General concepts of Radiation Protection

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

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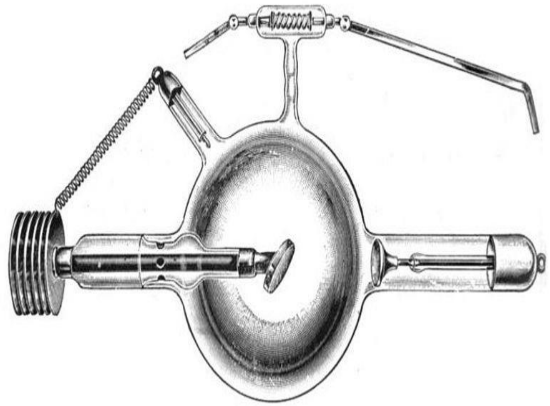
The beginning of Radiation Protection



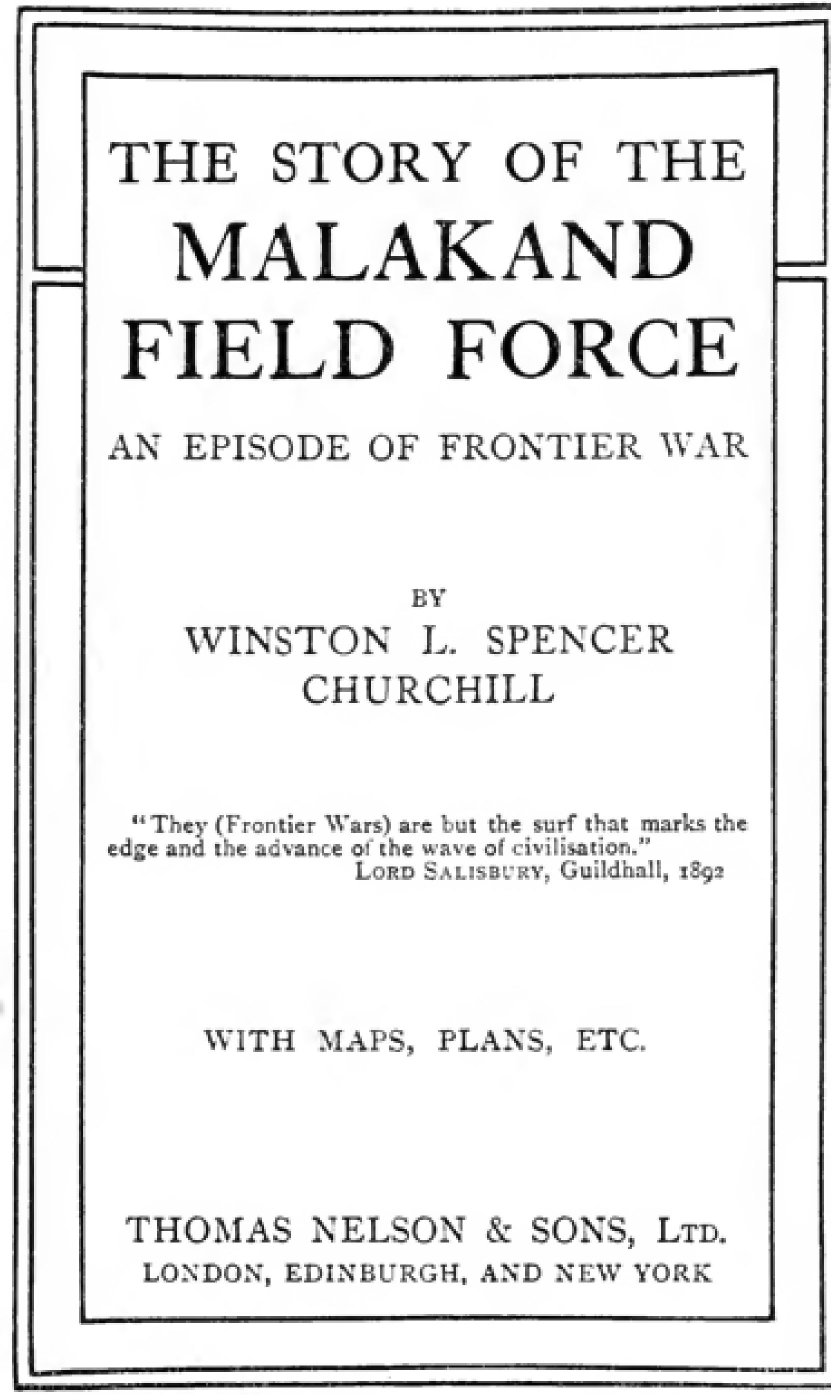
Wilhelm Conrad Röntgen, X-Ray tube, 1895

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.
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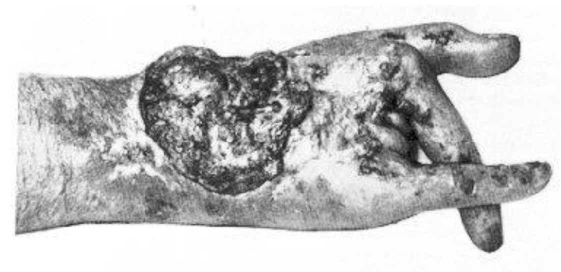
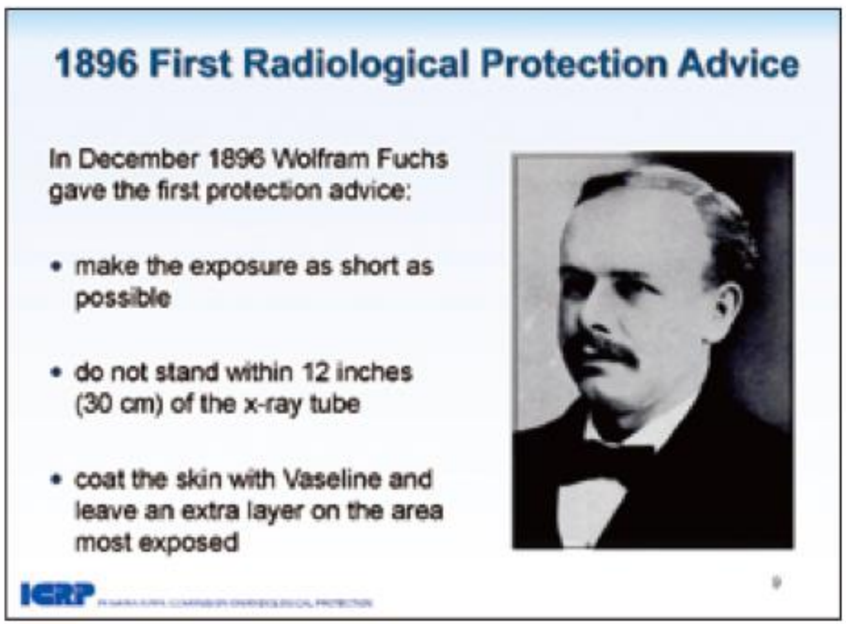
First problems

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



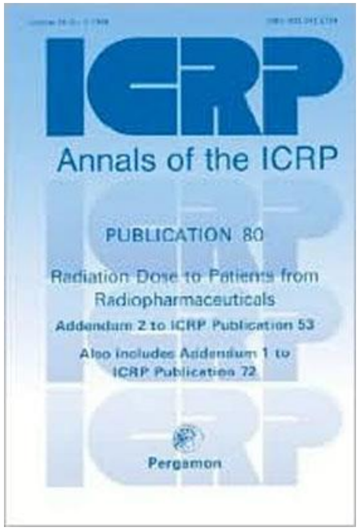
A new pathology was discovered "The hand of the radiologist"



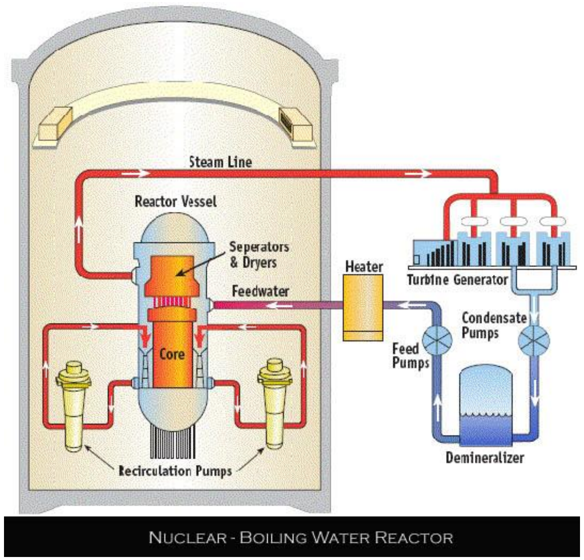
Radiation Protection origins

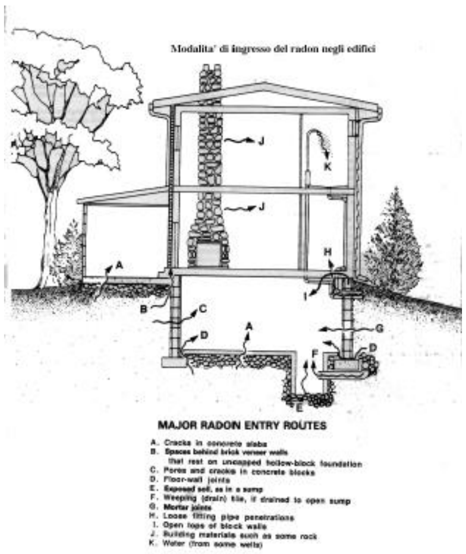
First international recommendations on on safe use of X rays were given in 1920. In 1925 the first International Congress on Radiology (ICR) was held in London. During the first ICR the **International Commission on Radiation Units and Measurements (ICRU) was created.**
During the second ICR, held in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



