 237.05 Np Neptunium	94 (244) Pu Plutonium	95 (243) Am Americium	96 (247) Cm Curium	97 (247) Bk Berkelium	98 (251) Cf Californium	99 (252) Es Einsteinium	100 (257) Fm Fermium	101 (260) Md Mendelevium	102 (259) No Nobelium	103 (262) Lr Lawrencium

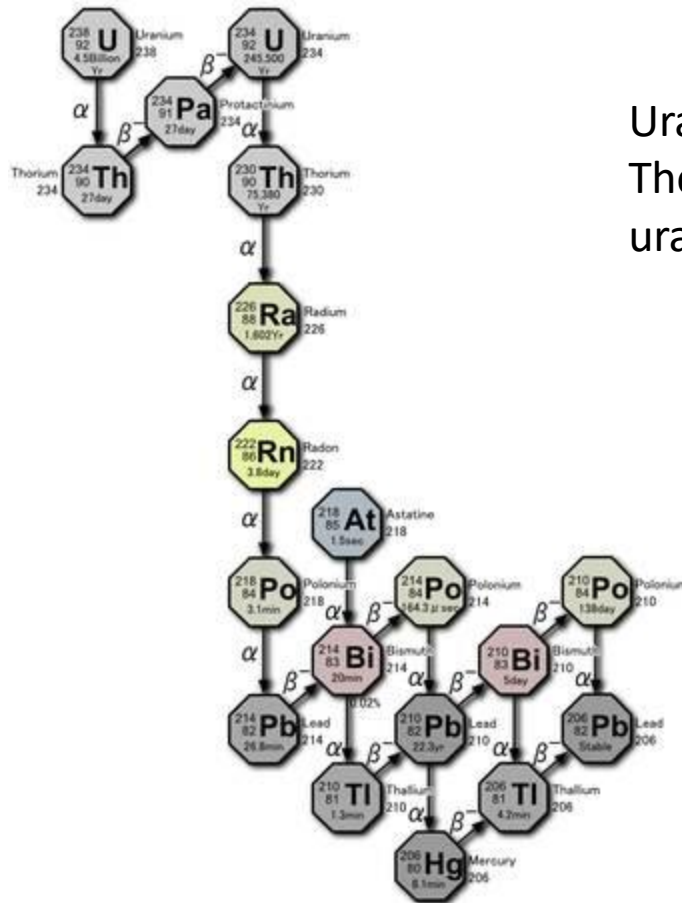
Copyright © 2009 Oxford Labs



Oklo (Gabon) natural nuclear reactor of 1.7 billion year ago, 100 kW thermal power

Plutonium may be considered as natural?

Natural background – Natural radionuclides



Uranium-238 decay chain;
There are two other decay chains:
uranium-235 and thorium 232

In nature we find uranium and
all its decay products.

Where?
EVERYWHERE

Natural background – Natural radionuclides

SORGENTE DI ACQUA MINERALE
«LEGGERMENTE RADIOATTIVA»
 ai sensi delib 31-3-37 - Cons. Sup. di Sanità

Analisi Chimica eseguita il 20 giugno 1951 dal Prof. Dr. Andrea Gandini, dell'Università di Genova.
 Un litro d'acqua contiene in grammi i seguenti ioni:

CATIONI	
Potassio	0,0046
Sodio	0,0631
Litio	0,0002
Calcio	1,1346
Magnesio	0,0093
Alluminio	0,0001
ANIONI	
Cloro	0,1822
Iodio	0,0002
Solfato	0,0401
Nitrato	0,0032
Idrocarbonato	0,3127
Acido metaeilico	0,0088
Sostanze organiche e perdite	0,0136
Gas disciolti	0,1174
Sostanze totali disciolte	0,7333
Radioattività in U Maché	8,42
Radioattività in Microcurie	3,06
Temperatura	14,5
Peso specifico D 15	1,0004
Punto di congelamento	0,031
Conducibilità a +18°C in Ohm recip. K 0,0012	
Resid. solido a 110°C per litro gr.	0,6682
• • • a 180°C	0,6370
• • • dopo calcinaz. • • •	0,6174

Analisi batteriologica eseguita il 30 agosto 1951 dall'Istituto d'Igiene dell'Università di Genova (Prof. Luigi Piras).
 «L'acqua della Fonte del Faro viene giudicata potabile dal punto di vista batteriologico»
 CONTENUTO C.C. 920
 ADDIZIONATA DI GAS CARBONICO

DISPEPSIE, CATARRI GASTRO-INTESTINALI E DIATESI URICA
 Autorizzata la vendita con Decreto del Ministero dell'Interno in data 24-6-1931 N. 162 con Decreto 23-7-1953 N. 593
 Vetro e tappo sterilizzati

FONTE del FARO
 (Savona) LAIGUEGLIA (Savona)
 AUTORIZZAZIONE MINISTERO SANITA' N. 400 DEL 30-11-1970

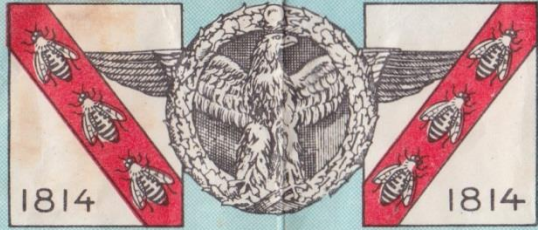
Acqua digestiva, diuretica, radioattiva, ottima per tavola, miscibile in tutte le proporzioni alle bevande alcoliche. È inalterabile e di lunga conservazione.
 Scaturisce dalla viva roccia a 15 m. sul livello del mare, in località di eccezionale bellezza panoramica nel giardino dell'Albergo della Fonte del Faro (terrazze a mare e spiaggia propria).
 Alle sue scaturigini si ha l'abbinamento delle cure marine con quelle dell'acqua minerale della Fonte del Faro, nei Comuni di Laigueglia, Alassio, stazioni climatiche balneari.

Natural background – Natural radionuclides

L'acqua della Fonte di NAPOLEONE è un'acqua minerale naturale, diuretica, notevolmente radioattiva.

Come risulta da numerose statistiche e dalle ricerche farmacologiche e cliniche eseguite presso l'Istituto di Idrologia medica dell'Università di Roma diretto dal Prof. Messini, è efficace soprattutto nella litiasi renale e nella cura di tutte le manifestazioni cliniche della uricemia, nelle forme catarrali gastrointestinali e nelle infiammazioni croniche delle vie urinarie.

È inoltre un'ottima acqua da tavola e per la sua leggerezza è assai raccomandata nell'alimentazione dei bambini, dei vecchi e dei malati.



1814

ACQUA MINERALE ANTIURICA

FORTE

MARCIANA MARINA S. GIUSEPPE SPAIO

NAPOLEONE

IMBOTTIGLIATA COME SGORGA DALLA SORGENTE
POGGIO DI MARCIANA - ISOLA D'ELBA

ADDIZIONATA DI GAS ACIDO CARBONICO

Decreto di autorizzazione alla vendita dell'Alto Camm. per l'igiene e la Sanità Pubbl. n. 797 del 20/11/62

ANALISI CHIMICA E COSTANTI CHIMICO - FISICHE

Temperatura dell'acqua (T) 109.60
 Conducib. elettr. spec. (K₁₈) 0.0000982
 Pressione osmotica (P) cm. 0.06025
 Densità (D₁₈) 0.999914
 Attività ioni idrogeno (P_H) 5.56
 Residuo fisso a 180° gr. p. l. 0.06865

Componenti salini espressi in joni, disciolti in un litro di acqua:

Jone sodio	Na	gr.	0.01502
+ potassio	K	»	0.00101
+ calcio	Ca	»	0.00292
+ magnesio	Mg	»	0.00156
+ ferro	Fe	»	0.00002
+ cloro	Cl	»	0.02430
+ nitrico	NO ₃	»	0.00024
+ idrocarbom.	HCO ₃	»	0.01148
+ solforico	SO ₄	»	0.00363
+ fosforico	PO ₄	»	0.00002
Acido bórico	H ₂ BO ₃	»	0.00020
Silice	SiO ₂	»	0.01382
Rame - Stagno - Manganese			
Alluminio - Stronzio			in tracce

Gas disciolti in un litro di acqua considerati a 0° a 760 mm.:

Anidride carbonica	cm ³	20.2
Ossigeno	»	6.1
Azoto e gas rari	»	20.8
Totale	cm³	47.1

Radio - emanazione:

Unità Mache 28.22 per litro

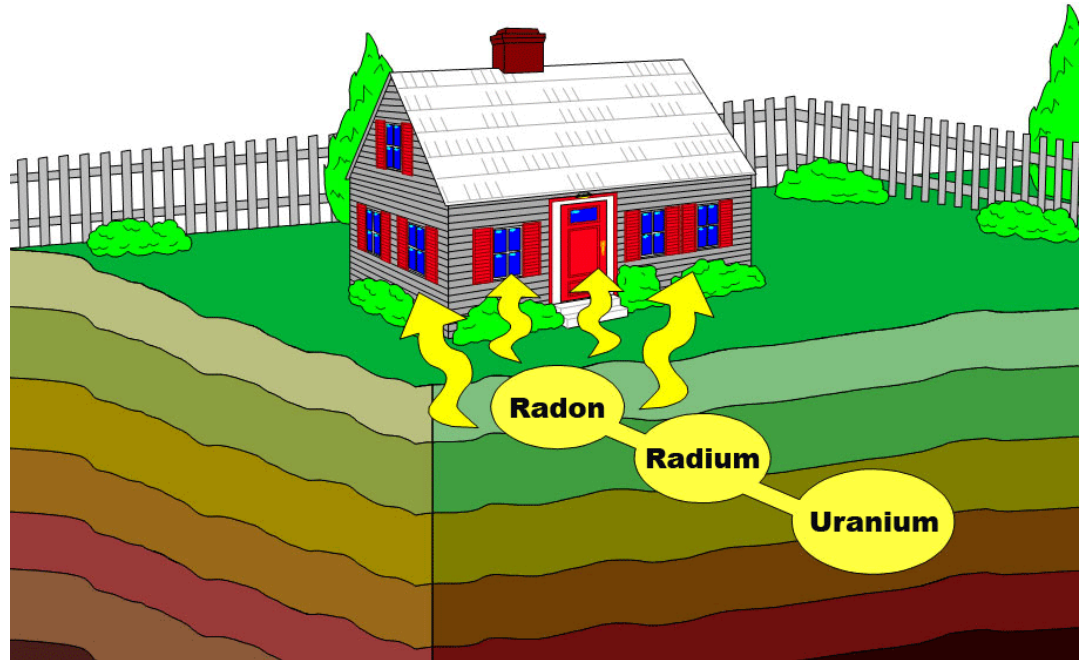
ANALISI BATTERIOLOGICA

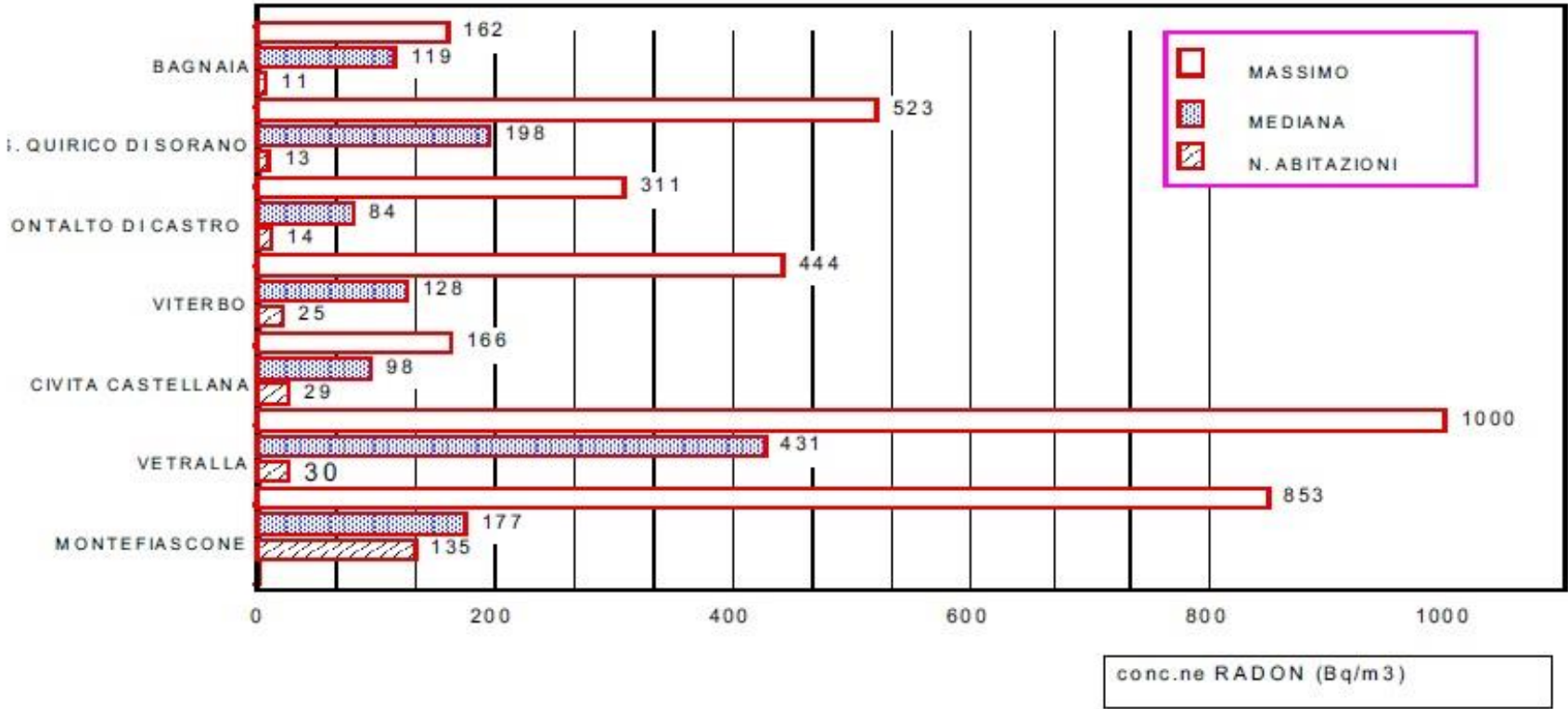
Acqua batteriologicamente pura.

Analisi chimica del 22 maggio 1947 ed analisi batteriologica del 6 dicembre 1946 eseguite nell'Istituto Superiore di Sanità, dai Prof. Bruno Visintin e Canio Russo.