R. Remetti "Radiation Protection lessons"





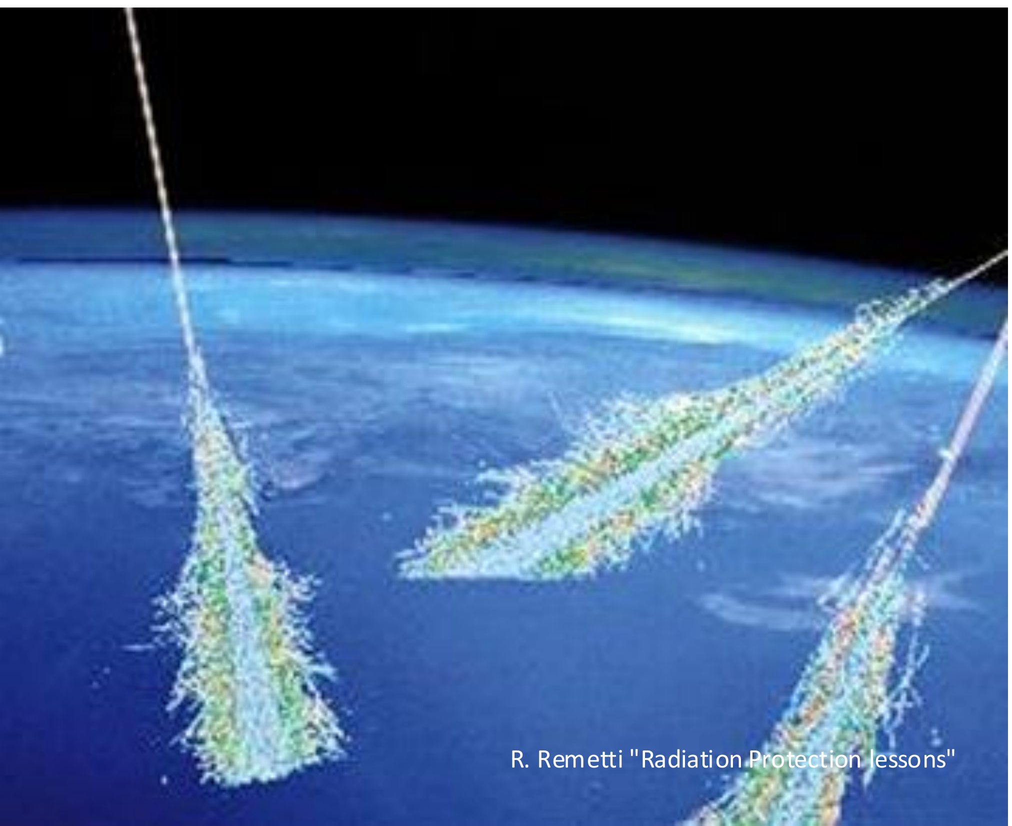
RP today

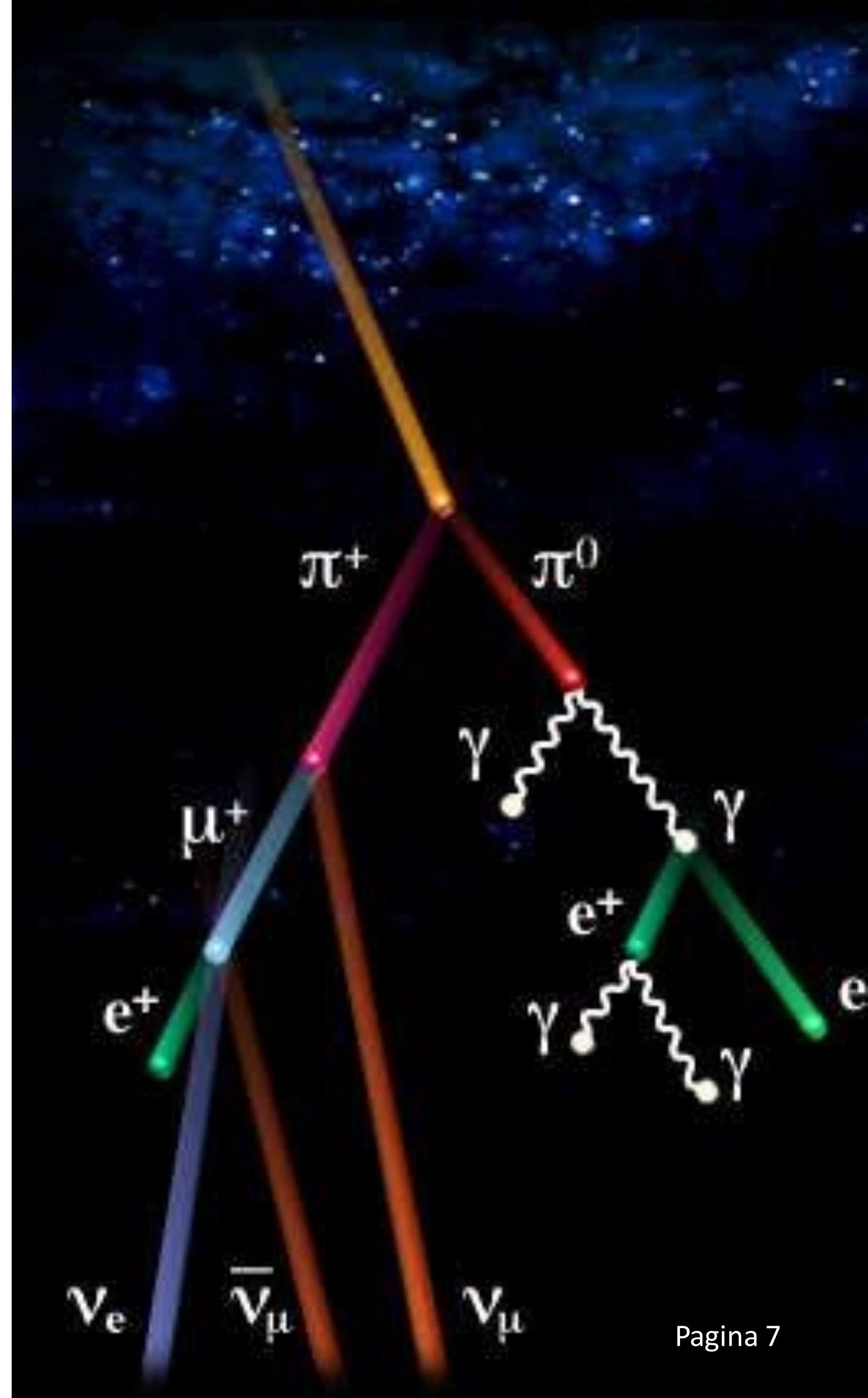
To protect mankind and environment (including flora and fauna) from harmuful effects and/or risks caused by radiation fields originated by

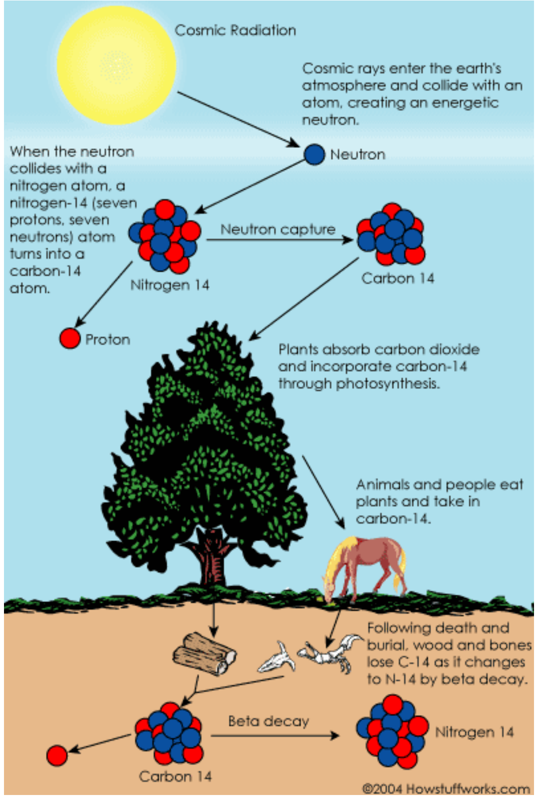
- Natural phenomena;
- Antropic activities.

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 biliion 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.



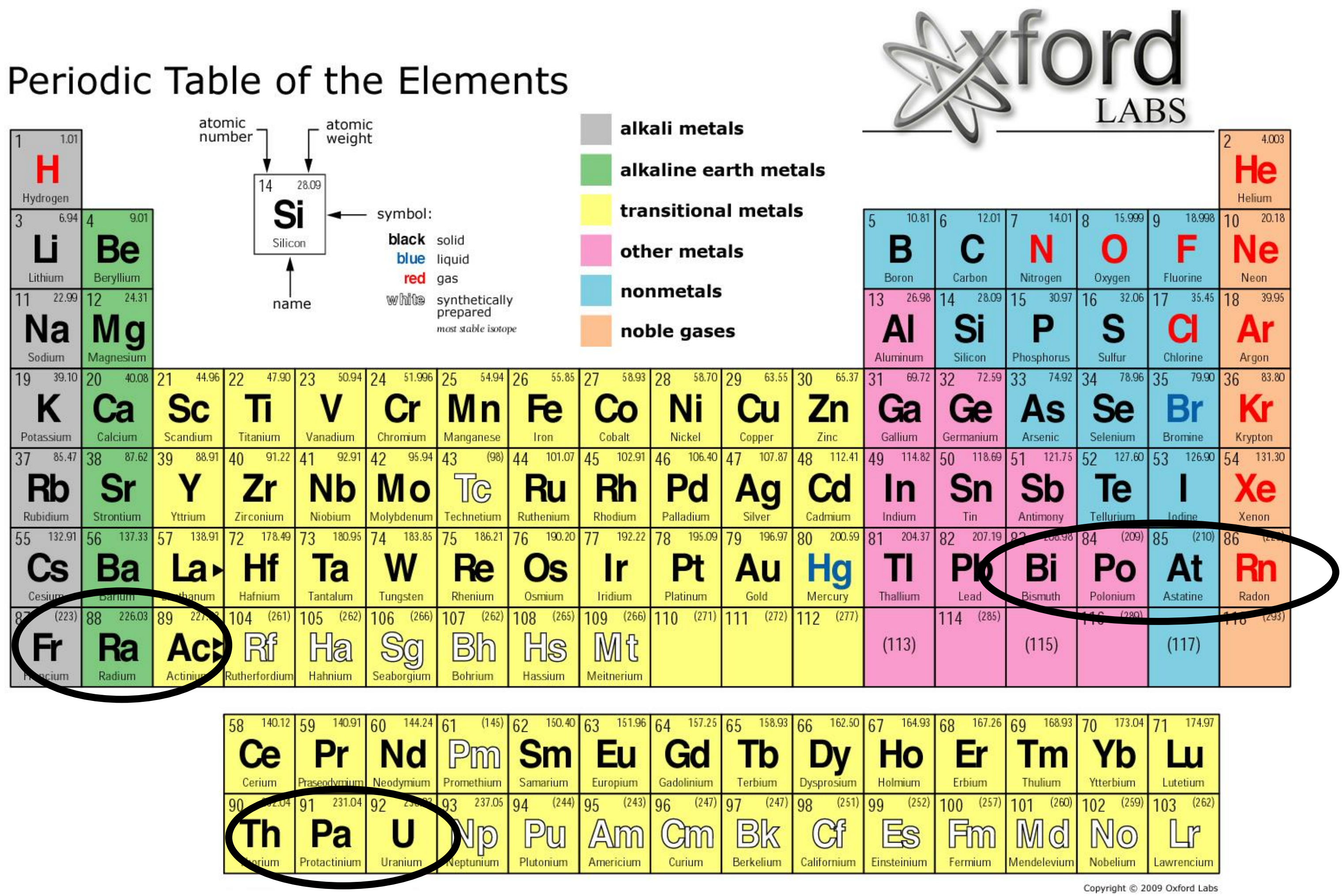




Natural background – Cosmogenic Radionuclides

- 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.

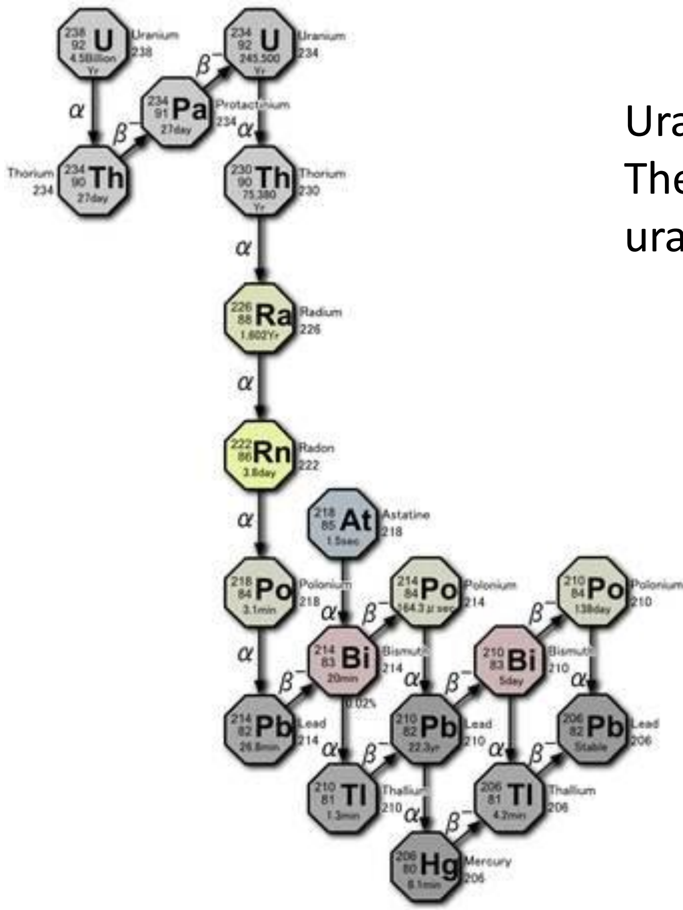
Natural background – Natural radionuclides



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.