CONT. MEDIO CL. 94

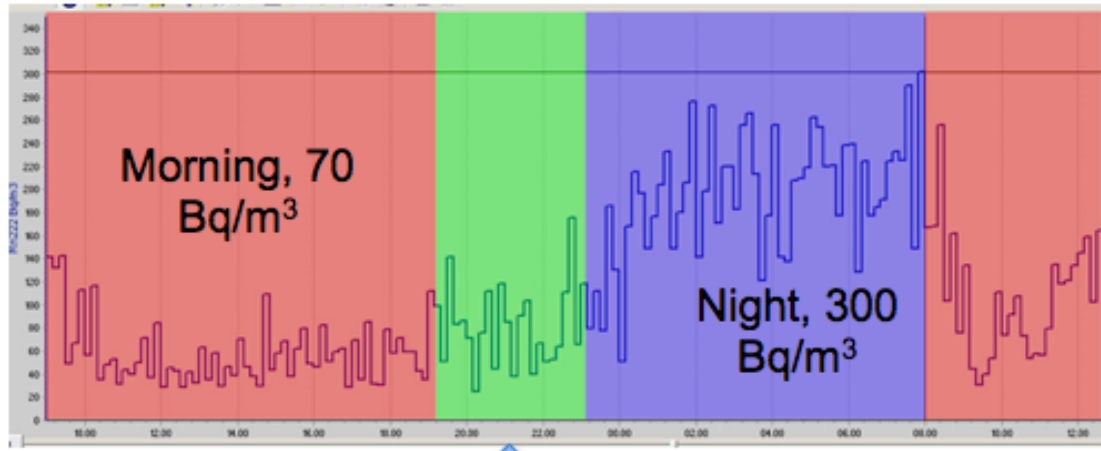
Natural background – radon





Natural background – radon

Source: ENEA

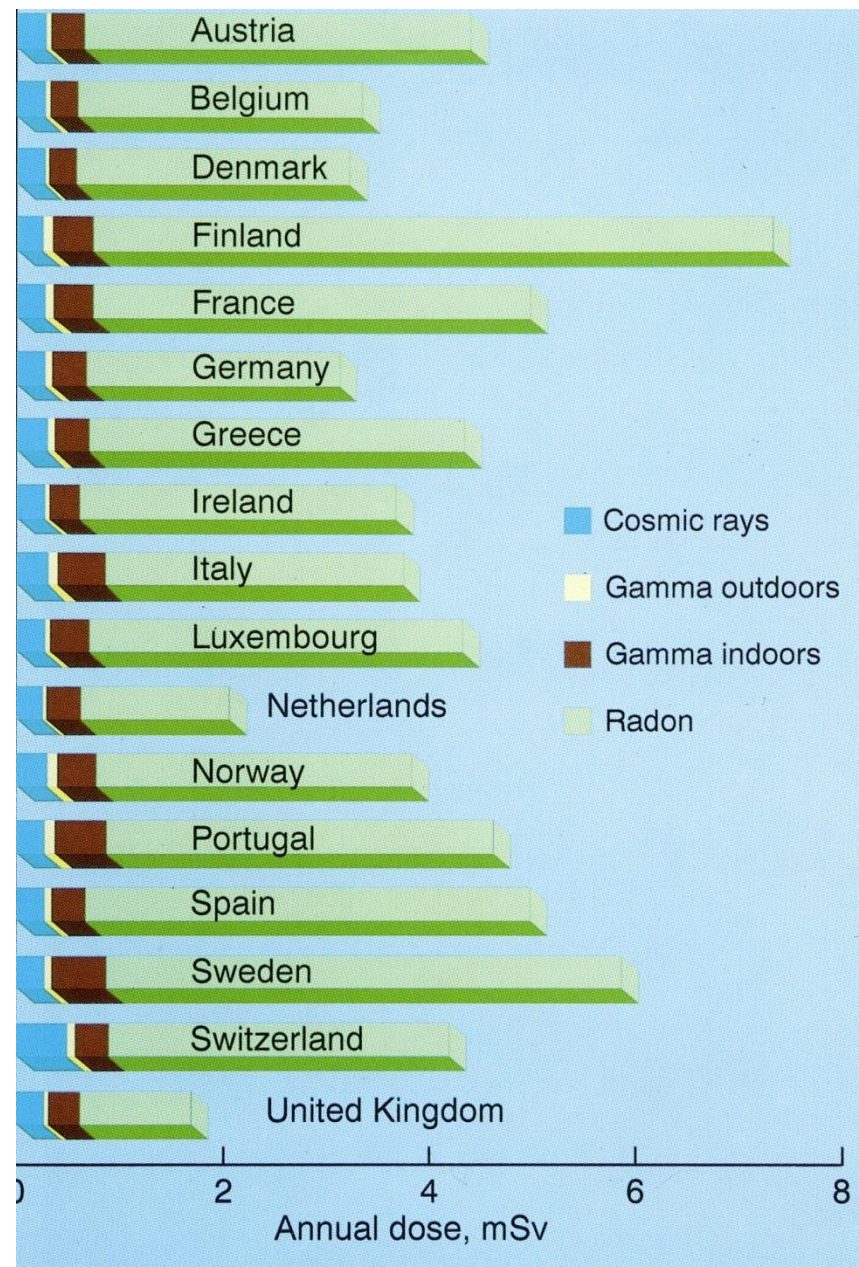


Start-up of heating system

Daily variation of indoor radon concentration inside an energy saving dwelling. Measurements carried out in 2011 by Genitron AlphaGuard (integration time of 10 minutes). The house is situated in a geological zone that is judged as "normal", regarding radon concentrations.

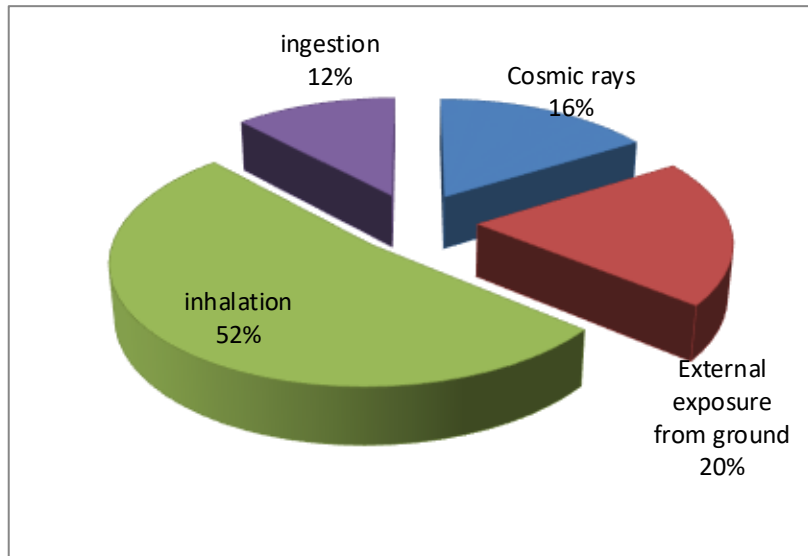
Natural background – radon

Natural background in Europe (from «Radiation Atlas», EC)



Natural Background

2,4 mSv per year (world average)



In Italy 3,4 mSv per year

NORM: Naturally Occurring Radioactive Materials

- All minerals and raw materials contain radionuclides of natural origin. The most important for the purposes of radiation protection are the radionuclides in the U-238 and Th-232 decay series. For most human activities involving minerals and raw materials, the levels of exposure to these radionuclides are not significantly greater than normal background levels and are not of concern for radiation protection. However, **certain work activities can give rise to significantly enhanced exposures that may need to be controlled by regulation.** Material giving rise to these enhanced exposures has become known as naturally occurring radioactive material (NORM).
- **Certain industries handle significant quantities of NORM, which usually ends up in their waste streams, or in the case of uranium mining, the tailings dam. Over time, as potential NORM hazards have been identified, these industries have increasingly become subject to monitoring and regulation.**





Oil pipe scale

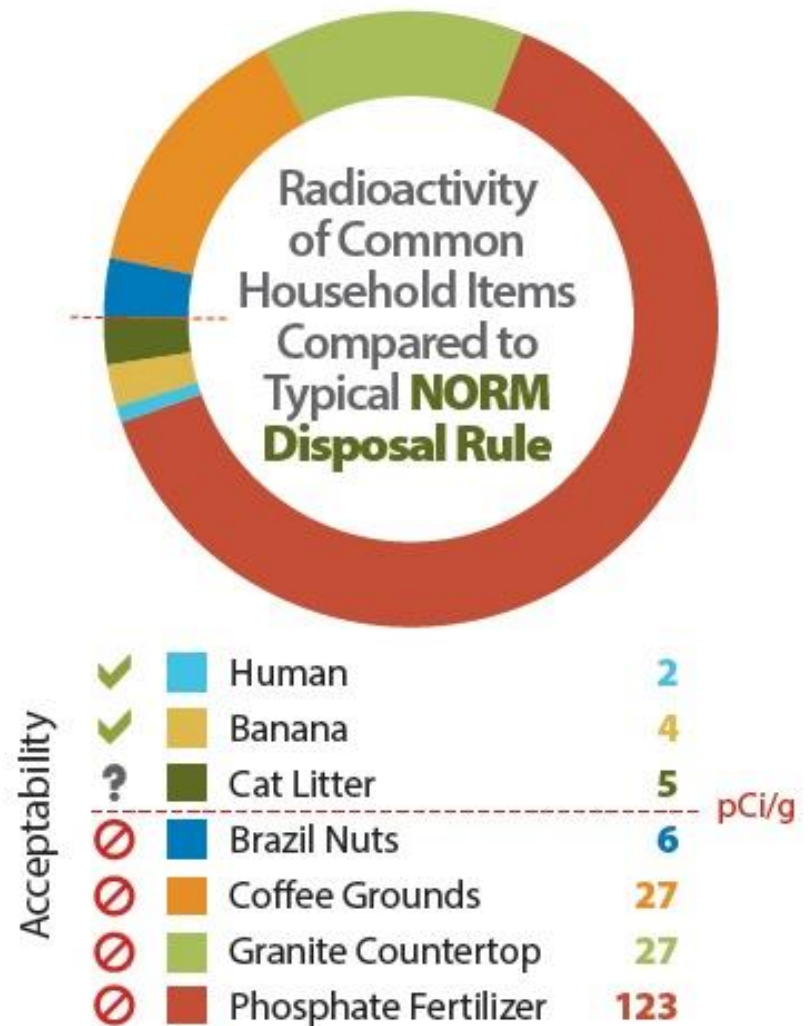
^{226}Ra , ^{232}Th e
 ^{40}K



NORM: Naturally Occurring Radioactive Materials

• Excluding uranium mining and all associated fuel cycle activities, industries known to have NORM issues include:

- The coal industry (mining and combustion)
- The oil and gas industry (production)
- Metal mining and smelting
- Mineral sands (rare earth minerals, titanium and zirconium).
- Fertiliser (phosphate) industry
- Building industry
- Recycling



NORM: Naturally Occurring Radioactive Materials



NORM in coal ashes and slug (Bq/kg)

	Uranium series, Ra-226	Thorium series	K-40
Hungary	200-2000	20-300	300-800
USA	100-600	30-300	100-1200
Germany ash	6-166	3-120	125-742
Germany slag	68-245	76-170	337-1240
Australia (U av 0.9 ppm, Th av 2.6 ppm)	Total: 2630		
Australia: NSW	Total: 3200		

Source: IAEA 2003 Tech Report 419, p 30; CSIRO for Australia

During combustion the radionuclides are retained and concentrated in the flyash and bottom ash, with a greater concentration to be found in the flyash. The concentration of uranium and thorium in bottom and flyash can be up to ten times greater than for the burnt coal, while other radionuclides such as Pb-210 and K-40 can concentrate to an even greater degree in the flyash. Some 99% of flyash is typically retained in a modern power station (90% in some older ones). While much flyash is buried in an ash dam, a lot is used in building construction.

Alkali-Activated Cements (AACs)



Ground-Granulated Iron Blast Furnace Slag



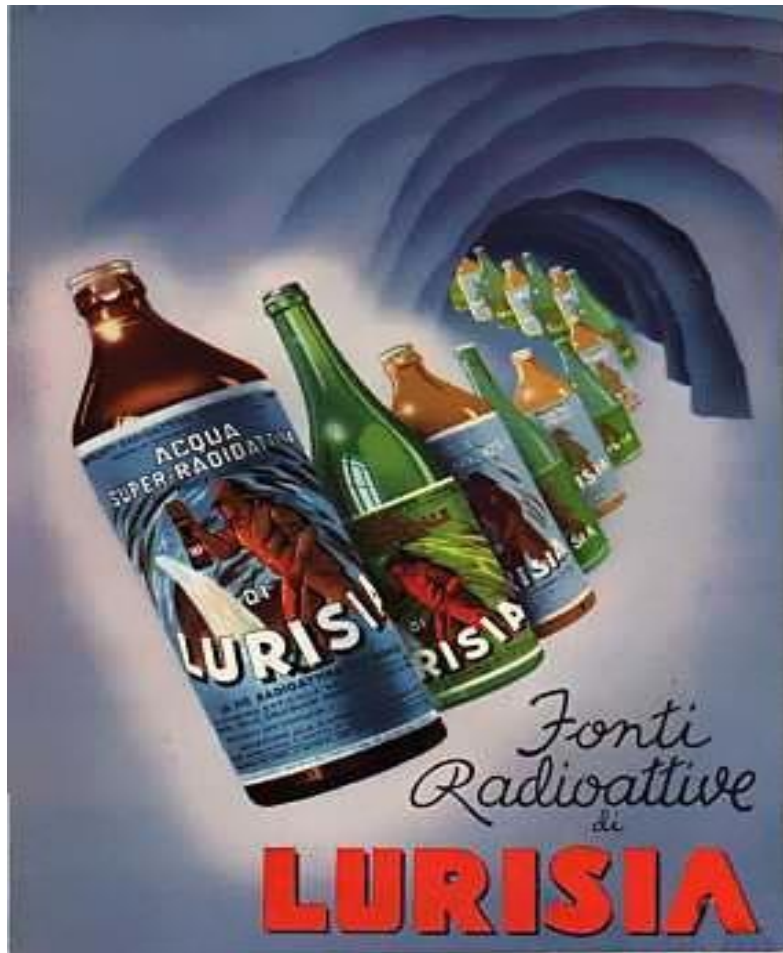
Coal Fly Ash



Alkali Activators (~10%)



NORM: Naturally Occurring Radioactive Materials



An Italian mineral water (1960s) with high radioactivity content; it originates from a spring near a uranium mine.

Some natural radionuclide in our body (from UNSCEAR 2008)

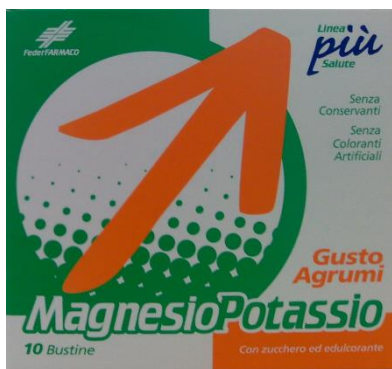
Table 9. Reference values for concentration of radionuclides of the uranium and thorium series in human tissues (mBq/kg) [U3]

<i>Radionuclide</i>	<i>Lung</i>	<i>Liver</i>	<i>Kidney</i>	<i>Muscle and other tissues</i>	<i>Bone</i>
^{238}U	20	3	30	5	100
^{230}Th	20	9	5	1	20–70
^{226}Ra	4.1	4.1	4.1	4.1	260
^{210}Pb	200	400	200	100	3 000
^{210}Po	200	600	600	100	2 400
^{232}Th	20	3	3	1	6–24
^{228}Ra	20	3	2	2	100

Some natural radionuclide in our body

Potassium-40 content of the body can be obtained from its natural abundance of 0.0117 percent of potassium and calculating the specific activity of natural potassium (30.5 Bq g⁻¹) using the half-life (1.28 x 10⁹ y). The potassium content of the body is 0.2 percent, so for a 70-kg person, the amount of 40K will be about 4.26 kBq. Carbon-14 content of the body is based on the fact that one ¹⁴C atom exists in nature for every 1,000,000,000,000 ¹²C atoms in living material. Using a half-life of 5,730 y, one obtains a specific activity of 0.19 Bq g⁻¹ of carbon. As carbon is 23 percent of the body weight, the body content of ¹⁴C for a 70-kg person would be about 3.08 kBq.

2 MeV gamma
rays



One banana sono presenti in contains
about 15 Bq of potassium - 40.
1 BED (Banana Equivalent Dose) is
near 0,1 μSv



Man made sources of radiation

Fall-out by nuclear test in atmosphere

Persistence in the environment of radionuclides due to fall-out of nuclear tests of '50, '60 years

Mainly cesium-137, strontium-90, and plutonium-239



USA, URSS e UK ended tests in 1958, and then signed NTBT in october 1963.

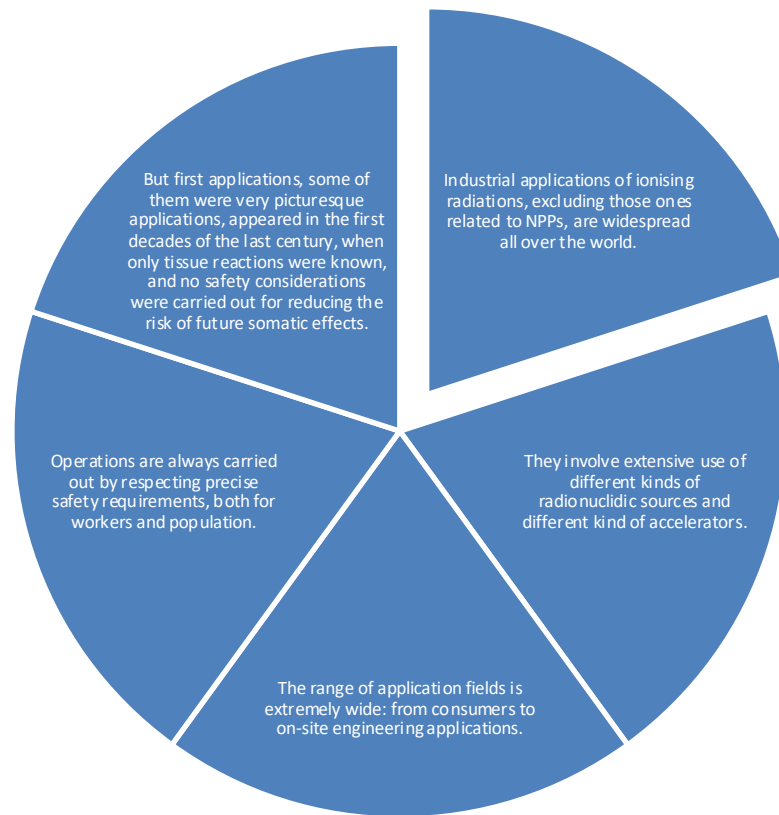
NTBT: Nuclear Test Ban Treaty

Current contamination from fall-out (source: UNSCEAR 2008)

Table 35. Latitudinal distribution of radionuclides from atmospheric nuclear tests based on ⁹⁰Sr measurements [U3]

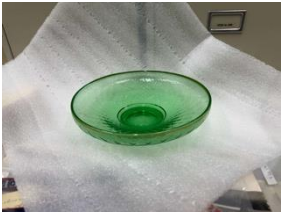
<i>Latitude band (°)</i>	<i>Population distribution (%)</i>	<i>Integrated deposition of ⁹⁰Sr (PBq)</i>	<i>Deposition in band (%)</i>	<i>Deposition density per unit deposition ((Bq/m²)/PBq)</i>	<i>Latitudinal value relative to hemispheric value</i>
Northern hemisphere					
80–90	0	1	0.2	0.56	0.12
70–80	0	7.9	1.7	1.48	0.32
60–70	0.4	32.9	7.1	3.78	0.81
50–60	13.7	73.9	16.1	6.27	1.35
40–50	15.5	101.6	22.1	7.01	1.51
30–40	20.4	85.3	18.5	5.09	1.09
20–30	32.7	71.2	15.5	3.85	0.83
10–20	11	50.9	11.1	2.58	0.56
0–10	6.3	35.7	7.8	1.76	0.38
Southern hemisphere					
80–90	0	0.3	0.2	0.53	0.14
70–80	0	2.5	1.7	1.5	0.4
60–70	0	6.7	4.6	2.46	0.66
50–60	0.5	12.1	8.4	3.28	0.88
40–50	0.9	28.1	19.5	6.19	1.65
30–40	13	27.6	19.1	5.26	1.4
20–30	14.9	28.1	19.5	4.85	1.29
10–20	16.7	17.8	12.3	2.89	0.77
0–10	54	21	14.6	3.3	0.88

Industrial Applications of ionising radiations



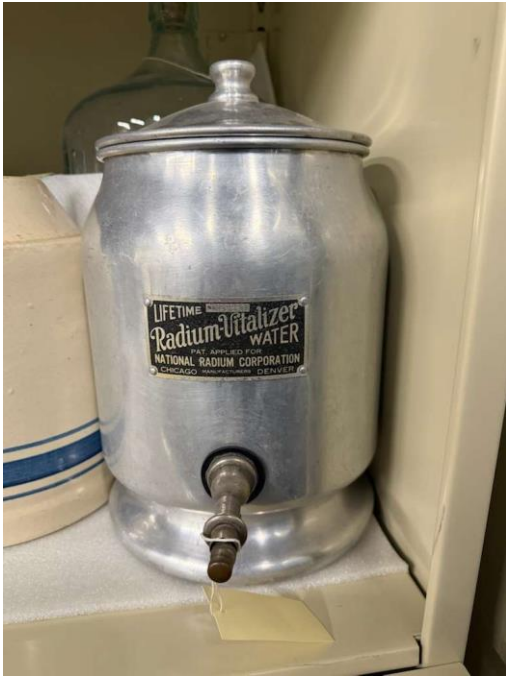
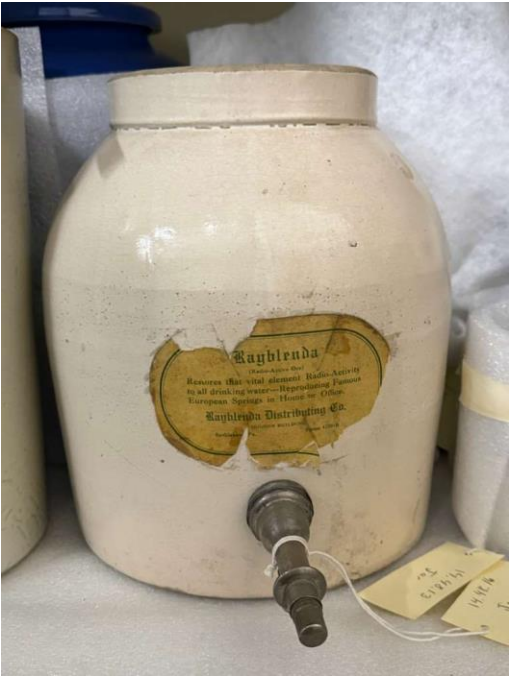
Past applications (cont.)

- ❑ Radioactivity was discovered at the end of the XIX century, and it was soon considered as an extraordinary aspect of the life, capable to give exceptional advantages to mankind.
- ❑ In the first decades of the XX century a variety of applications appeared, and many of them were very picturesque



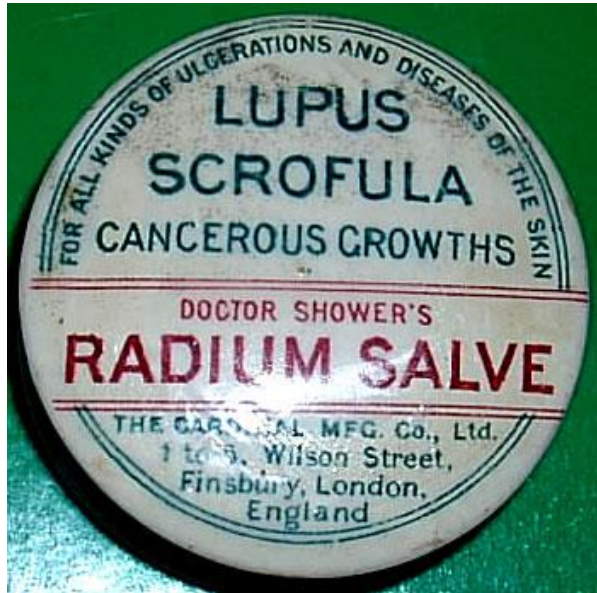
Radium Jars

Late '20s, early '30s of the last century. To be used as a tonic for the health.



Past applications (cont.)

It seemed that radioactivity could cure every diseases




HAVE YOU

ANEMIA	GOITER	KIDNEY TROUBLE
ARTHRITIS	CHRONIC PERITONITIS	LIVER TROUBLE
FEMALE TROUBLE	HIGH BLOOD PRES-	LUMBAGO
DEBILITY	SURE	MALNUTRITION
GASTRIC ULCERS	HEART DISORDER	PROSTATE DISORDERS
DIABETES	HAY FEVER	RHEUMATISM
GOUT		

OR ANY OTHER COMMON AILMENT

Drink Radioactive Water

THE LIFETIME RADIIUM WATER JAR IS GUARANTEED



While in Salt Lake make our store your headquarters. Nice, comfortable place to rest and all the genuine guaranteed Radioactive water you wish to drink. The more you drink the better we will like it. It's FREE.

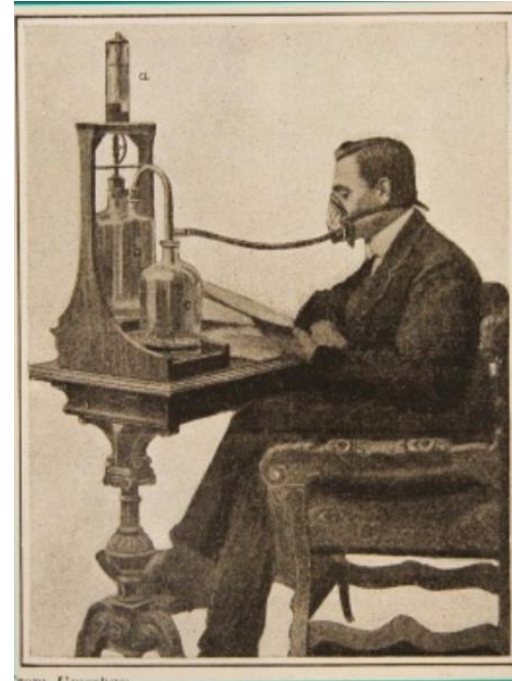
It aids nature by increasing the number of and building up the red corpuscles of the blood, eliminates poisons from the system, causes the best of digestion of your food. Nature then cures you.

GET WELL STAY WELL.

MANDIS SALES COMPANY

Wasatch 1477 113 South Main
Branch offices at 2477 Kiesel Ave., Ogden, Utah.
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Past applications (cont.)

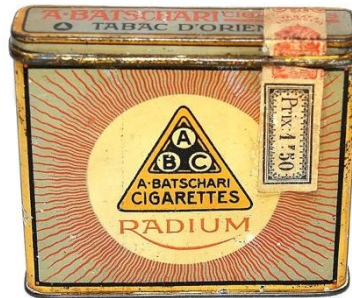


Radon generator for inhalations. Now we consider radon as an existing exposure situation which is the second cause of lung cancer; the first cause is cigarettes smoking.

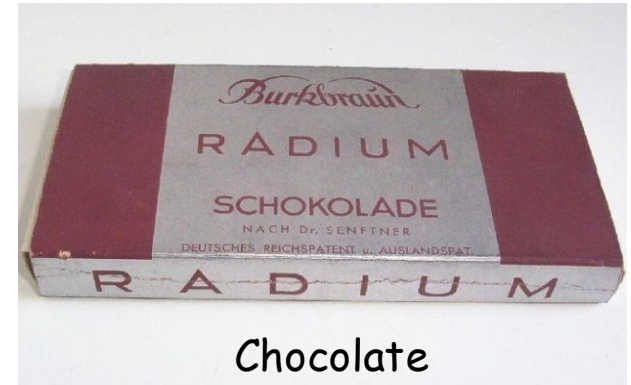
Past applications (cont.)



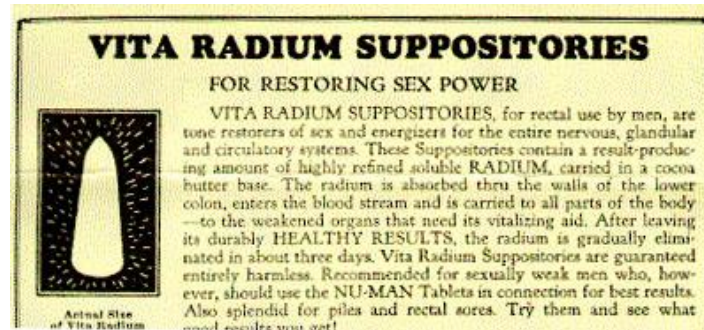
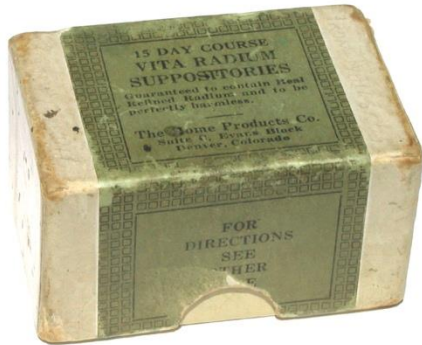
Radioactive condoms



Cigarettes



Chocolate



Suppositories for restoring sex power and for curing haemorrhoids

Some applications were extremely picturesque!

Past applications (cont.)

Anyway, some applications rendered possible night flights of the first airplanes, and deep sea exploration. The radium painting of watches' dials was considered as a top military secret. Similar applications remain still now, but the less harmful tritium is used instead of radium.

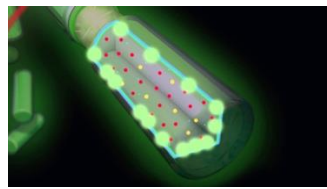
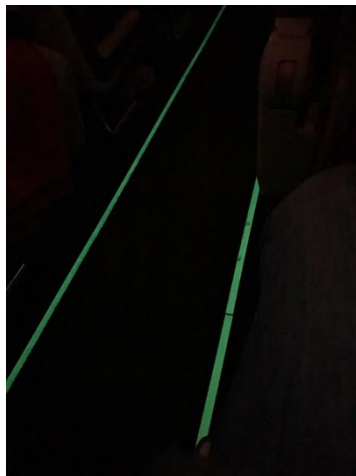


Current applications

Current applications are distinguished according to the decay mode of the radioisotope. In every case applications are implemented respecting radiation protection principles, and their correct utilisation will never cause harm to the health.

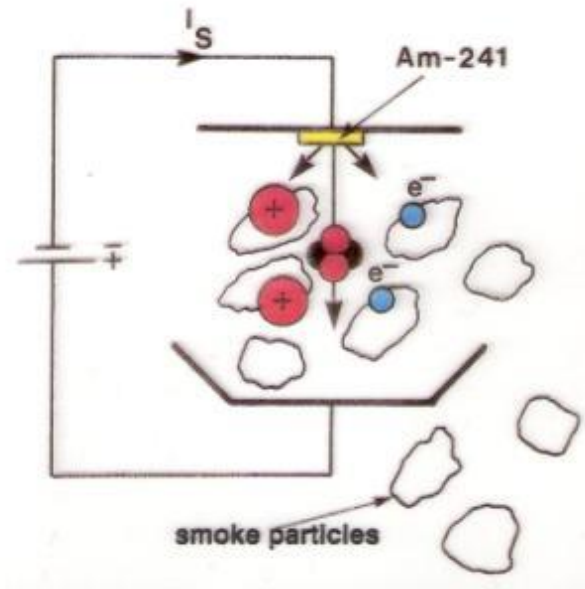
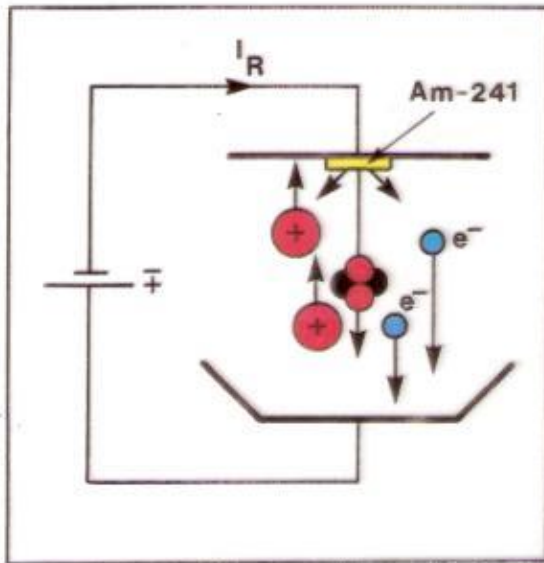


Safety signals tritium painted



Modern watches with sealed tritium gas tubes

Alpha techniques

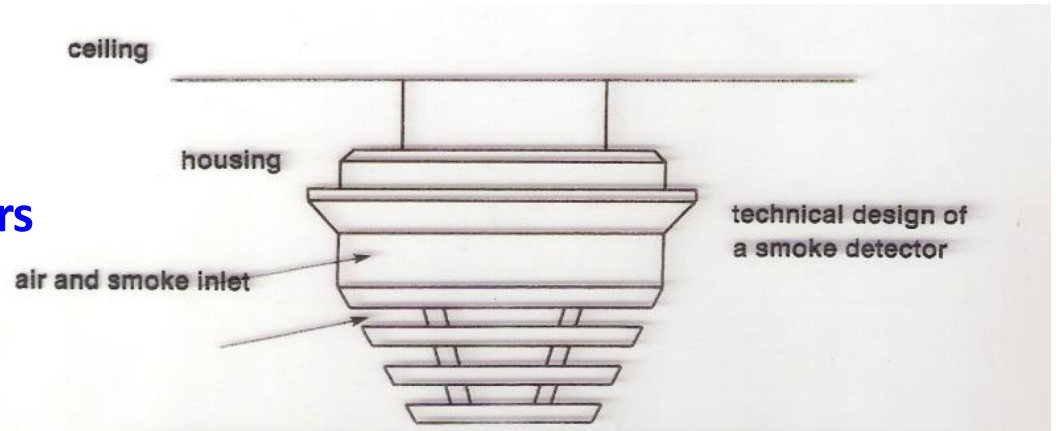


Smoke detectors

Alpha particles from ^{241}Am source ionise air producing electrical current. When there is smoke presence, the electrical current reduces giving alarm.