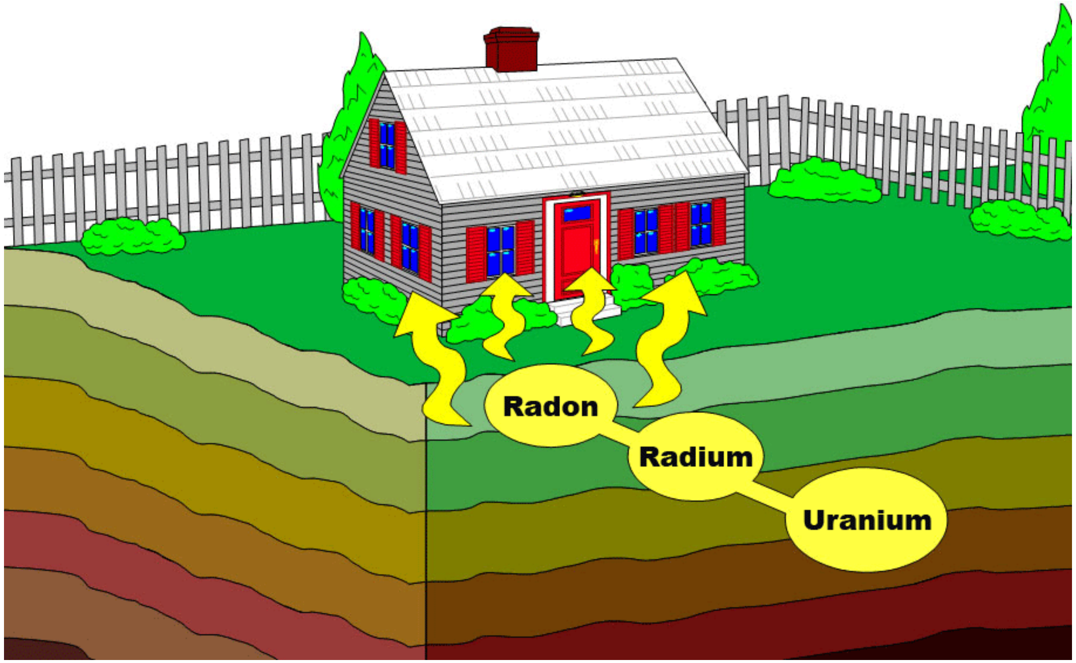
Where?

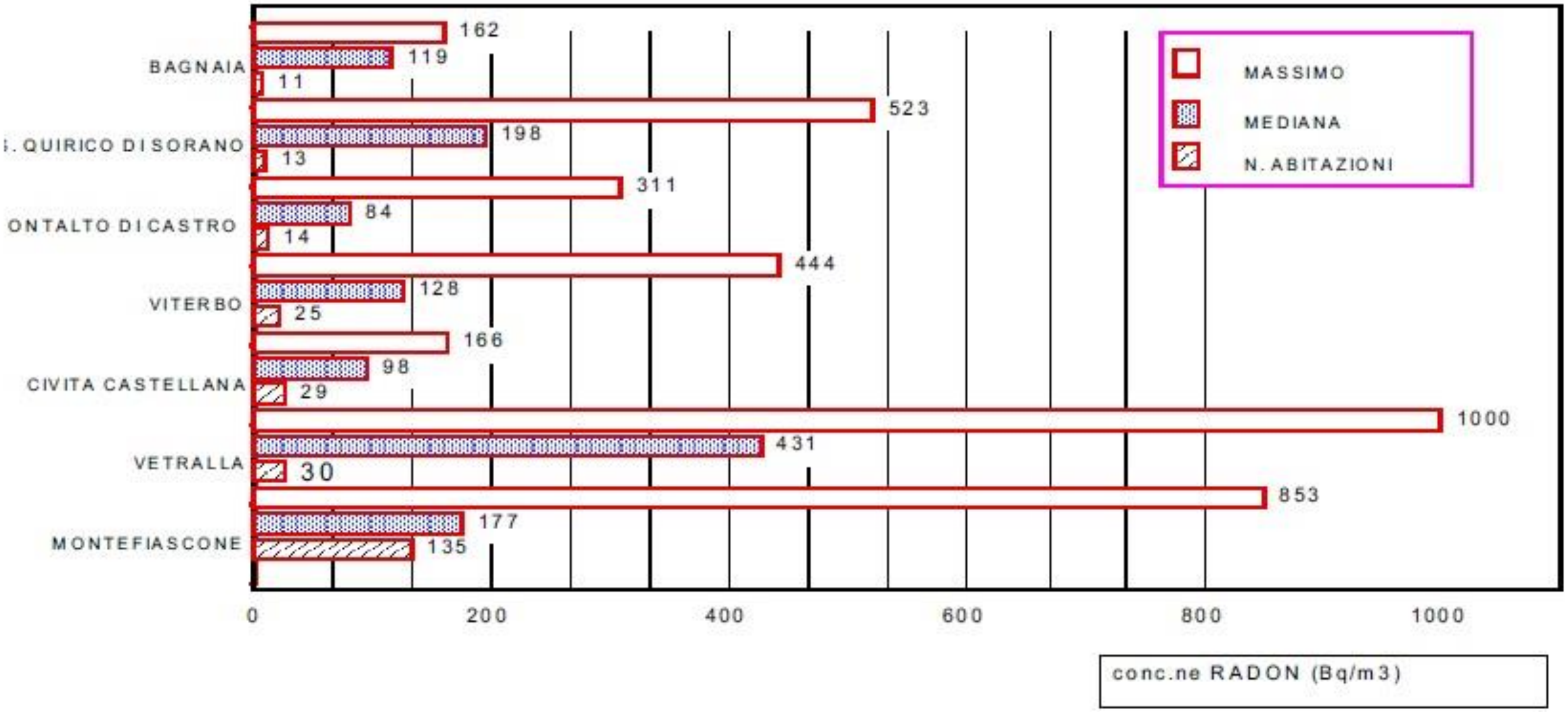
EVERYWHERE

Natural background – Natural radionuclides

Natural background – Natural radionuclides

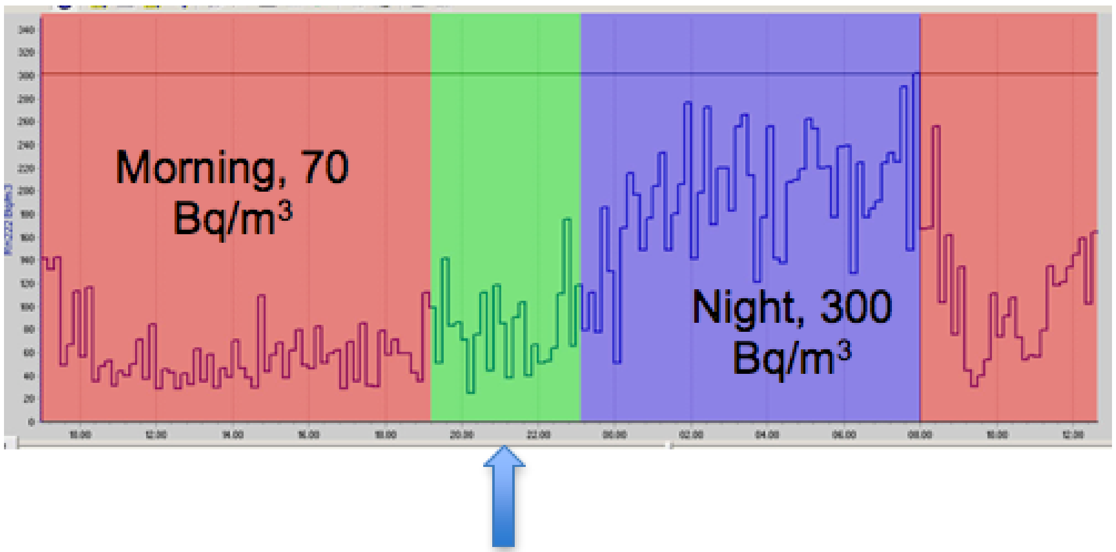
Natural background – radon





Natural background – radon

Source: ENEA

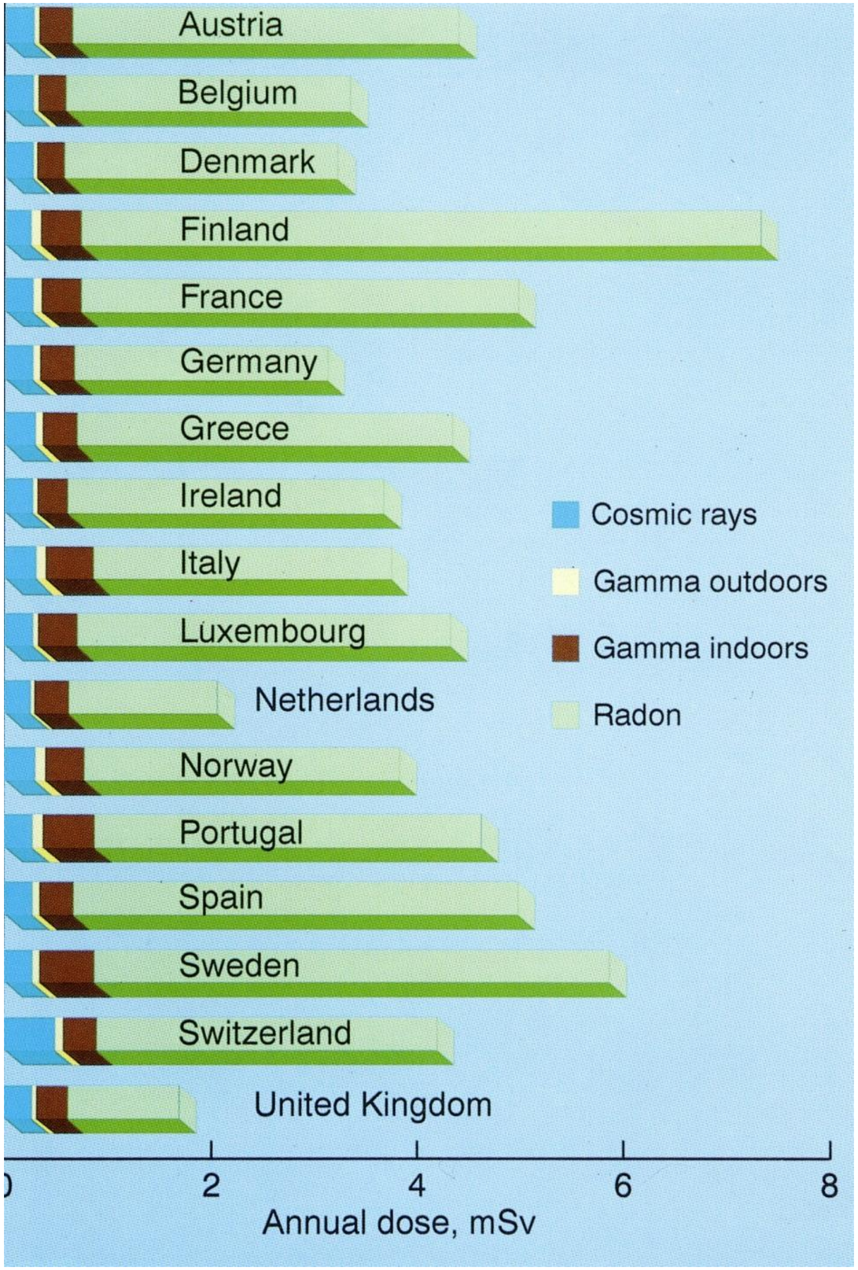


Start-up of heating system

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.

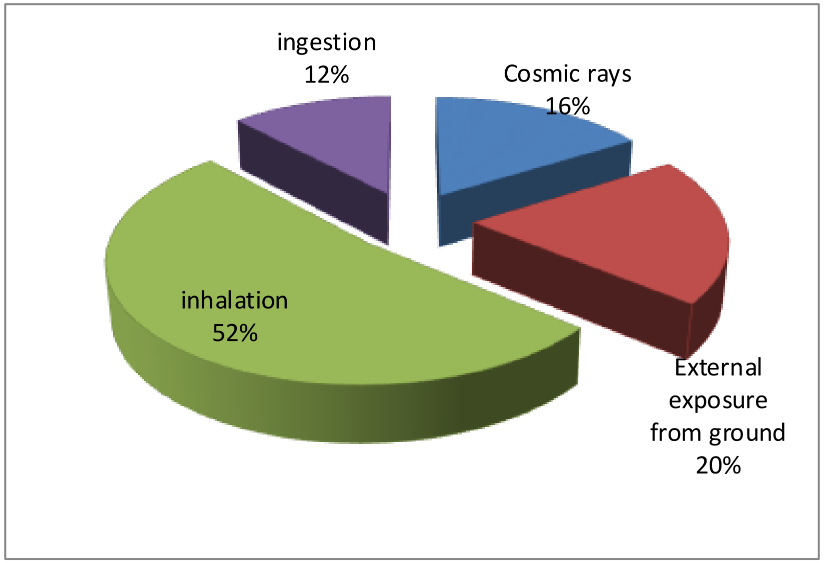
Natural background – radon

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.**

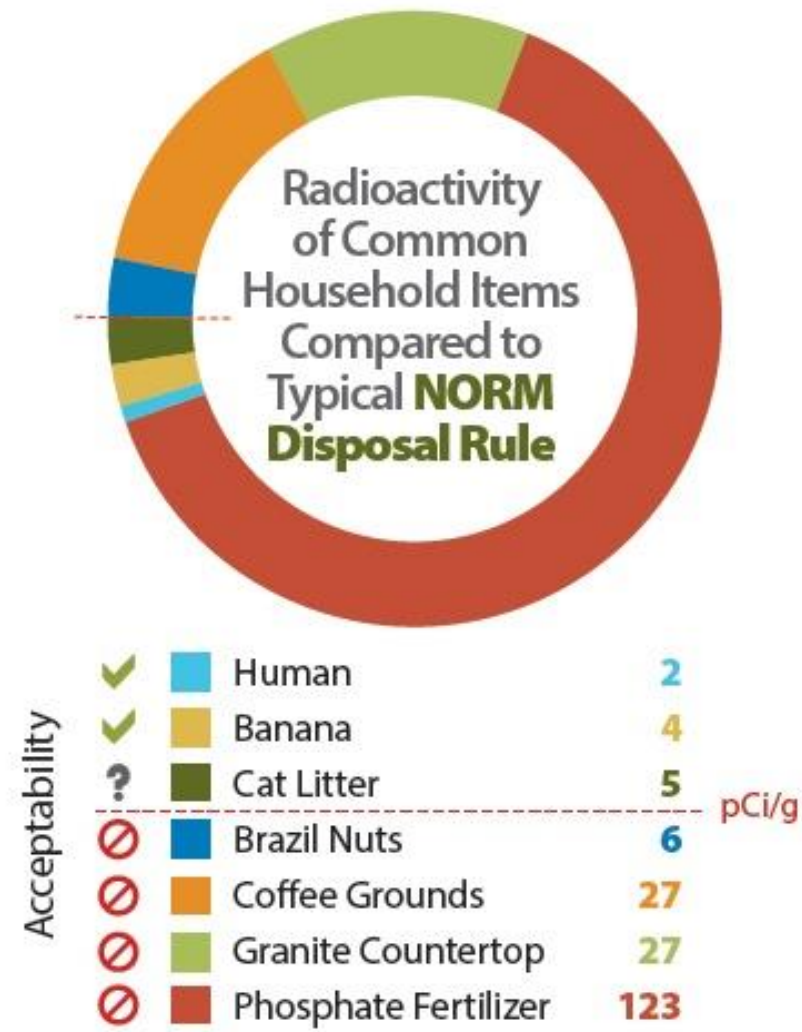
Oil pipe scale

^{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)

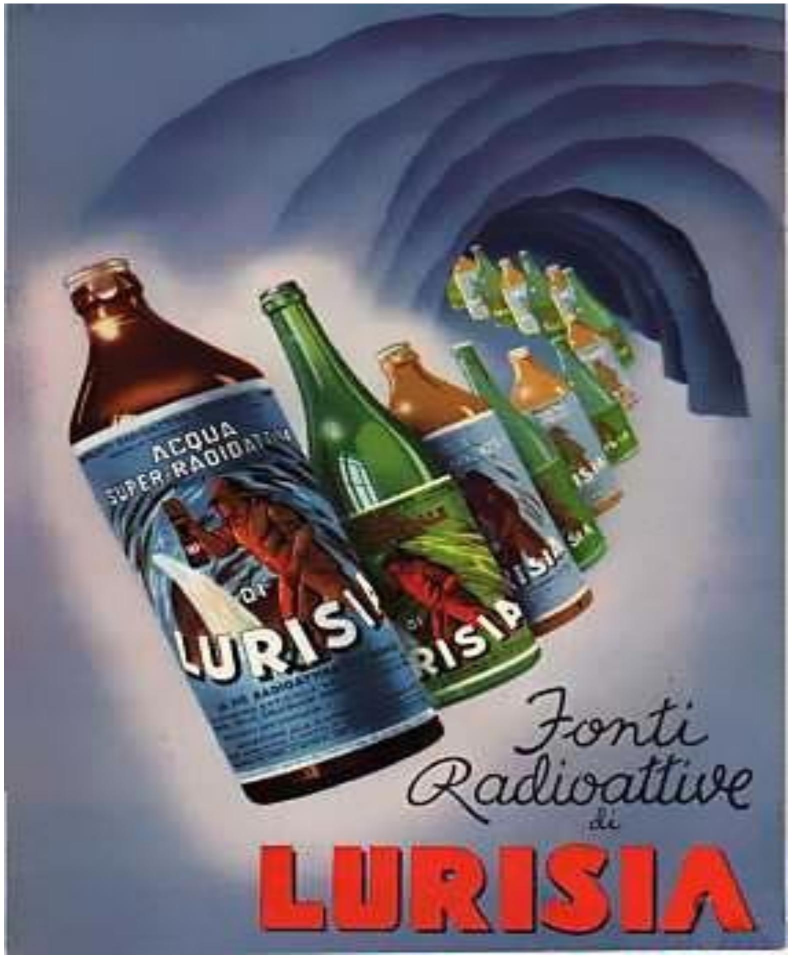
	Uranium series, Ra-226	Thorium series	K-40
Hungary	200-2000	20-300	300-800
USA	100-600	30-300	100-1200
Germany ash	6-166	3-120	125-742
Germany slag	68-245	76-170	337-1240
Australia (U av 0.9 ppm, Th av 2.6 ppm)		Total: 2630	
Australia: NSW		Total: 3200	

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%)
Drexel

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]

Radionuclide	*Lung*	*Liver*	*Kidney*	*Muscle and other tissues*	*Bone*
^{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 ^{14}C atom exists in nature for every 1,000,000,000,000 ^{12}C 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 ^{14}C 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.

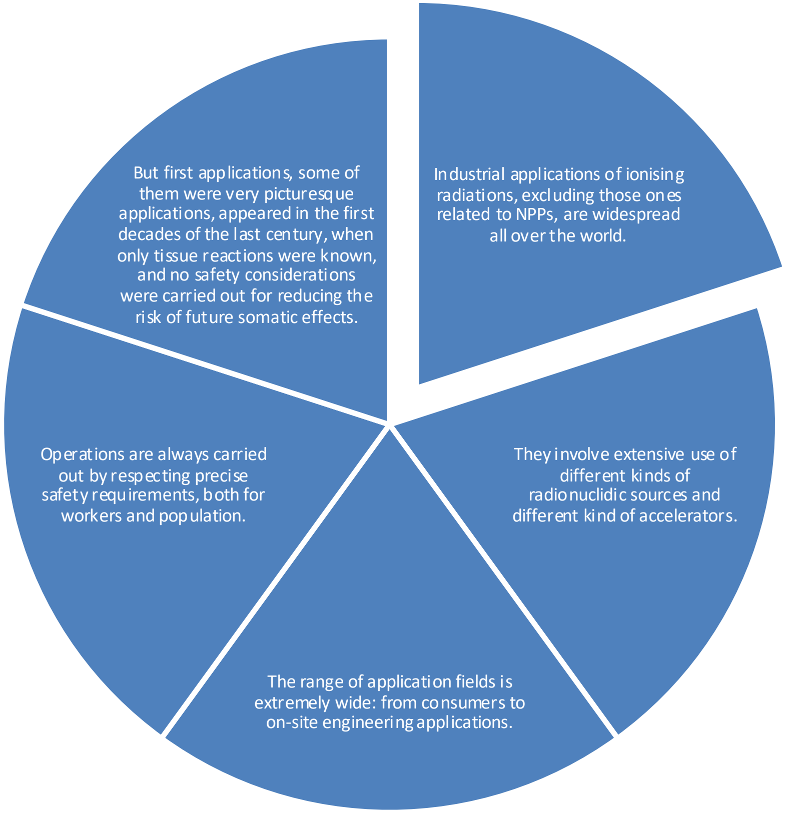
NTBT: Nuclear Test Ban Treaty

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

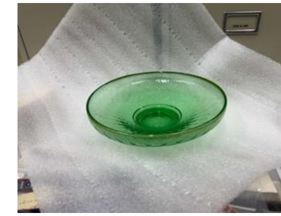
Table 35. Latitudinal distribution of radionuclides from atmospheric nuclear tests based on ^{90}Sr measurements [U3]

Latitude band (°)	*Population distribution (%)*	*Integrated deposition of ^{90}Sr (PBq)*	*Deposition in band (%)*	*Deposition density per unit deposition ((Bq/m²)/PBq)*	*Latitudinal value relative to hemispheric value*
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

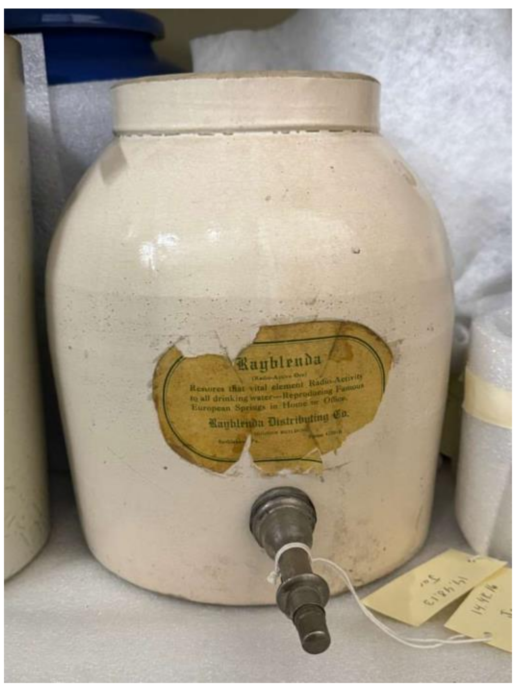


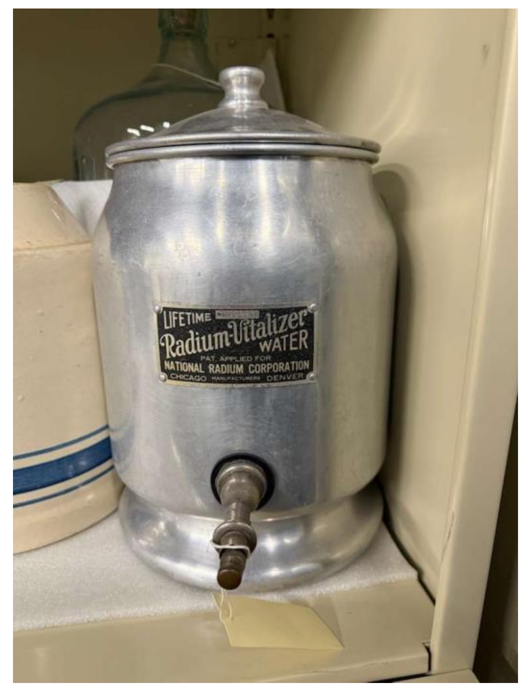
Past applications (cont.)