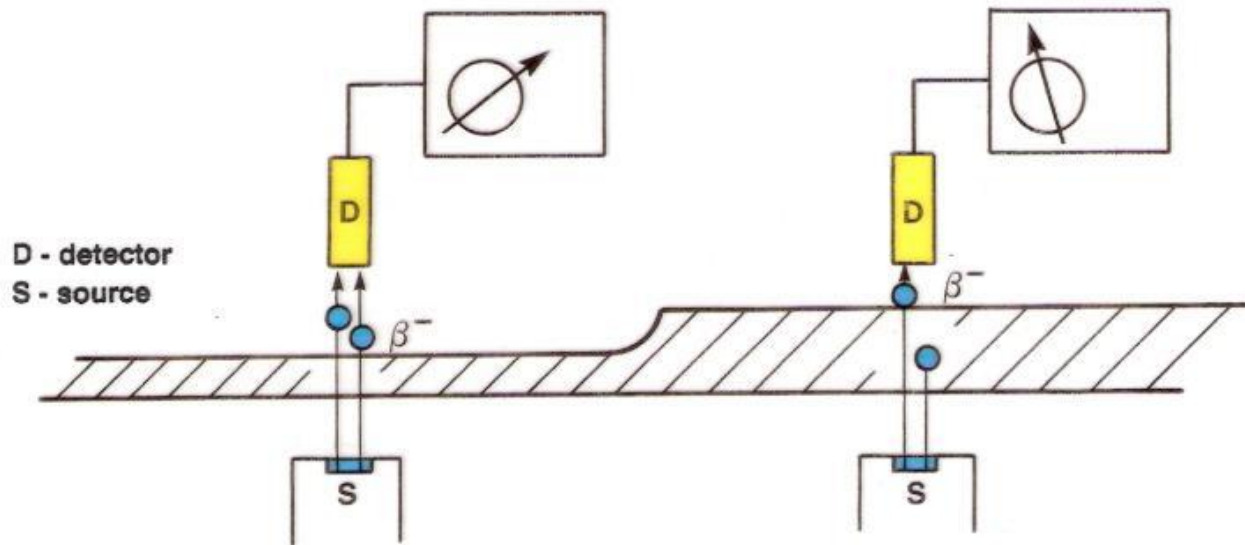
Alpha techniques (cont.)

Typical design of smoke detectors



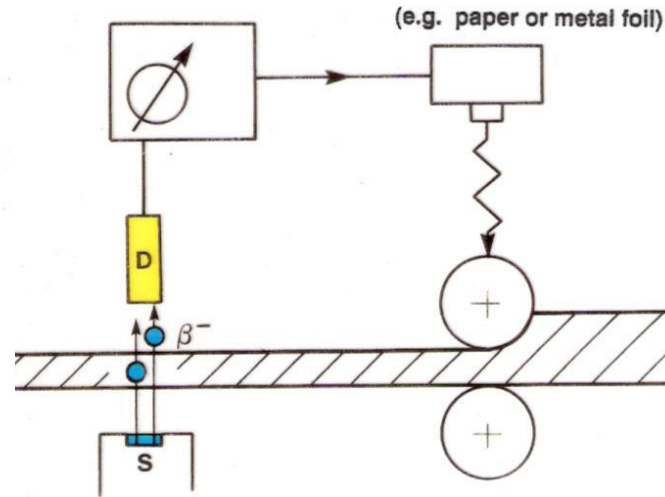
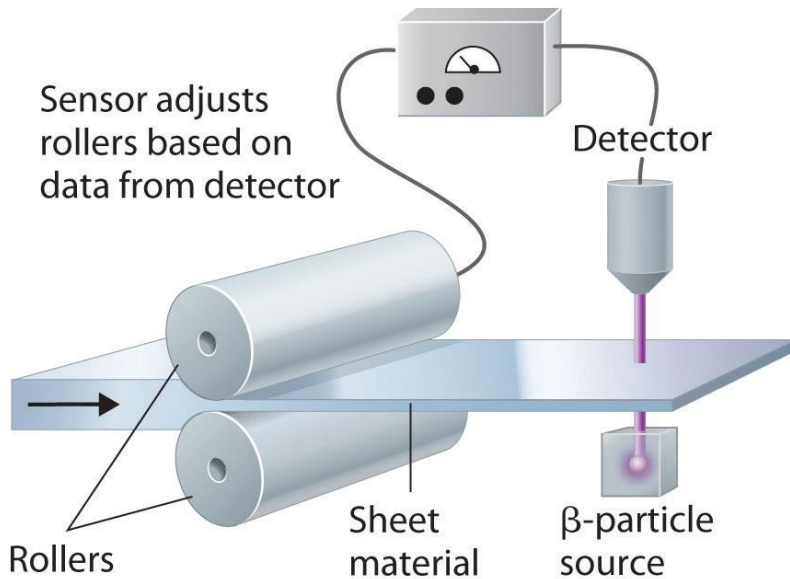
Americium-241 sources

Beta techniques



Measurement of thin thicknesses, e.g. paper. Electrons from a beta source are able to pass thin thicknesses but when thickness grows their transmission is reduced. A Geiger counter measures such a reduction.

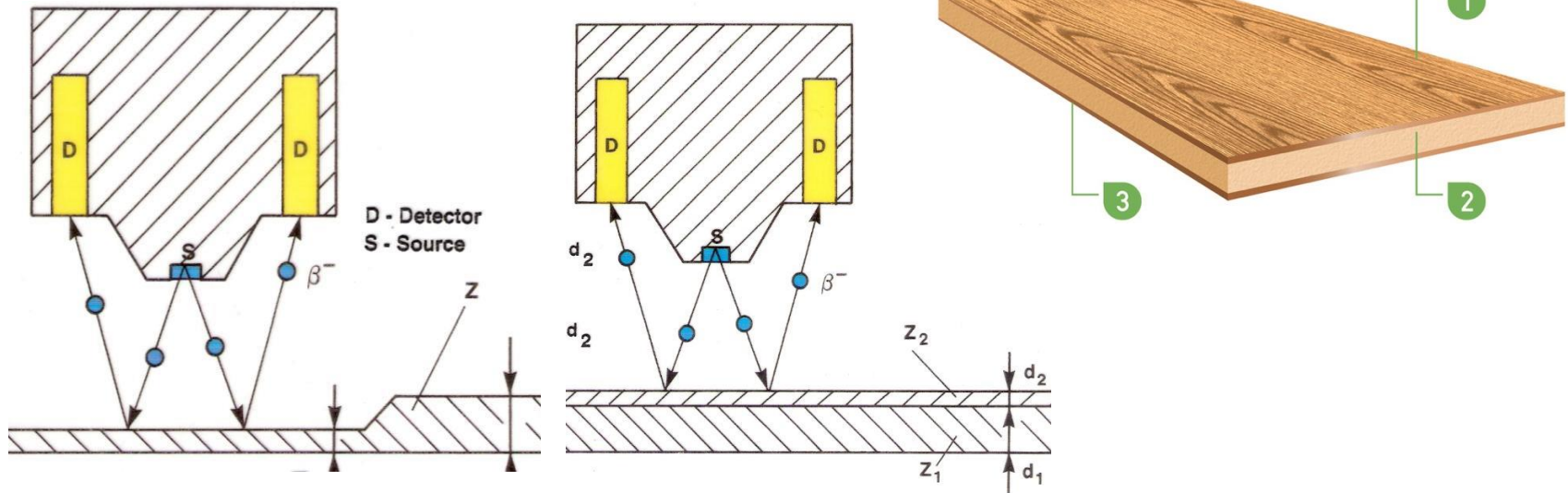
Beta techniques (cont.)



Real time control of paper thickness.

When Geiger counter detects variations in calibrated transmission a mechanical device automatically restores correct thickness.

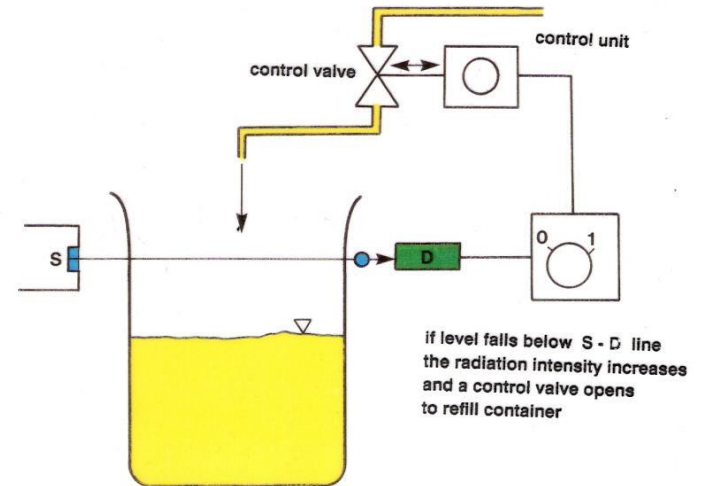
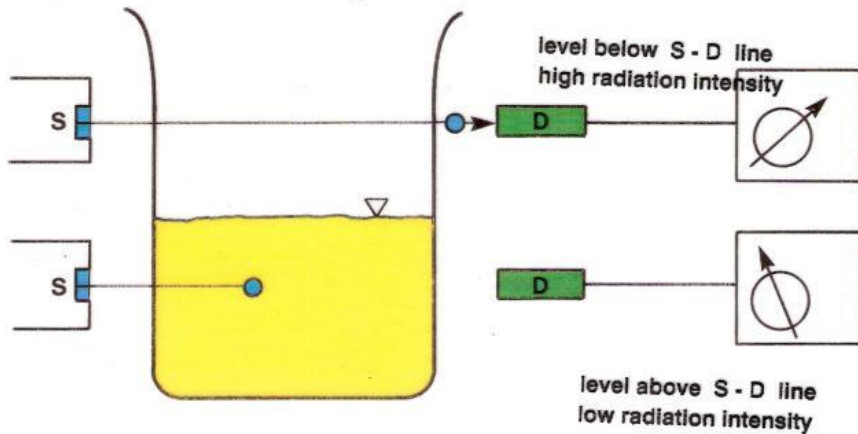
Beta techniques (cont.)



Measurement of coatings, e.g. for production of veneered panels.

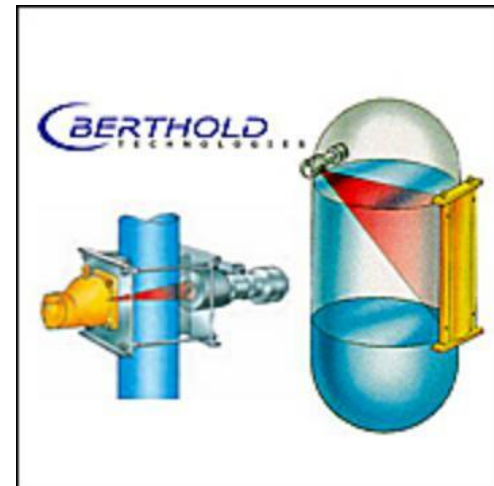
The measurement is based on beta backscattering, which depends on the coating only, and not from the support material.

Gamma techniques

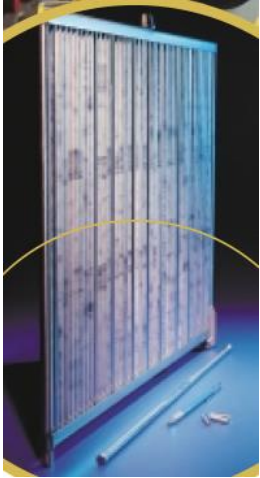


Gamma level gauge

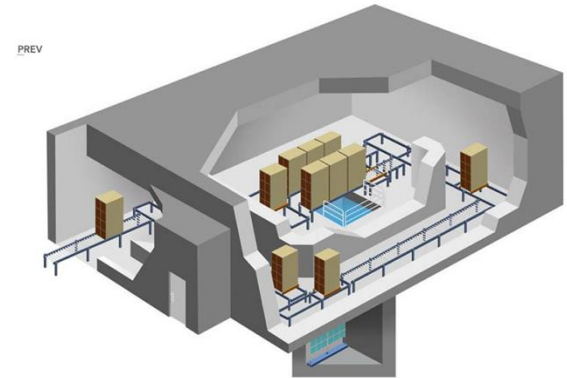
Utilised in chemical industry when corrosive liquids are involved. For controlling correct level there is no need of direct contact with the liquid.