- 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

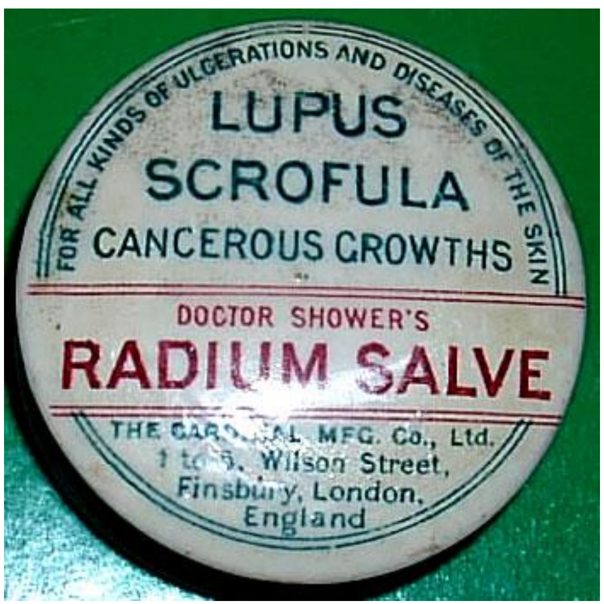
Radium Jars
Late '20s, early '30s of the last century. To be used as a tonic for the health.



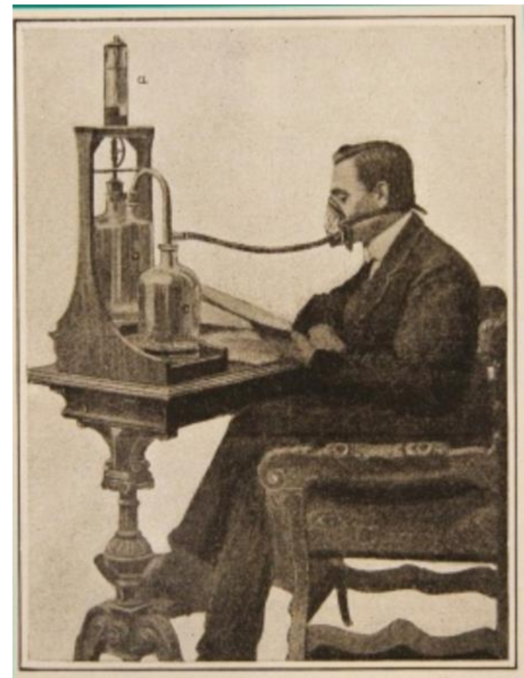


Past applications (cont.)

It seemed that radioactivity could cure every deseases



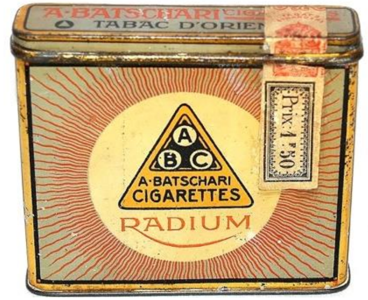
Past applications (cont.)



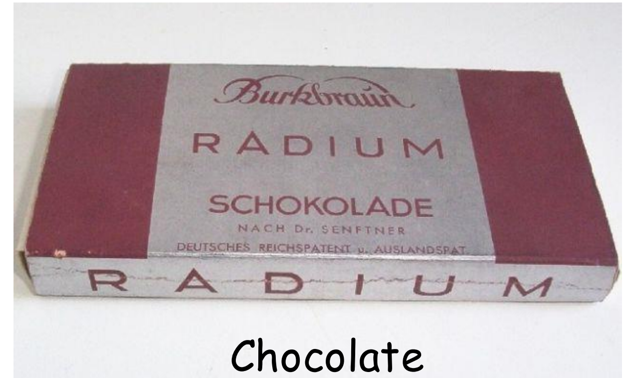
Radon generator for inhalations. Now we consider radon as an existing exposure situation which is the second cause of lung cancer; the first cause is cigarettes smoking.

Past applications (cont.)

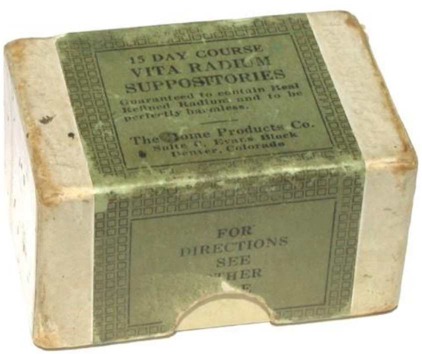
Radioactive condoms

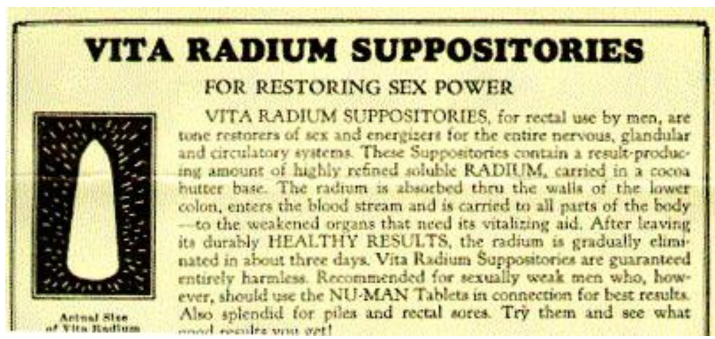


Cigarettes



Chocolate





VITA RADIUM SUPPOSITORIES

FOR RESTORING SEX POWER

VITA RADIUM SUPPOSITORIES, for rectal use by men, are tone restorers of sex and energizers for the entire nervous, glandular and circulatory systems. These Suppositories contain a result-producing amount of highly refined soluble RADIUM, carried in a cocoa butter base. The radium is absorbed thru the walls of the lower colon, enters the blood stream and is carried to all parts of the body—to the weakened organs that need its vitalizing aid. After leaving its durably HEALTHY RESULTS, the radium is gradually eliminated in about three days. Vita Radium Suppositories are guaranteed entirely harmless. Recommended for sexually weak men who, however, should use the NU-MAN Tablets in connection for best results. Also splendid for piles and rectal sores. Try them and see what good results you get!

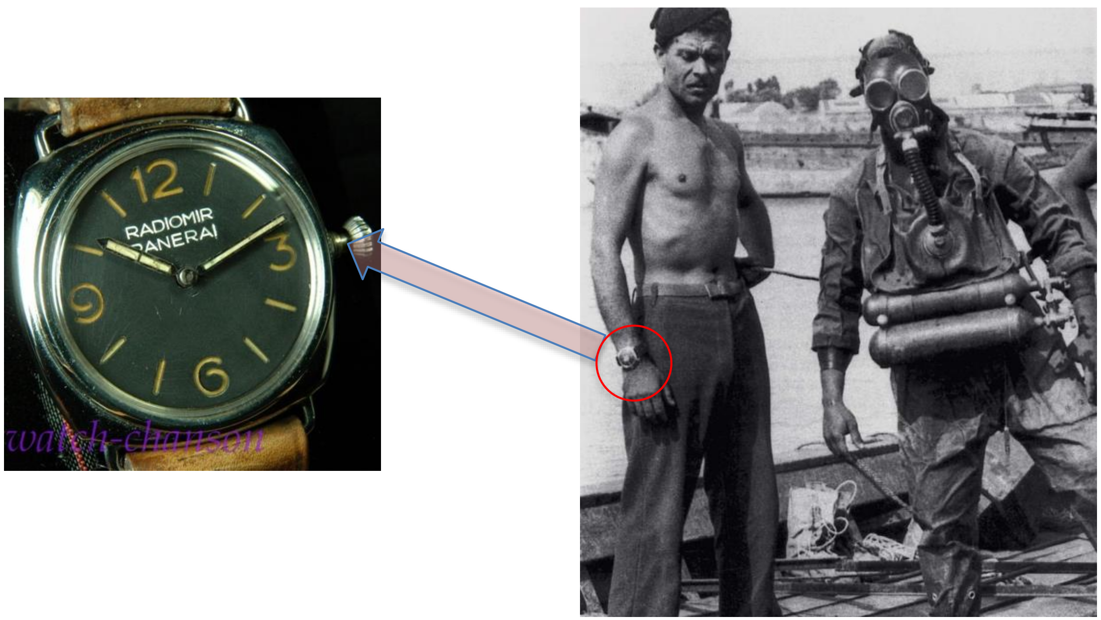
Actual Size of Vita Radium

Suppositories for restoring sex power and for curing haemorrhoids

Some applications were extremely picturesque!

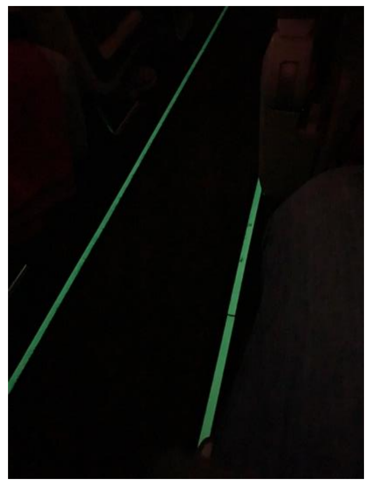
Past applications (cont.)

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.

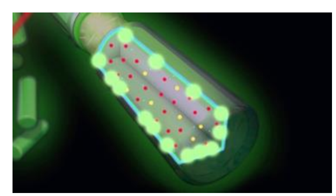


Current applications

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.

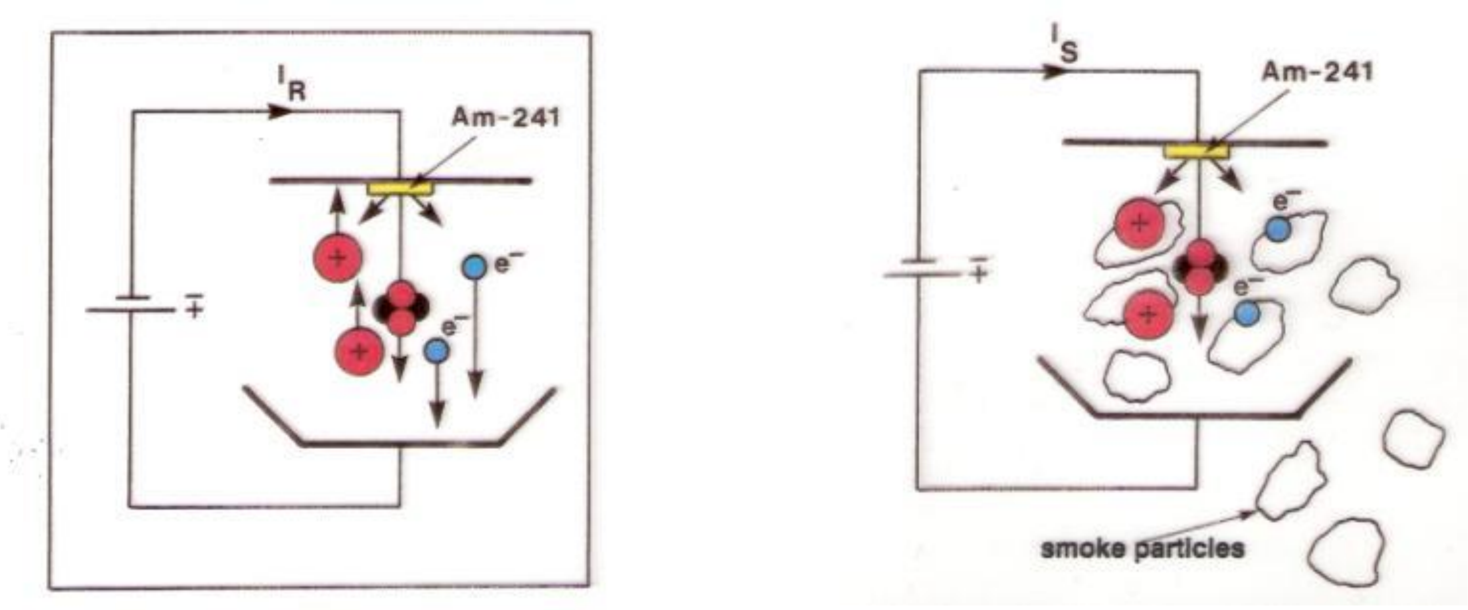


Safety signals tritium painted



Modern watches with sealed tritium gas tubes

Alpha techniques

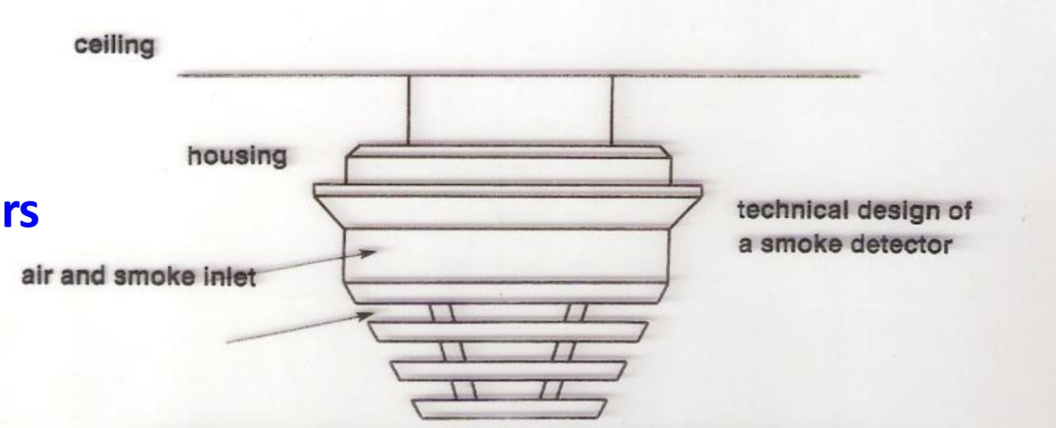


Smoke detectors

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

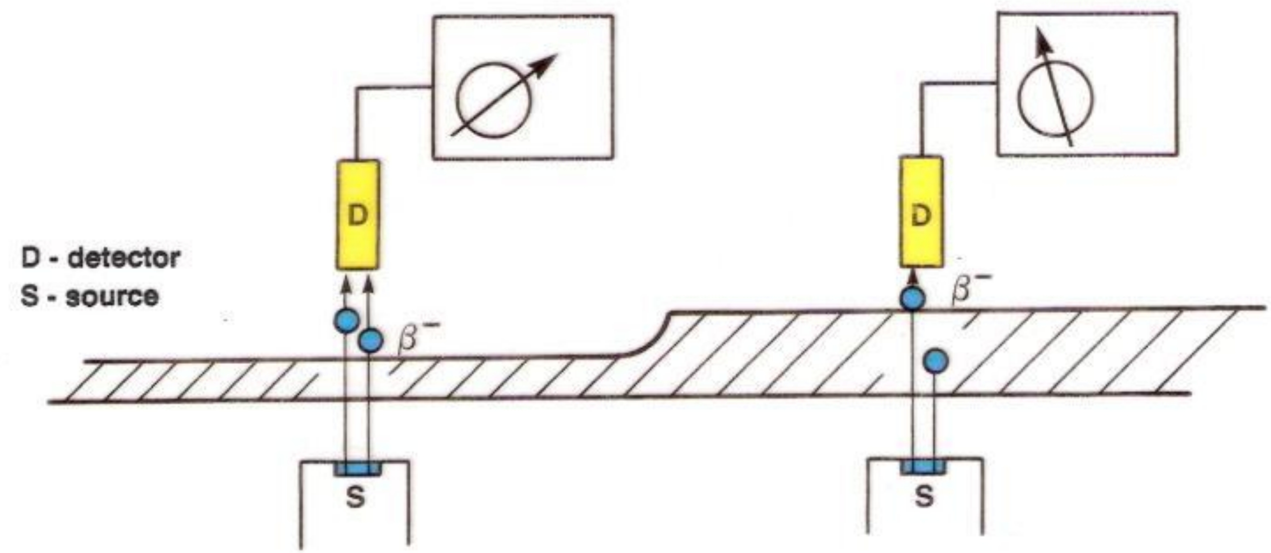
Alpha techniques (cont.)

Typical design of smoke detectors



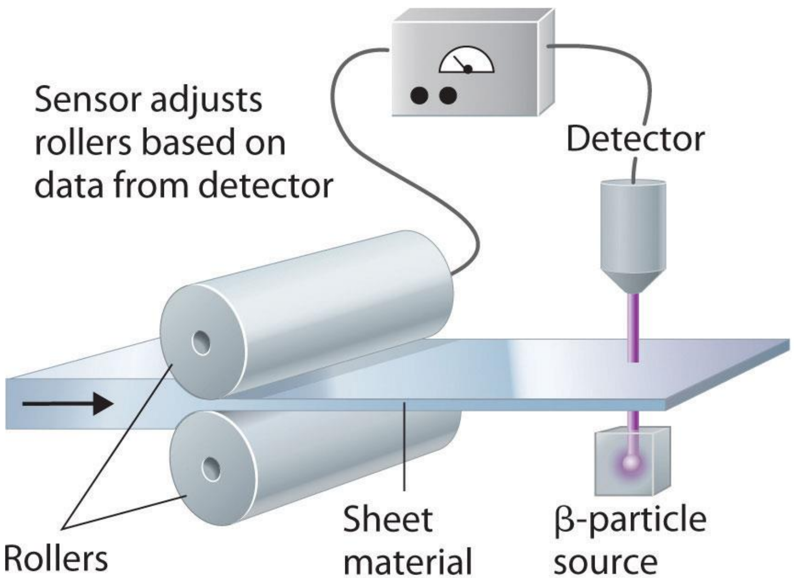
Americium-241 sources

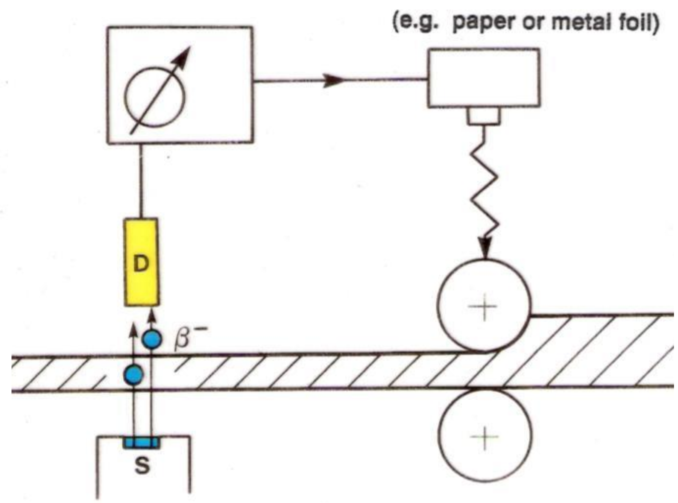
Beta techniques



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.

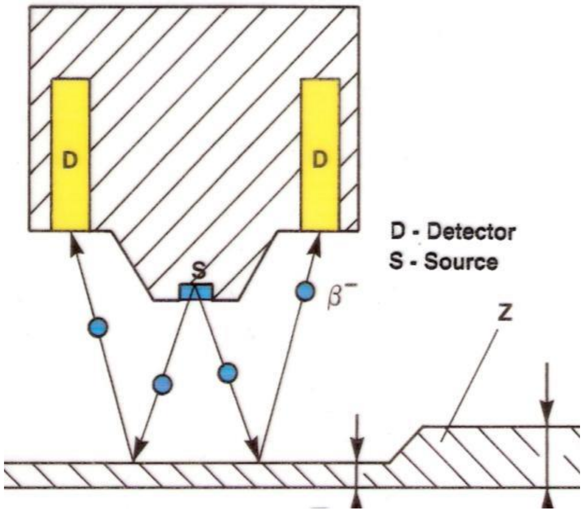
Beta techniques (cont.)

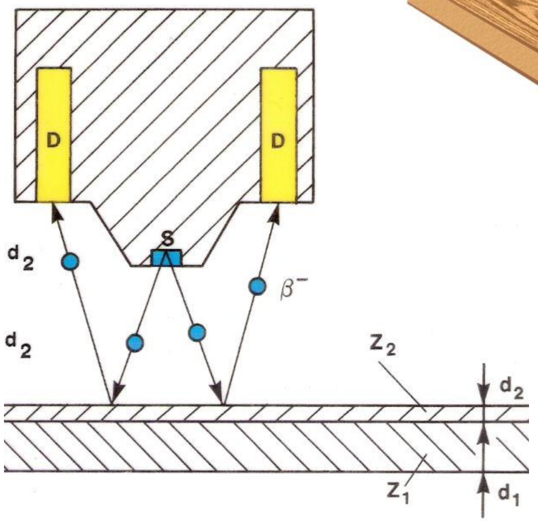




Real time control of paper thickness.

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

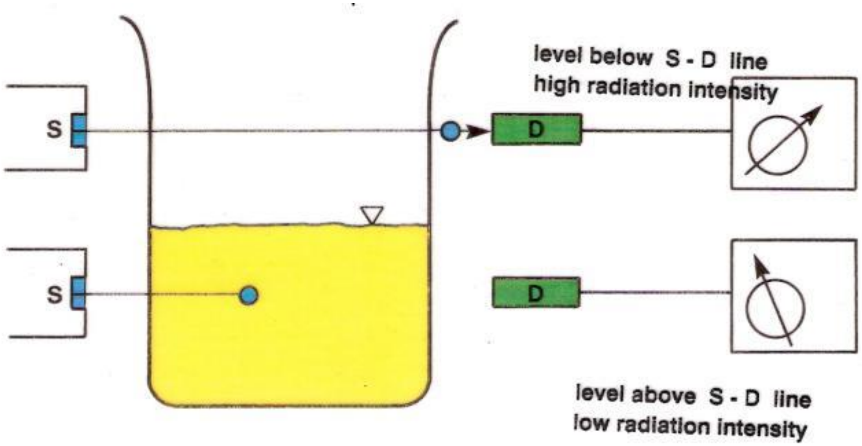


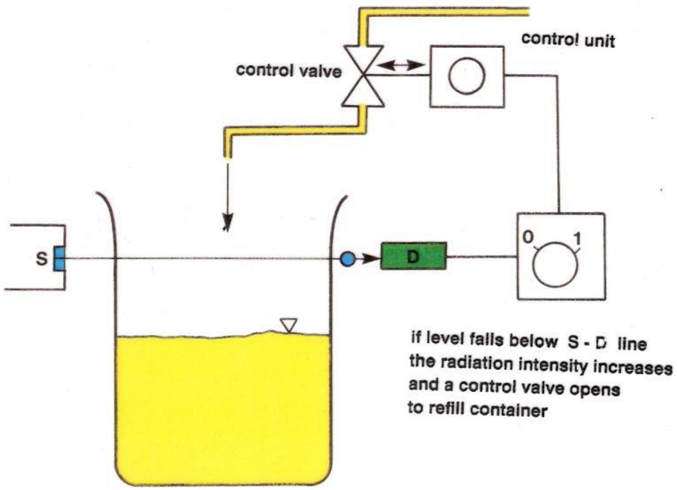


Measurement of coatings, e.g. for production of veneered panels.