Gamma techniques (cont)



**Sterilization plants
For sterilizing medical materials, or
foodstuffs.**



GammaFIT Flexible Irradiator: Automatic Pallet
Image 9 of 9

CLOSE X

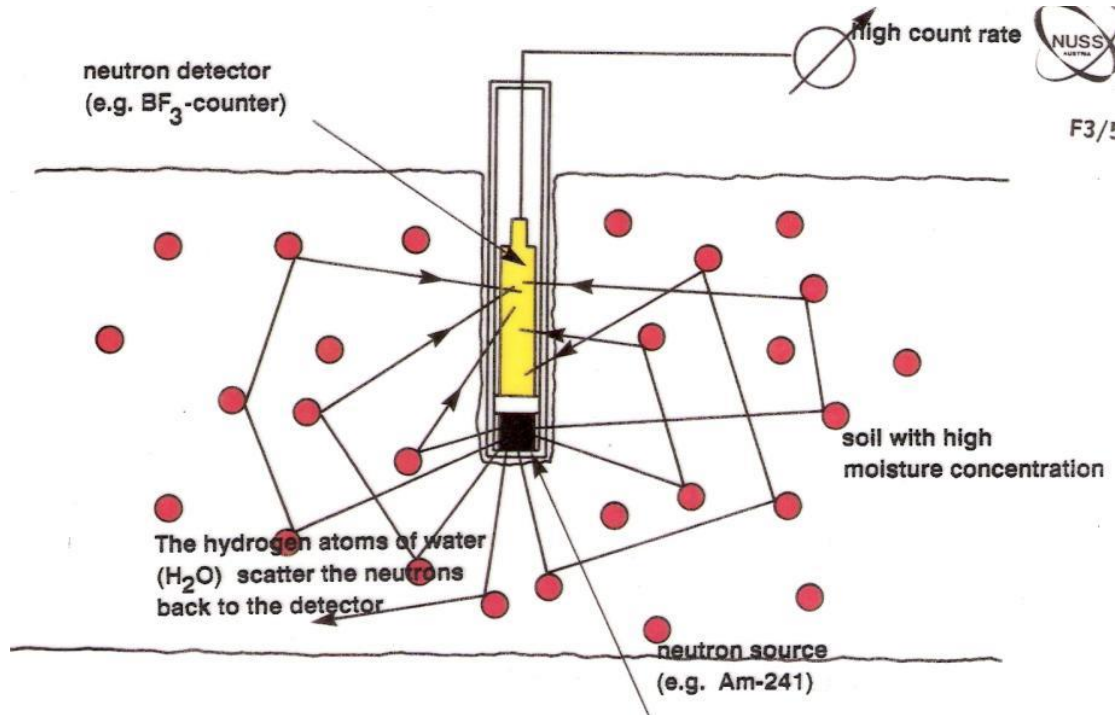
C-188 Specs at a Glance

Standard Source Activity Range	Up to 14,250 Ci (527 TBq)
Dimensions	451.6 mm (17.78 inches) in length 11.1 mm (0.437 inches) in diameter
Weight	0.24 kg (0.53 pounds)
Source Rack Arrangement	Customized to individual requirements for optimum dose uniformity



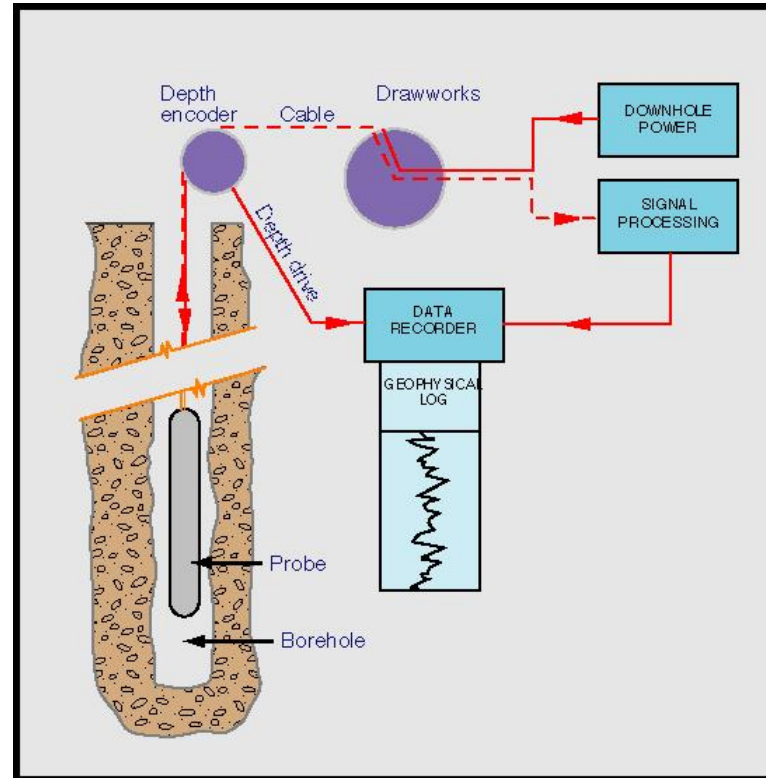
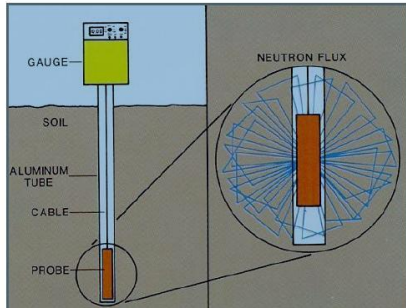
**Several modern
radiation accidents
occurred in such kind of
plants. Particular care is
needed for
management**

Neutron techniques



Borehole logging for oilfields detection

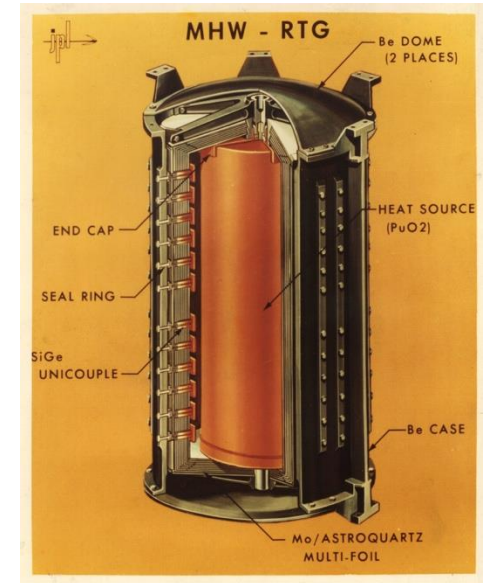
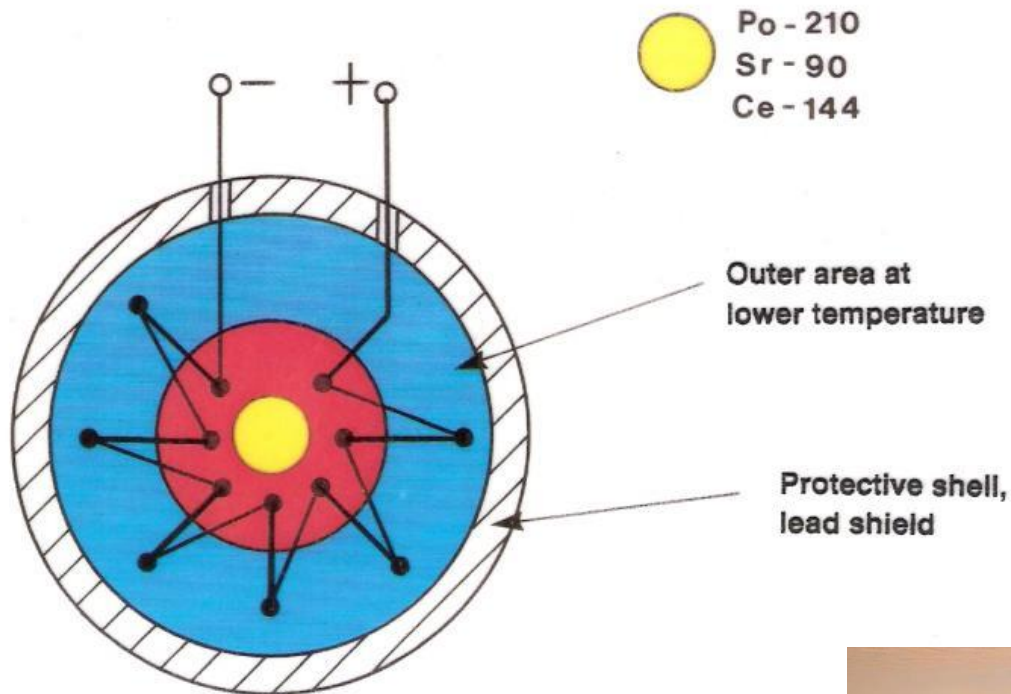
Neutron techniques (cont.)



Sometimes dismissed devices are erroneously considered as metal scrapes to be recycled. When melted, the americium-beryllium neutron source can be very harmful.

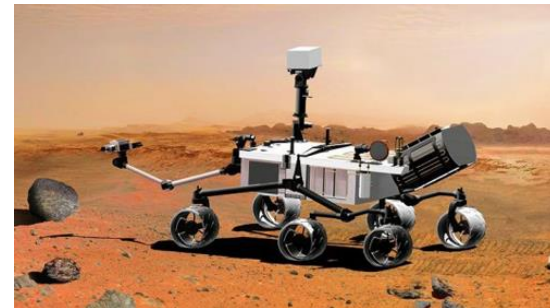
Other applications

Thermoelectric generators



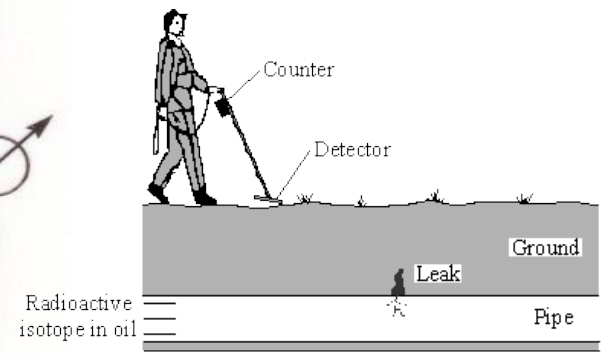
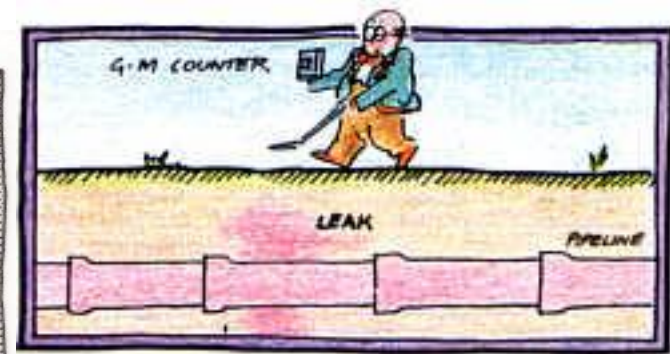
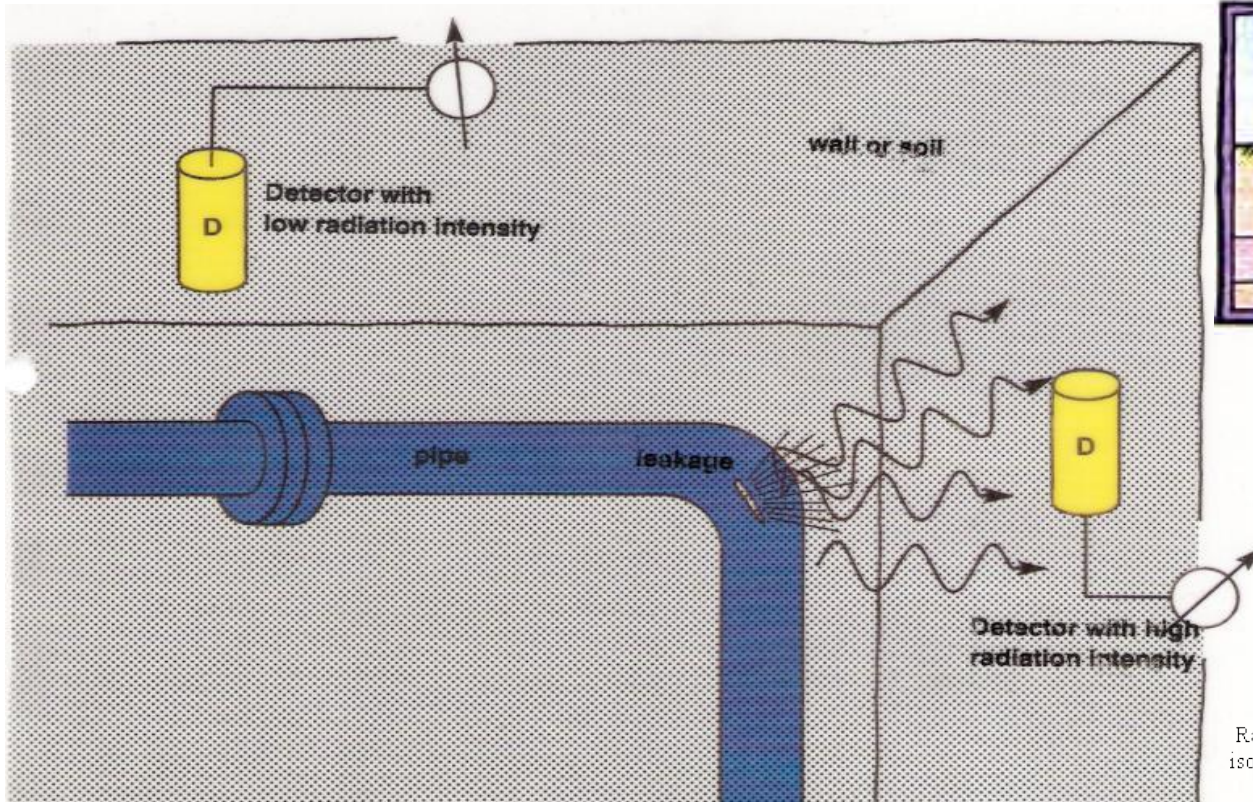
The inner red area is heated by the absorption of radiation, the blue area is at lower temperature.
A serie of thermocouples produce a voltage of several mW.

Advantages : Completely free from maintenance



Other applications (cont.)