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

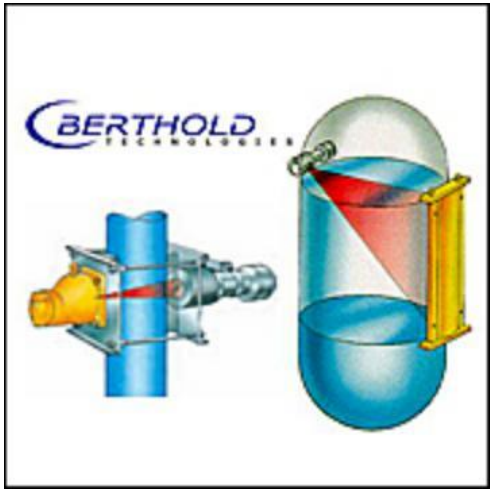
Gamma techniques



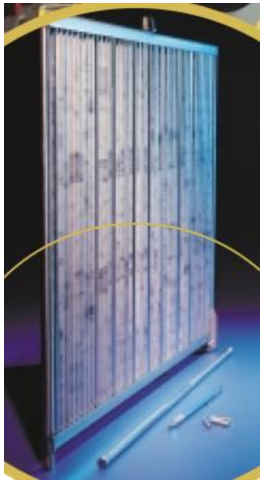


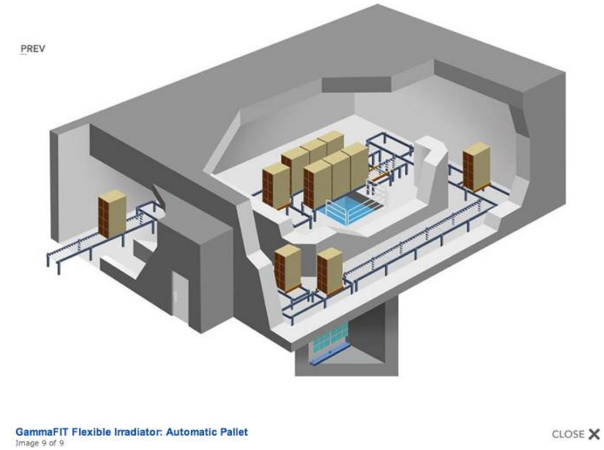
Gamma level gauge

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)





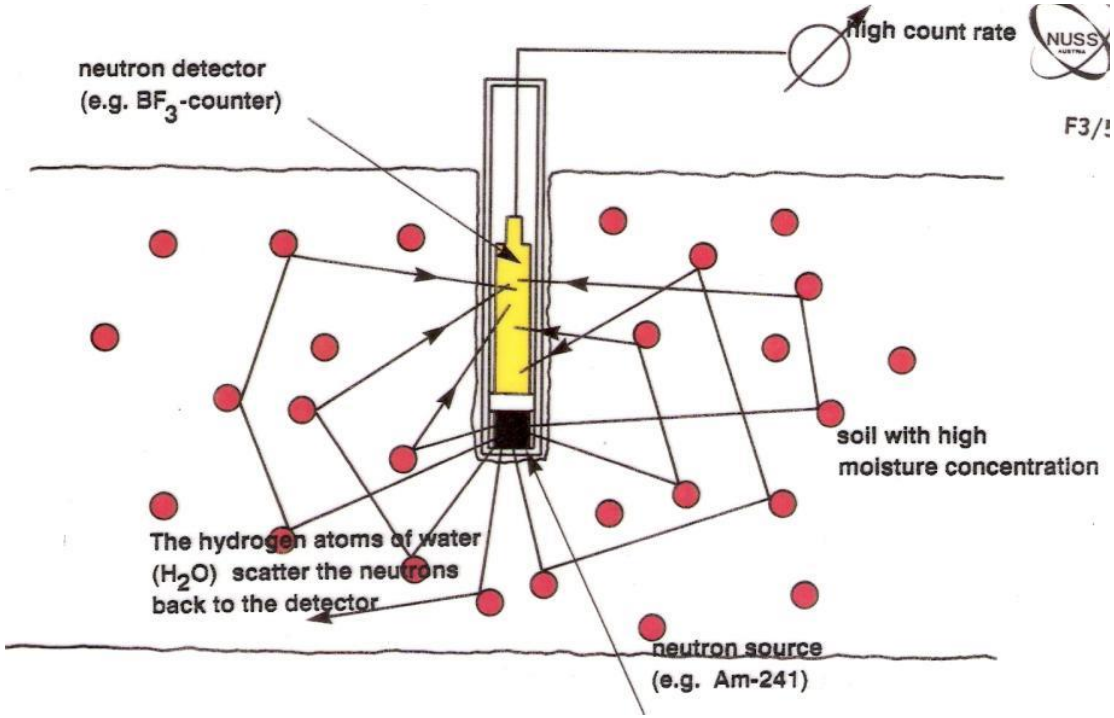
Sterilization plants
For sterilizing medical materials, or foodstuffs.

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

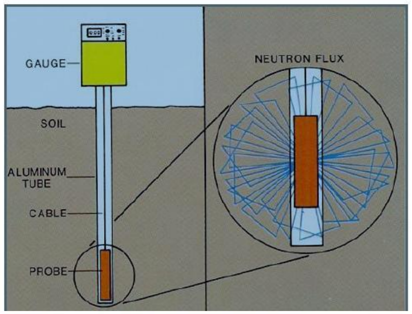
Several modern radiation accidents occurred in such kind of plants. Particular care is needed for management

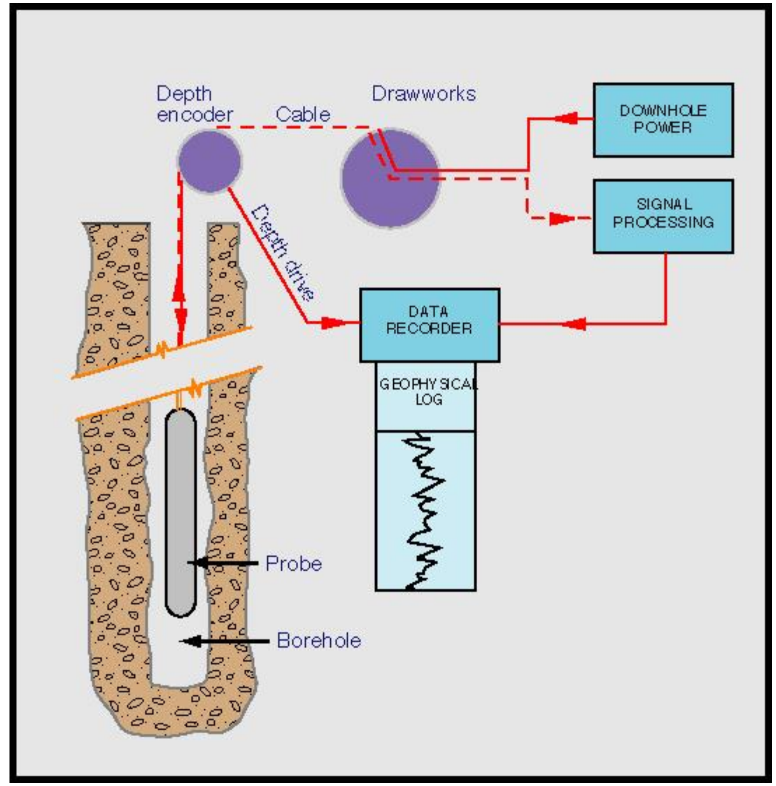
Neutron techniques



Borehole logging for oilfields detection

Neutron techniques (cont.)

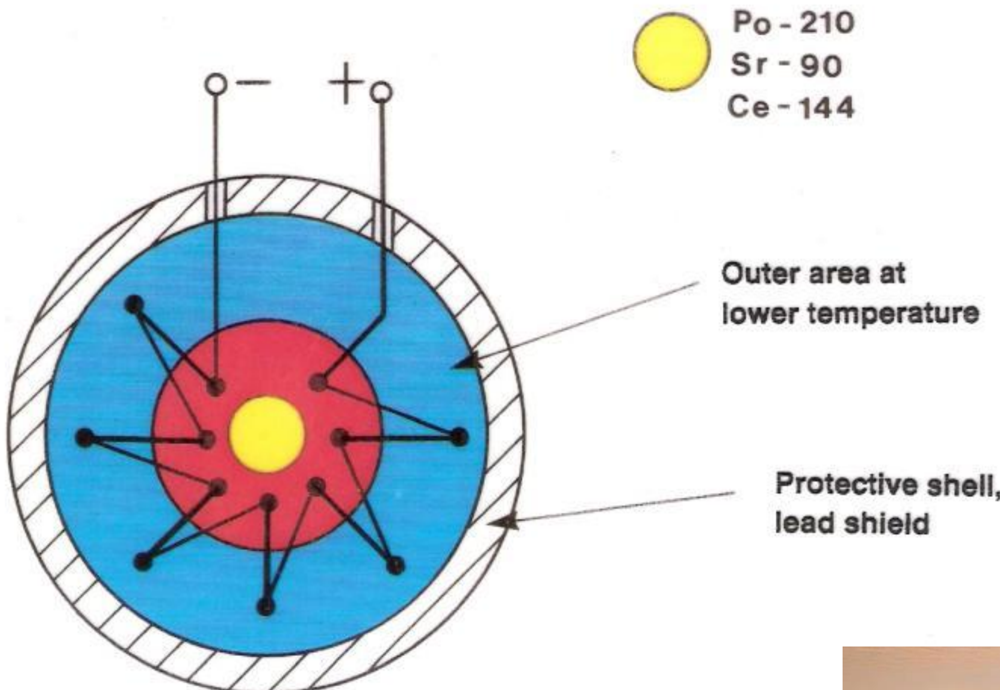


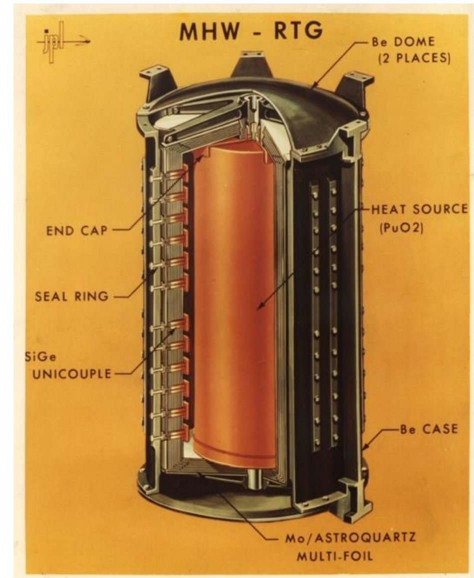


Sometimes dismissed devices are erroneously considered as metal scrapes to be recycled. When melted, the americium-beryllium neutron source can be very harmful.