Radioactive tracers



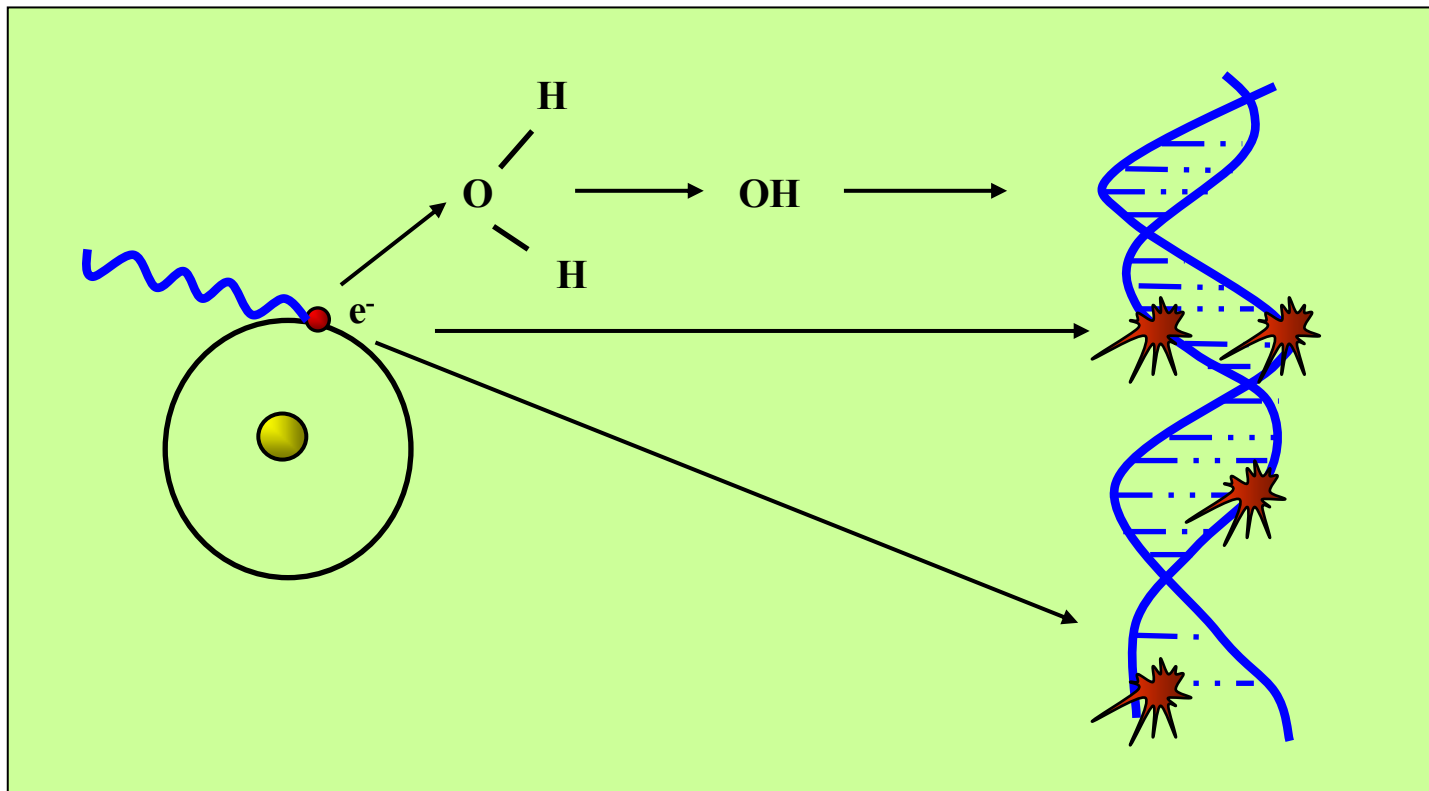
Radioactive lightning rods

- radium-226 ,
americium-241
- From 25 to 90 MBq

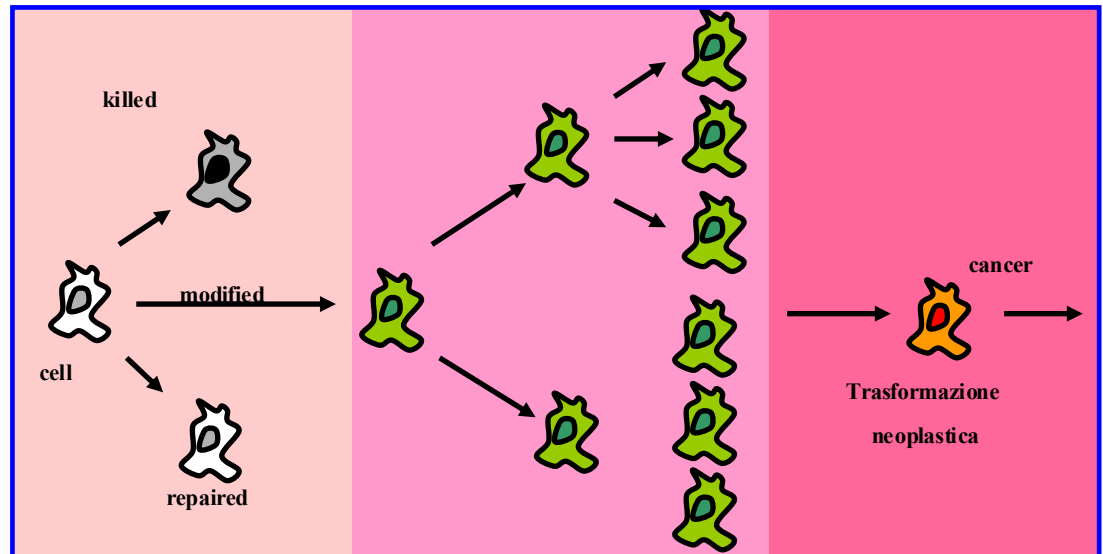


Interaction with DNA

DNA Damage



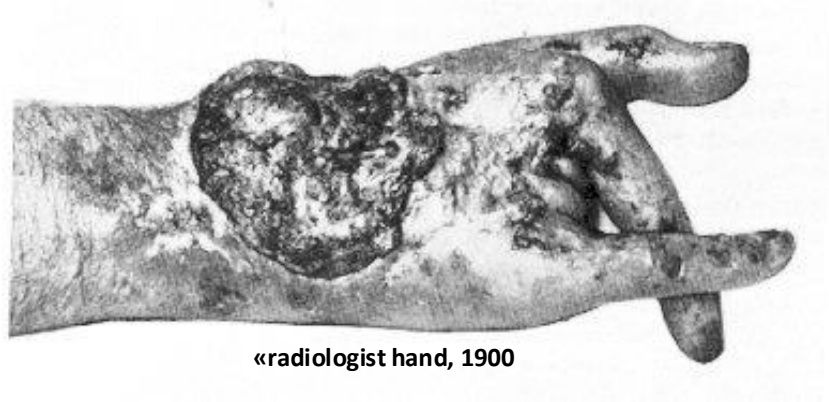
-
- Cells may be killed or damaged:
 - High number of killed cells of the same biological tissue:
Tissue Reactions
 - Modified cells:
Stochastic risk
(chance of future cancer)
 -
 -



**Tissue reactions (very very high doses of radiation – tenths of gray –
1Gy = 1 J/kg, Gy is the measurement unit of the quantity «ABSORBED DOSE»**



Ir-192 ,, Iran 1992



«radiologist hand, 1900



Cs-137, Georgia 1997

Pathologies to whole body from acute irradiation

- ❑ **0,25 Gy:** transitional early drop in the number of lymphocytes
- ❑ **0,50 Gy:** nausea, decreased appetite, mild illness, early reduction of lymphocytes, granulocytes decrease in the second and third week
- ❑ **1,00 Gy:** for 1 o 2 days nausea, vomiting, weakness, strong and rapid decrease in lymphocytes; between the second and the fourth week leukopenia and then anaemia then

Hospitalization for Acute Radiation Syndrome (ARS)

- ❑ **2,00 Gy:**
 - Prodromal phase (1-2 days) - discomfort, relevant reduction of lymphocytes, strong nausea, vomit, lack of appetite, nervousness.
 - Latent phase without symptoms (two weeks for 2 Gy, less for higher doses).
 - Acute phase (from the 2nd to the 6th week) – serious asthenia, vomit, high and irregular fever, tachycardia and hypotension, tendency to cardio circulatory collapse, diarrhoea, leukopenia, anaemia, immune system crumble. Without proper therapies death in 5-10% of cases.
 - Improvement and recovery (from the 8^o to the 15th week).

Pathologies to whole body from acute irradiation

- ❑ **4 Gy:** serious and fast ARS; conjunctivitis, erythema, epilation.
 - Without proper treatment 50% death rate (DL 50%: Lethal Dose 50%).
 - Proper cures:
 - Blood transfusion
 - Bone marrow transplant
 - Antibiotic treatment in sterile chambers
 - The critical period happens at the 4th – 5th week, when septicaemia risk is maximum

6 Gy: More serious and fast ARS, without intensive therapies near 100% death rate within 30 days

10-30 Gy: latent phase shortens, death in a couple of weeks

>30 Gy: immediate death for brain syndrome.

Chernobyl accident

Tissue reactions:

- 28 workers died for ARS

Stochastic risk:

- About 10^4 Thyroid cancers expected in 50 years
- About $6 \cdot 10^3$ after 30 years have been accounted for
- 15 cases caused the death of the patient.

Stochastic risk

For tissue effects similar consideration are also made for other pathogenic noxae (chemical pollutants, and non-ionizing radiation).

In practice the ruling philosophy is *limiting the polluting agent exposure to prevent tissue reactions.*

Tissues reactions are always characterised by a threshold

In radiation protection we consider stochastic risks also. Up to now it is a unique characteristic

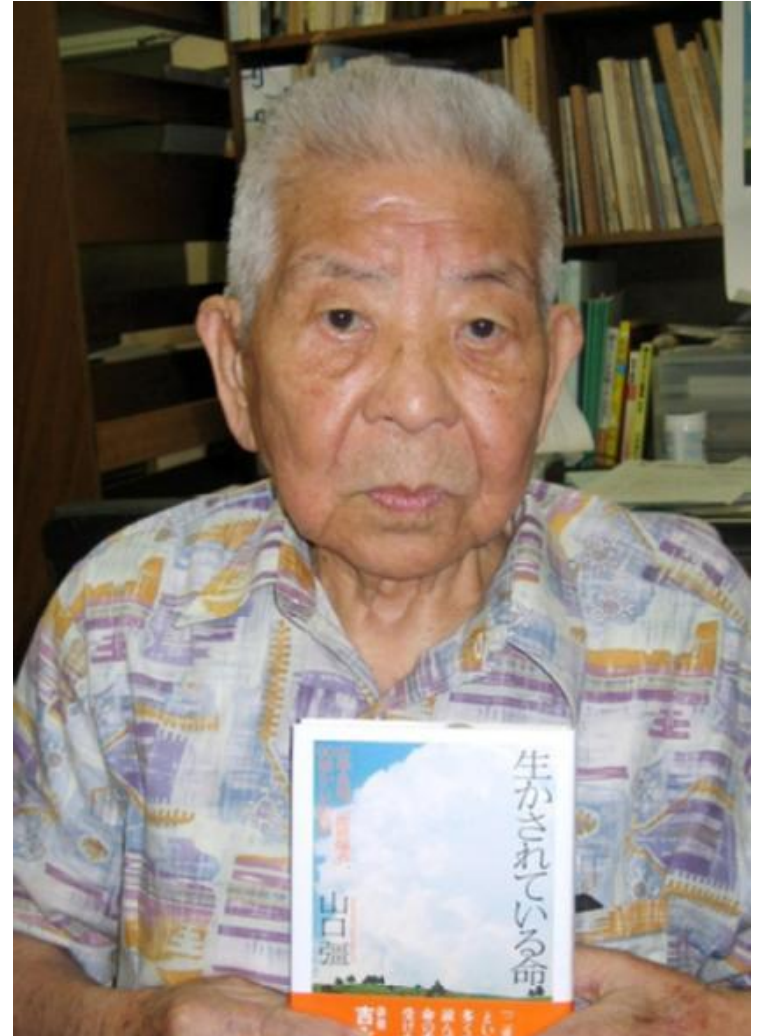
Stochastic risk

Tsutomu Yamagouchi, born in 1916, resided in Hiroshima for job. On August 6th, 1945, he was irradiated from the first A-Bomb.

Remained without job, he decided to reach his home town, 260 miles SW, Nagasaki.

He reached Nagasaki on August 9th, 1945, just in time to be irradiated from the second A-Bomb.

Tsutomu Yamaguchi has died on January 2010, at the age of 94.



absorbed dose

absorbed dose, D , is the mean energy imparted to a portion of matter of mass dm . It is measured in "gray". $1 \text{ Gy} = 1 \text{ J kg}^{-1}$

$$D = \frac{d\bar{\varepsilon}}{dm} \quad (\text{Gy})$$

$$D = \lim_{m \rightarrow 0} \frac{\bar{\varepsilon}}{m}$$

$$D = \lim_{V \rightarrow 0} \frac{1}{\rho} \frac{\bar{\varepsilon}}{V}$$

Absorbed dose rate is the derivative of D vs. time $\dot{D} = \frac{dD}{dt} \quad (\text{Gy s}^{-1})$

D_T : *absorbed dose given to a biological tissue*

Equivalent dose (to tissue)

$$H_T = \sum_R W_R D_{T,R}$$

W_R are the Radiation weighting factors.

Equivalent dose is measured in ***sievert, Sv***

In the past (Publication 26 - ICRP 1977) the corresponding quantity was the "dose equivalent"

$$H = QD$$

D the absorbed dose in one point. And Q was the "quality factor" of the radiation

The old measurement unit of the dose equivalent was the rem; 1 Sv=100 rem

Radiation weighting factors

ICRP Publication 103

Table 2. Recommended radiation weighting factors.

Radiation type	Radiation weighting factor, w_R
Photons	1
Electrons ^a and muons	1
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20
Neutrons	A continuous function of neutron energy (see Fig. 1 and Eq. 4.3)

All values relate to the radiation incident on the body or, for internal radiation sources, emitted from the incorporated radionuclide(s).

Radiation weighting factors

ICRP Publication 103

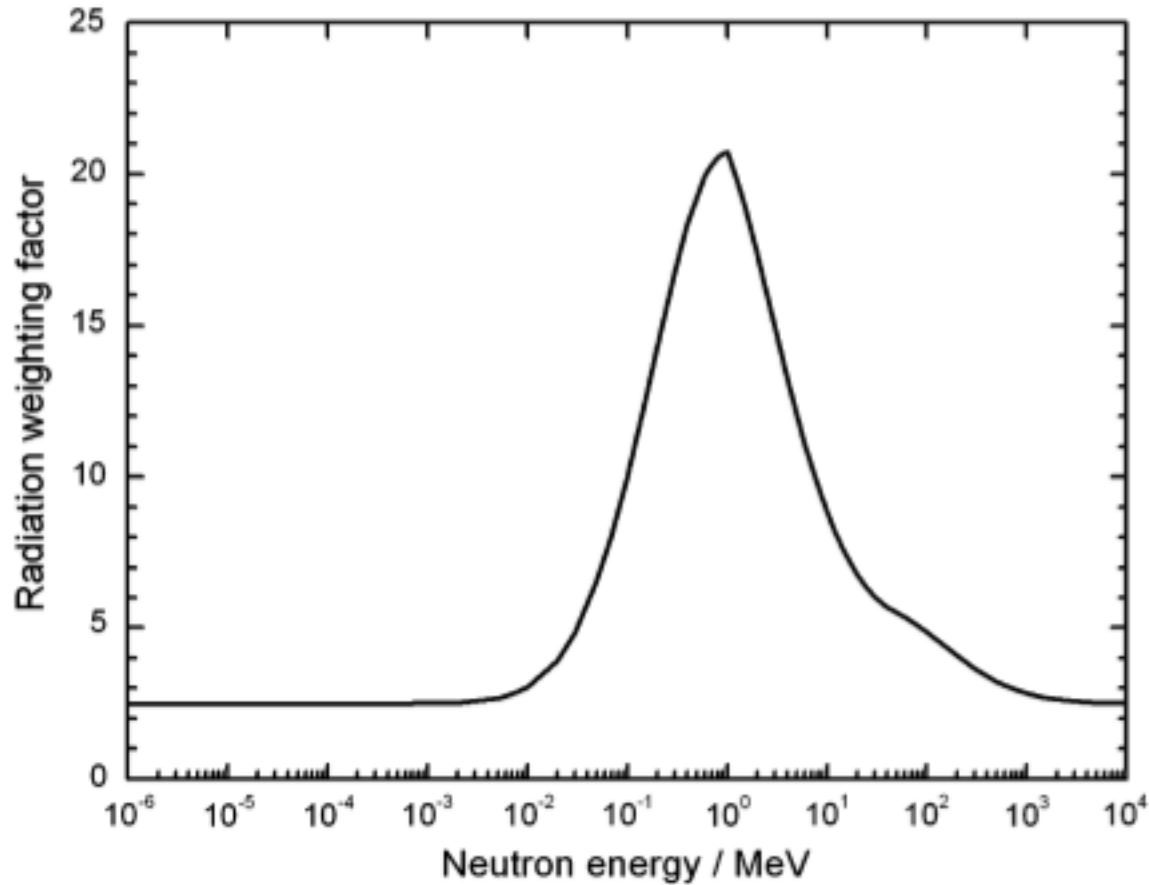


Fig. 1. Radiation weighting factor, w_R , for neutrons versus neutron energy.

The following continuous function in neutron energy, E_n (MeV), is recommended for the calculation of radiation weighting factors for neutrons:

$$w_R = \begin{cases} 2.5 + 18.2e^{-[\ln(E_n)]^2/6}, & E_n < 1 \text{ MeV} \\ 5.0 + 17.0e^{-[\ln(2E_n)]^2/6}, & 1 \text{ MeV} \leq E_n \leq 50 \text{ MeV} \\ 2.5 + 3.25e^{-[\ln(0.04E_n)]^2/6}, & E_n > 50 \text{ MeV} \end{cases}$$

Effective dose

$$E = \sum_T w_T H_T = \sum_T w_T \sum_R w_R D_{T,R}$$

Effective dose is measured in sievert (Sv)

w_T are the tissue weighting factors

Dose limit for professional exposed workers : 20 mSv a⁻¹

Dose limit for population: 1 mSv a⁻¹

ICRP Publication 103

Table 3. Recommended tissue weighting factors.

Tissue	w_T	$\sum w_T$
Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder tissues*	0.12	0.72
Gonads	0.08	0.08
Bladder, Oesophagus, Liver, Thyroid	0.04	0.16
Bone surface, Brain, Salivary glands, Skin	0.01	0.04
	Total	1.00

* Remainder tissues: Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate (♂), Small intestine, Spleen, Thymus, Uterus/cervix (♀).

Stochastic risk

The energy deposition in cell systems by the ionizing radiation is a process implying random consequences: even at extremely low doses it is possible that a sufficient amount of energy is deposited into a critical volume within a cell so as to bring about changes or cell death. The killing of one more cells has no effect on the tissues, but changes of a single cell can lead to harmful transformations (initiation of carcinogenesis).

The risks entailed by damage to a single cell are called stochastic.

Stochastic risk

Stochastic risks' characteristics:

- They are also possible at very low doses;
- Do not provide a threshold dose;
- They can be somatic or genetic;
- Increasing dose increases their frequency, not their severity.

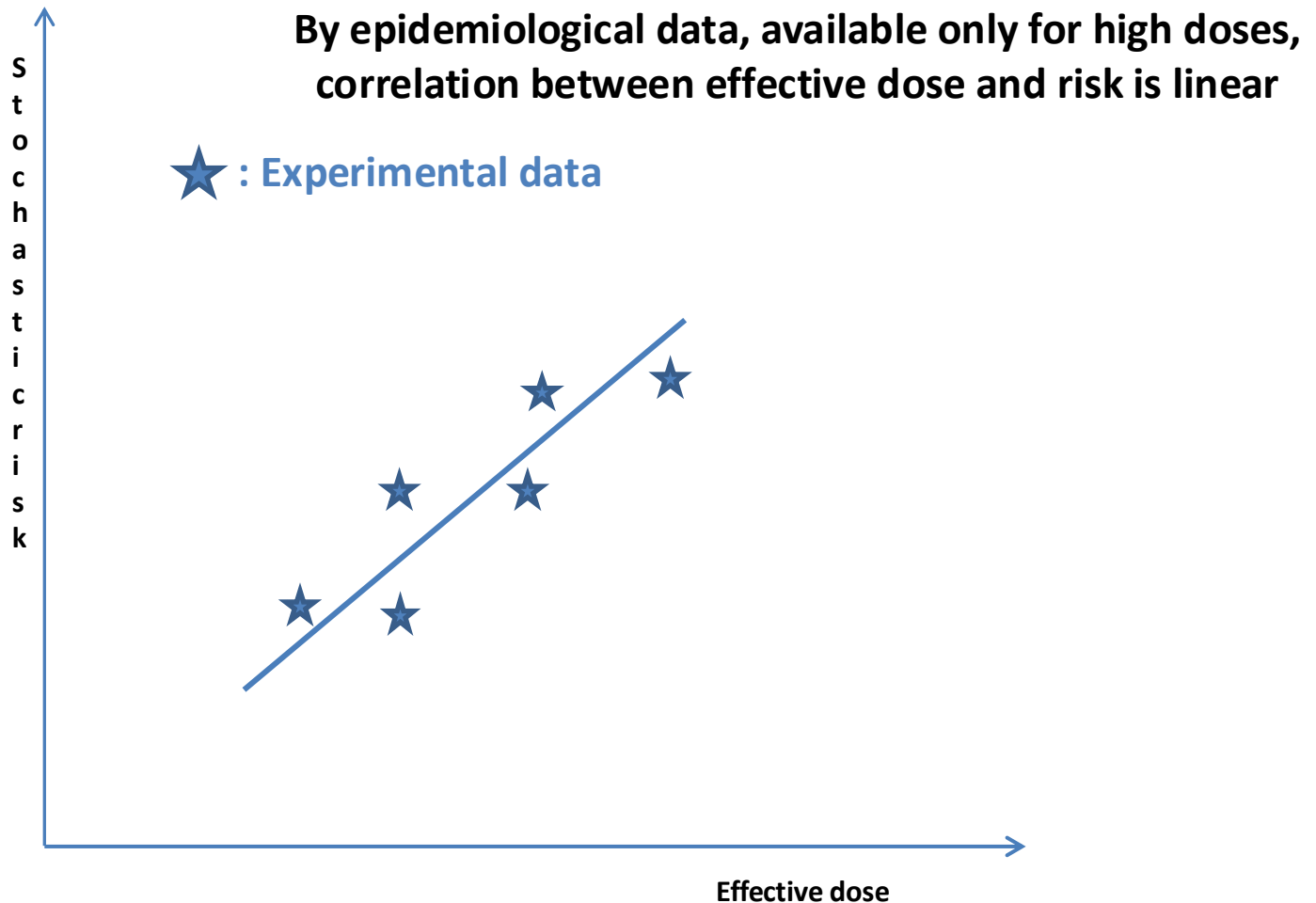
Both tumors of the lymphatic-hemopoietic (leukemia) and solid tumours are initiated by damaged cells that are propagated incorrectly .

The ionizing radiation can promote development but not the growth, of carcinogenesis

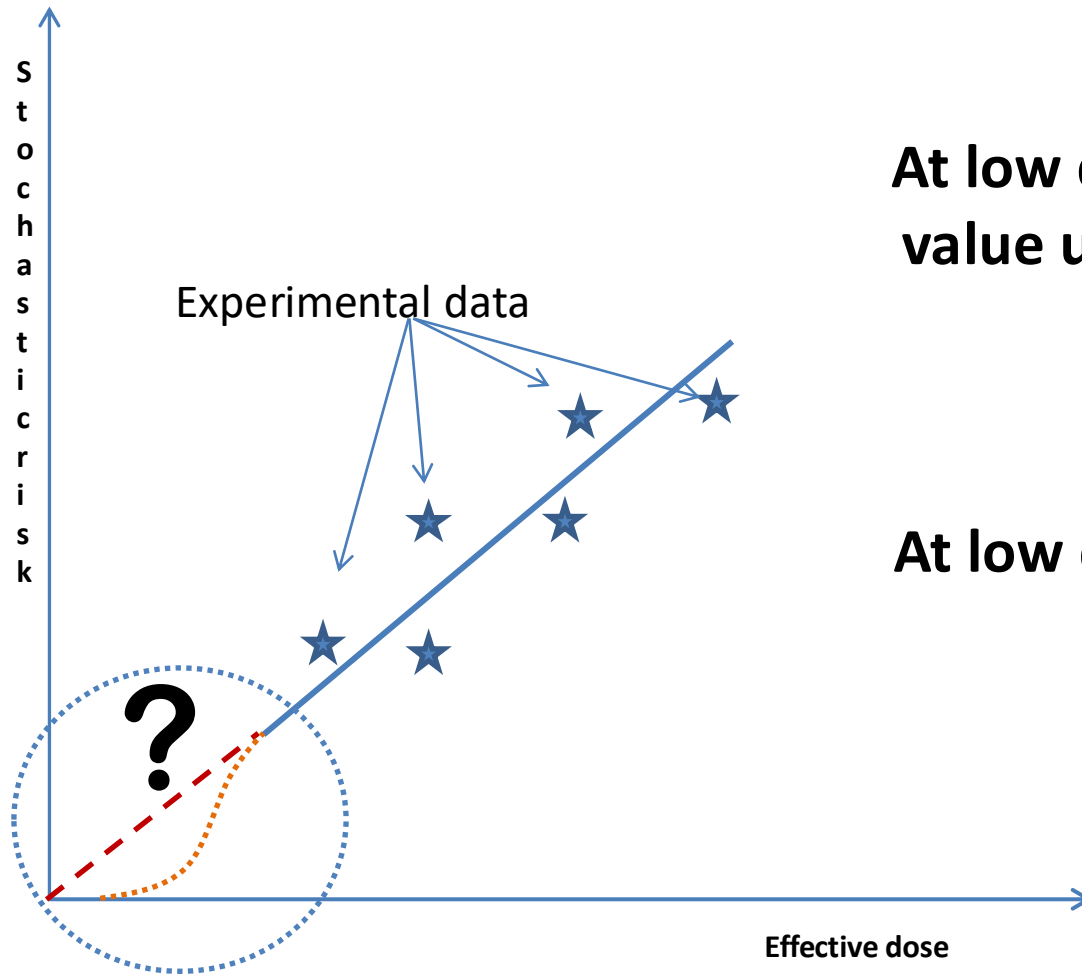
Very often the cellular damage are resolved by cell repair mechanisms

Carcinogenesis and hereditary effects

The risk of carcinogenesis is currently evaluated on the basis of epidemiological considerations based on «follow-up» of survivors of the nuclear bombings in JAPAN in 1945 (Life Span Study - LSS)



Carcinogenesis and hereditary effects - extrapolation to low doses



At low doses is there a threshold value under which no effect can exist?

At low doses can harmful effects exist?

Carcinogenesis and hereditary effects - extrapolation to low doses

Currently, the accepted hypothesis is the following:

Linear-no-threshold (LNT) model

A dose-response model which is based on the assumption that, in the low dose range, radiation doses greater than zero will increase the risk of excess cancer and/or heritable disease in a simple proportionate manner.

Carcinogenesis and hereditary effects - extrapolation to low doses

The probabilistic nature of stochastic effects and the properties of the LNT model make it impossible to derive a clear distinction between 'safe' and 'dangerous', and this creates some difficulties in explaining the control of radiation risks. The major policy implication of the LNT model is that some finite risk, however small, must be assumed and a level of protection established based on what is deemed acceptable. This leads to the ICRP's system of protection with its three fundamental principles of protection:

- 1. Justification.**
- 2. Optimisation of protection.**
- 3. Application of dose limits.**

Carcinogenesis and hereditary effects - extrapolation to low doses

Current critic view on LNT model and the ICRP's response

- *Cell repair mechanisms of spontaneous oxidative DNA lesions are frequently observed: the few (in comparison) lesions induced by ionizing radiation would not give significant consequences.*
 - *It is assumed that the DNA breaks caused by ionizing radiation are more difficult to repair.*
- *Adaptive response of cells: the organism adopts its defence in proportion to the offense (immune stimulation), as with the lymphocytes*
 - *It is assumed that there is scarce significant biological evidence*
- *Epigenetics : Radiation can not influence the «cellular signalling» which is the root cause of cancer*
 - *It is assumed that significant biological evidence does not exist*

Carcinogenesis and hereditary effects - extrapolation to low doses

By linear extrapolation at low doses region the following risks coefficients are obtained

ICRP Publication 103

Table 1. Detriment-adjusted nominal risk coefficients (10^{-2} Sv^{-1}) for stochastic effects after exposure to radiation at low dose rate.

Exposed population	Cancer		Heritable effects		Total	
	Present ¹	<i>Publ. 60</i>	Present ¹	<i>Publ. 60</i>	Present ¹	<i>Publ. 60</i>
Whole	5.5	6.0	0.2	1.3	5.7	7.3
Adult	4.1	4.8	0.1	0.8	4.2	5.6

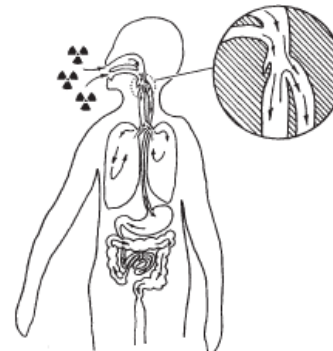
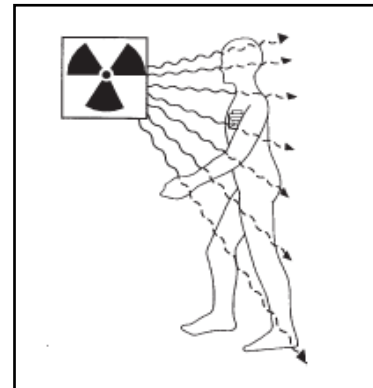
¹ Values from Annex A.

External irradiation

Dose can be conferred by sources placed outside (external irradiation), or inside (internal irradiation) human body .

- Internal irradiation is due to radionuclides intake: inhalation of natural or artificial radionuclides, environmental contamination, nuclear medicine applications, etc.
- External irradiation is due to sources placed outside human body, e.g. and X-ray tube, a gamma source, etc...

Irradiation { **external**
internal

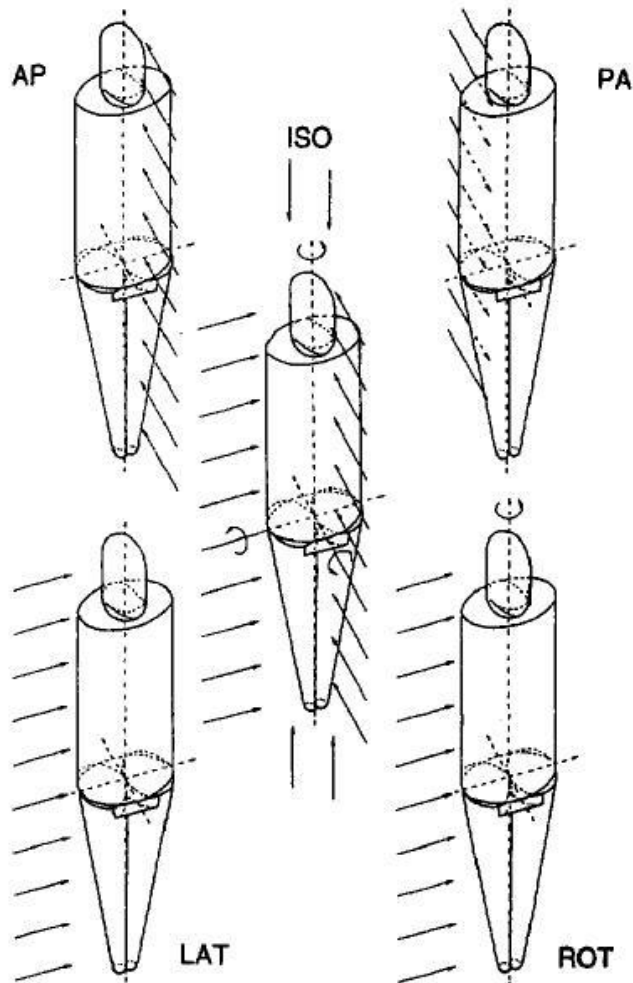


Radiation type	Energy	Position of dose equivalent maximum
beta and electrons	$\leq 4 \text{ MeV}$	Within the first centimetre of soft tissue
	$> 4 \text{ MeV}$	Greater and greater depths. For some GeV the depth is larger than 30 cm (average thickness of human body)
gamma	$< 1 \text{ MeV}$	Under germinative layer
	$1 \text{ MeV} < E < 2 \text{ MeV}$	About 1 cm
	$2 \text{ MeV} < E < 10 \text{ MeV}$	Between 1 cm and 4 cm
neutrons	$< 20 \text{ MeV}$	Surface or first centimetre
	$> 20 \text{ MeV}$	Greater and greater depths

Penetration capability of radiation inside human body

organ	Depth (mm)
Red bone marrow	20
Male gonads	4 - 10
Female gonads	70
Lens eye	3
skin	0,07

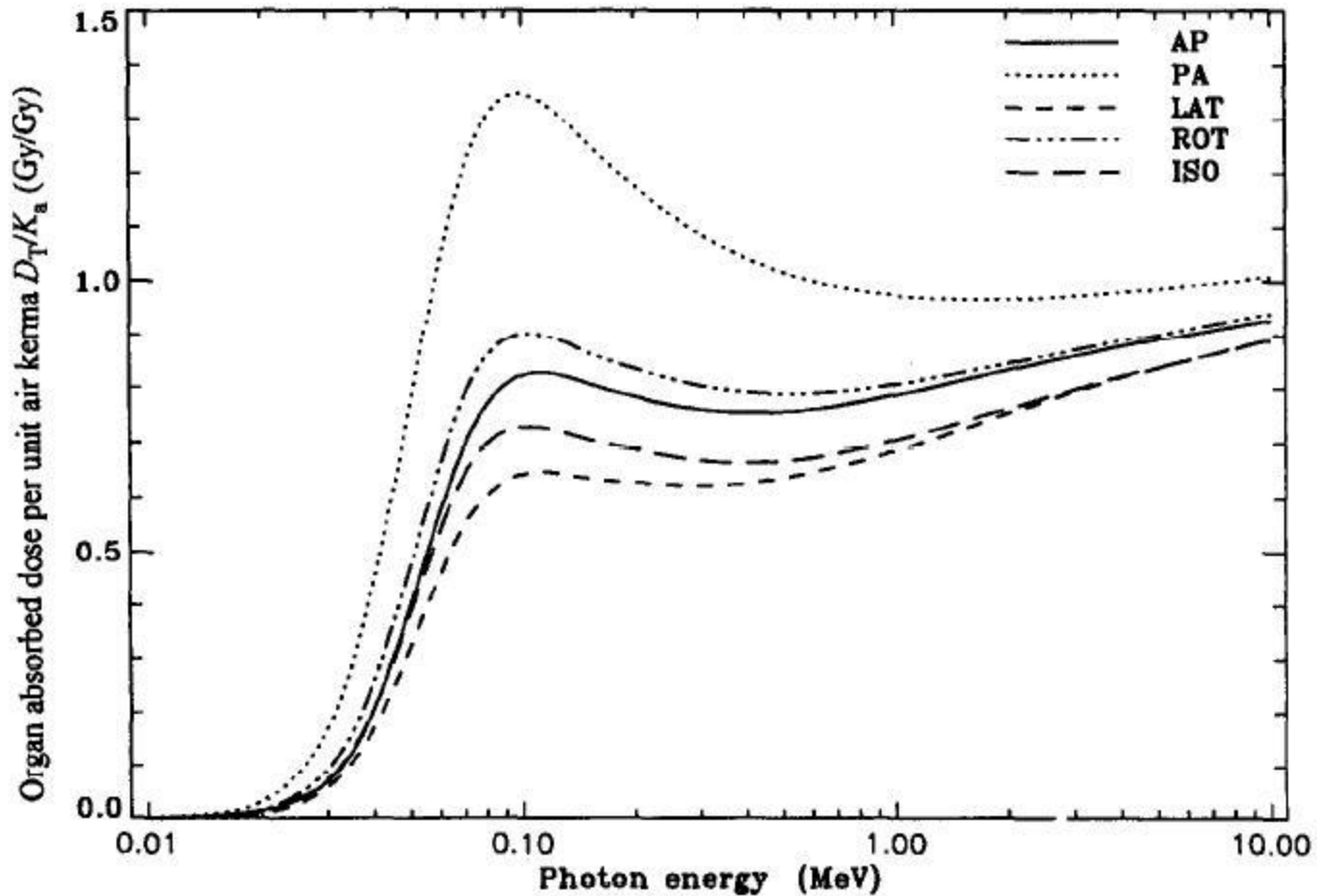
Average depth of some organs (measured from cutaneous surface)



AP: Antero-Posterior
PA: Postero-Anterior
LAT: Lateral
ROT: Rotazionale
ISO: Isotrope

Irradiation geometries

External irradiation - photons

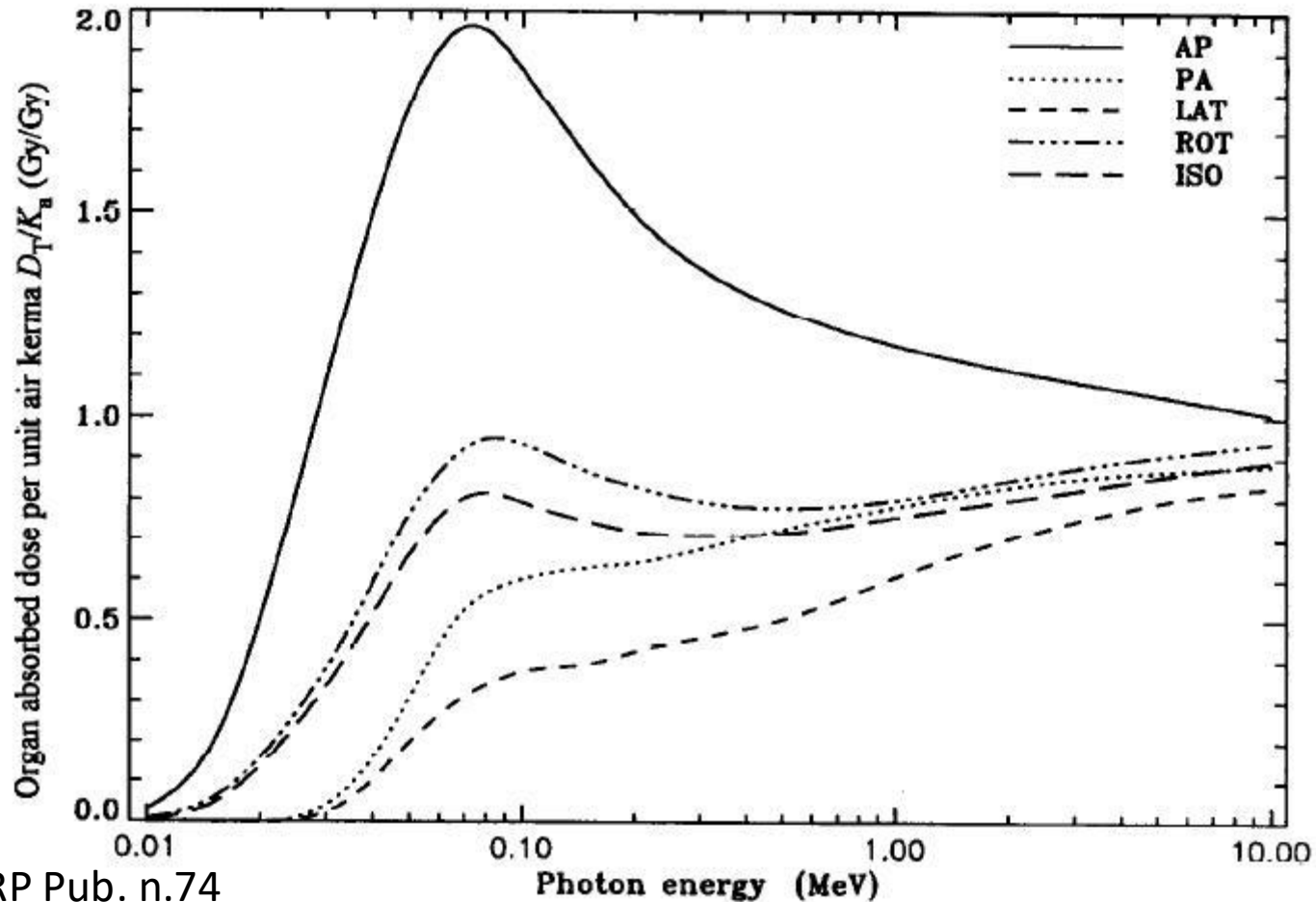


From ICRP Pub. n.74

Fig. A.2. Bone (red marrow) absorbed dose per unit air kerma free-in-air.

External irradiation - photons

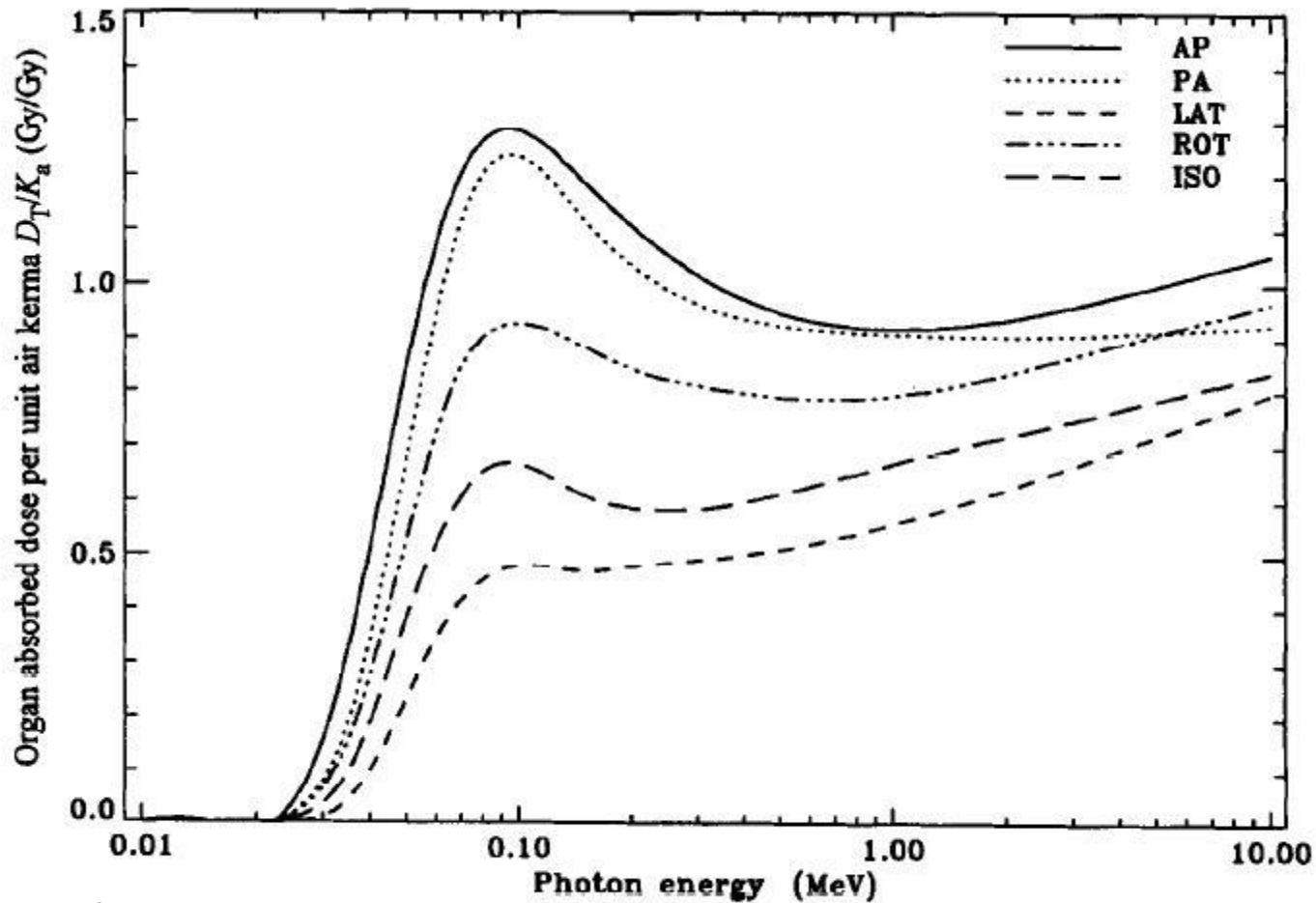
CONVERSION COEFFICIENTS FOR USE IN RADIOLOGICAL PROTECTION



From ICRP Pub. n.74

Fig. A.7. Gonads, male (testes) absorbed dose per unit air kerma free-in-air.

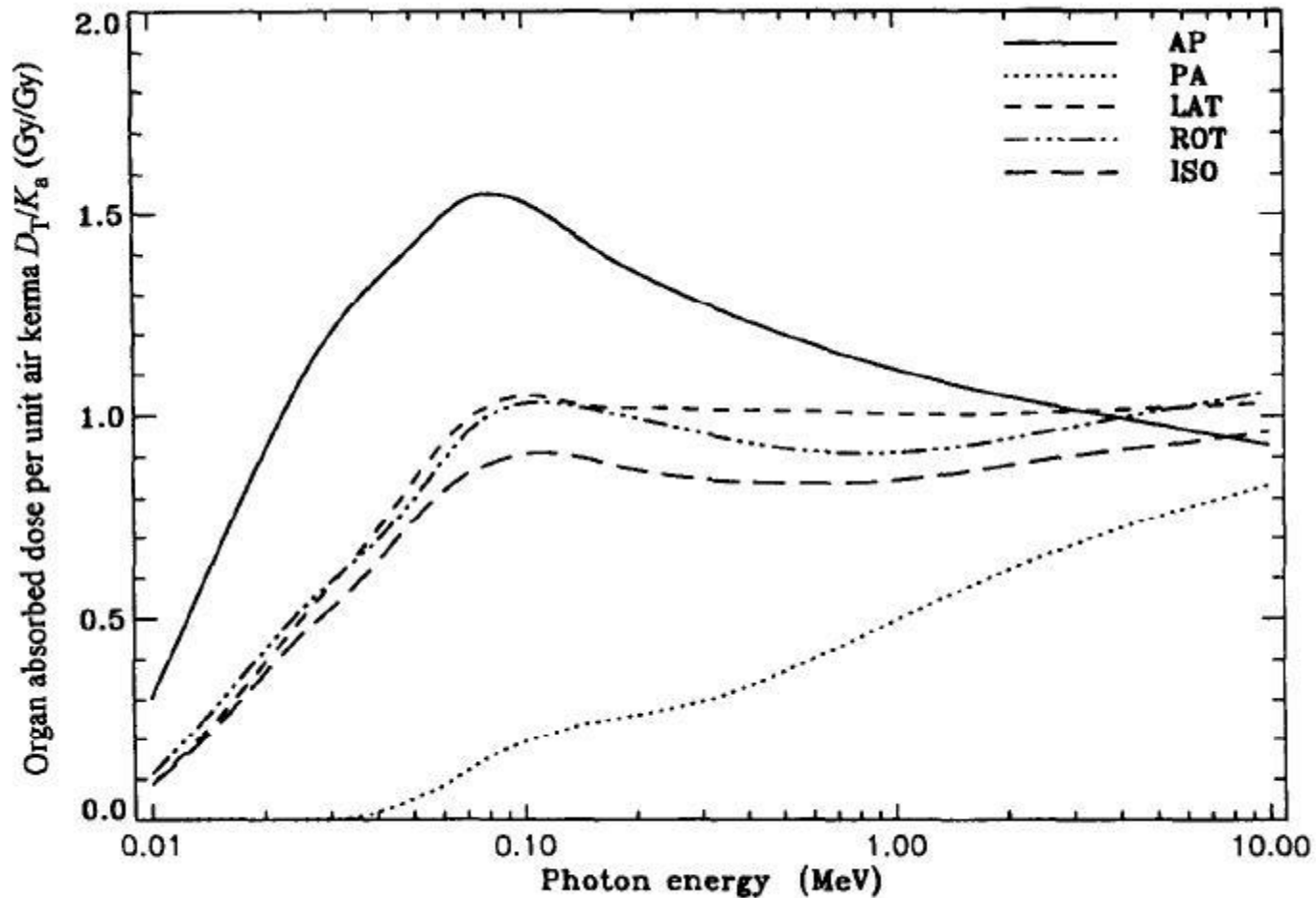
External irradiation - photons



From ICRP Pub. n.74

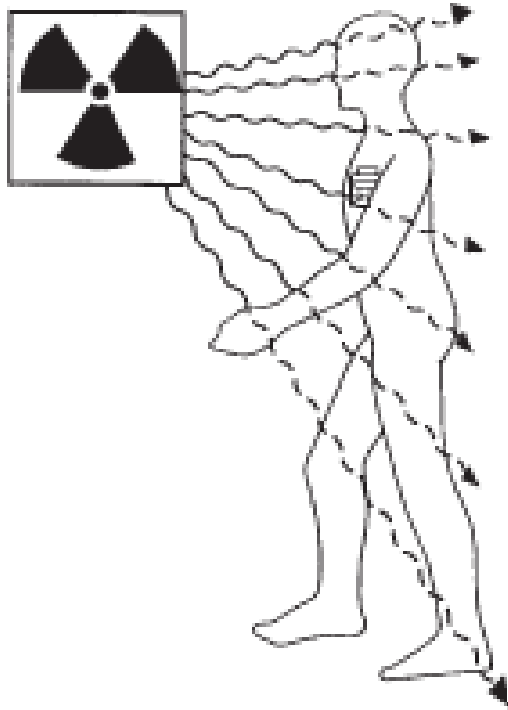
Fig. A.6. Gonads, female (ovaries) absorbed dose per unit air kerma free-in-air.

External irradiation - photons



From ICRP Pub. n.74

Fig. A.17. Eye lens absorbed dose per unit air kerma free-in-air.



- In your laboratory you will receive an effective dose less than $5 \mu\text{Sv}$
- About 50% of the threshold of non radiological relevance ($10 \mu\text{Sv a}^{-1}$)



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UNIVERSITÀ DI ROMA

**Master in
Protezione dalle radiazioni ionizzanti**

MASTER PRORADION

A.A. 2024/2025

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