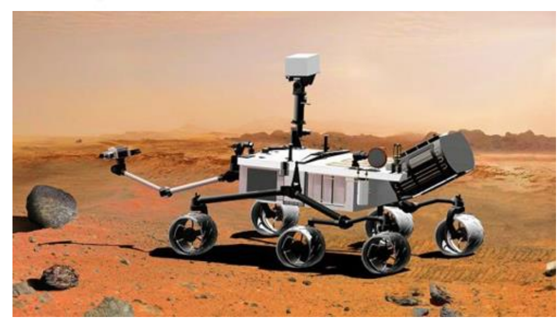
Other applications

Thermoelectric generators





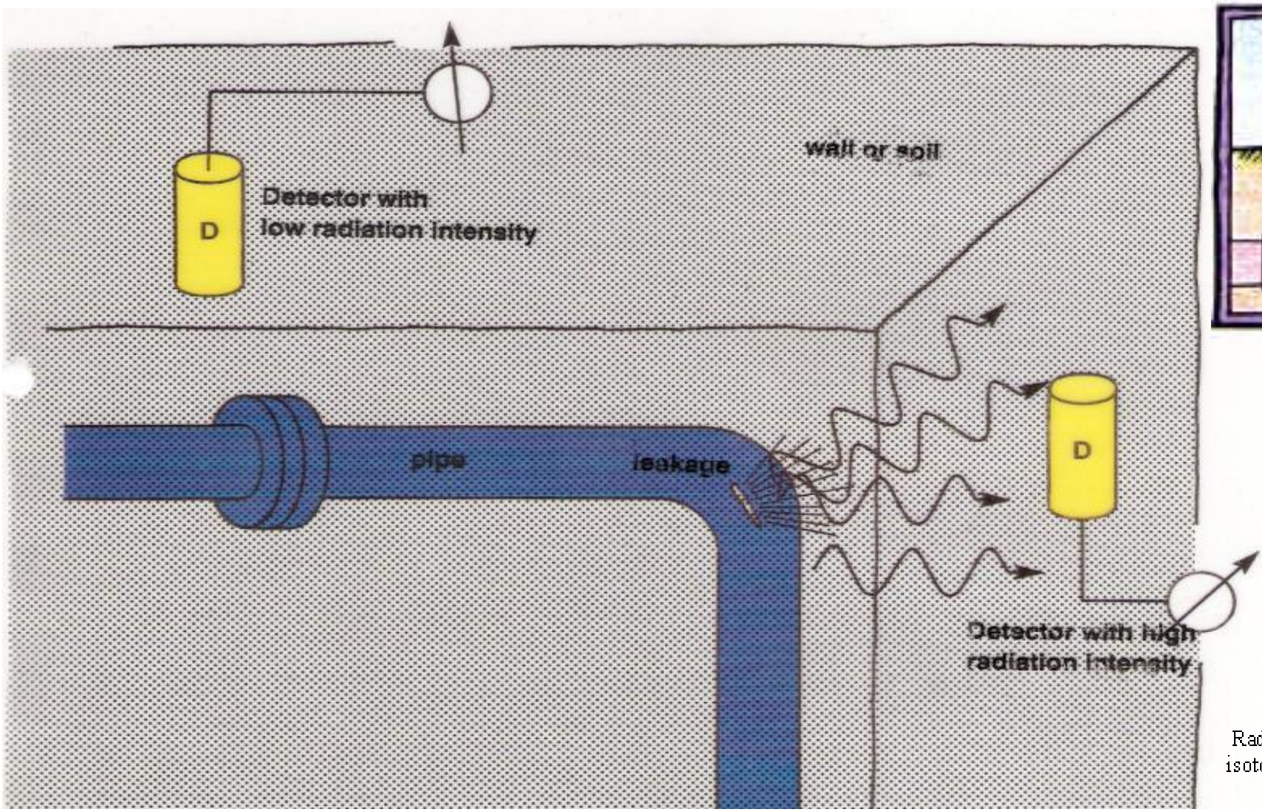
The inner red area is heated by the absorption of radiation, the blue area is at lower temperature.
A serie of thermocouples produce a voltage of several mW.

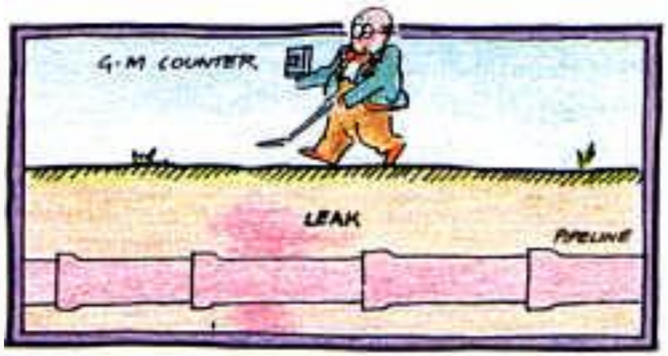


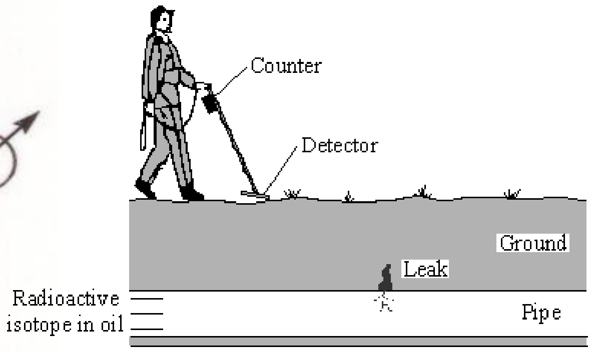
Advantages : Completely free from maintenance

Other applications (cont.)

Radioactive tracers





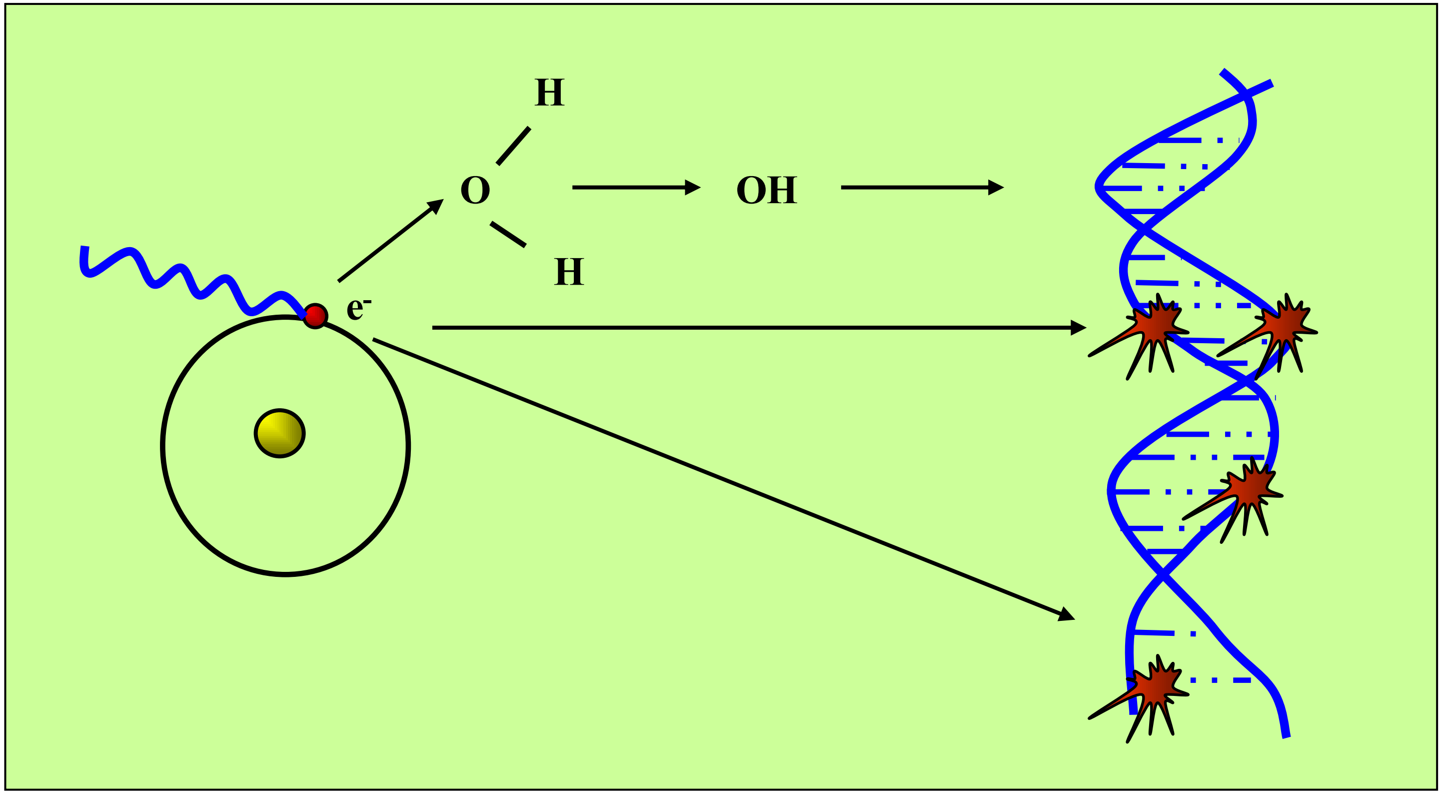


Radioactive lightning rods

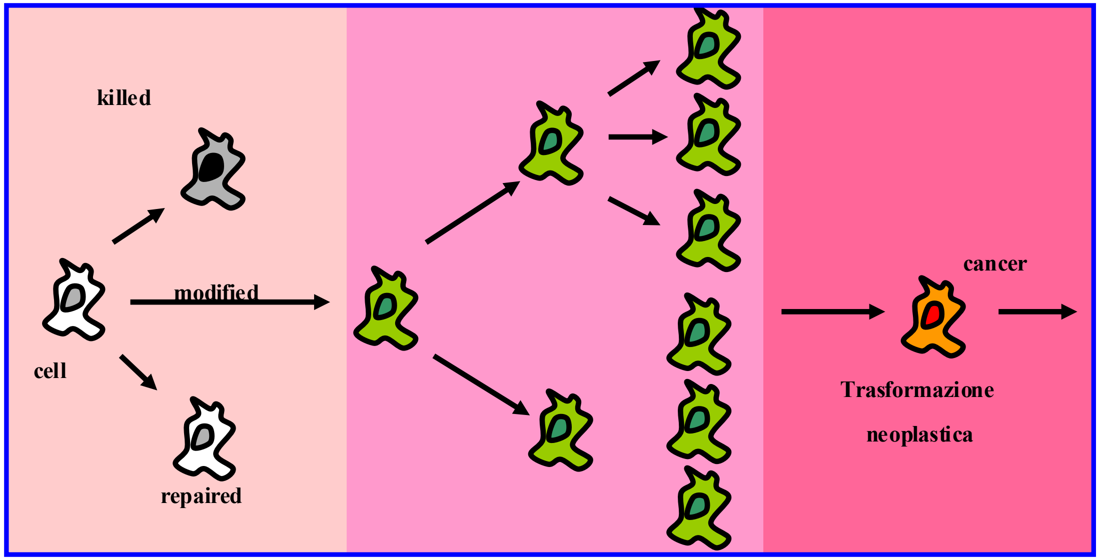
- radium-226 , americium-241
- From 25 to 90 MBq

Interaction with DNA

DNA Damage

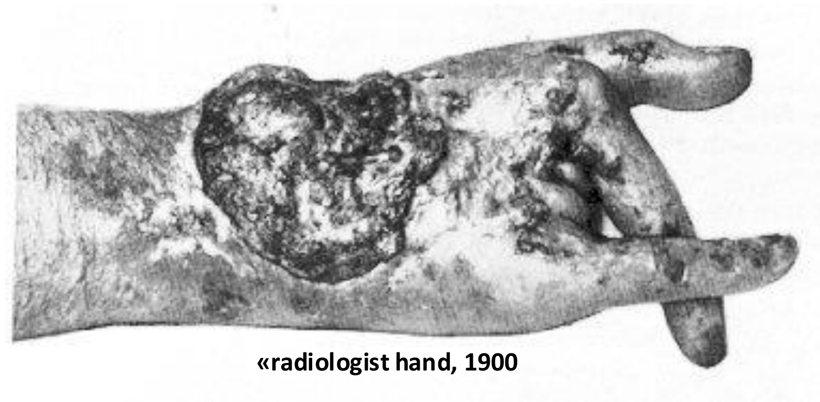


- Cells may be killed or damaged:
- High number of killed cells of the same biological tissue: Tissue Reactions
- Modified cells: Stochastic risk (chance of future cancer)
-



Tissue reactions (very very high doses of radiation – thenths 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 2^{nd} to the 6^{th} 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° to the 15^{th} 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 4^{th} – 5^{th} 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 Thyroyd cancers expected in 50 years
- About 6 10^3 after 30 years have been accounted for
- 15 cases caused the dead 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 Gy = 1 J kg^{-1}

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

$$D = \lim_{m \to 0} \frac{\bar{\varepsilon}}{m} \qquad\qquad D = \lim_{V \to 0} \frac{1}{\rho} \frac{\bar{\varepsilon}}{V}$$

Absorbed dose rate is the derivative of D vs. time

$$\dot{D} = \frac{dD}{dt} \qquad (Gy\, s^{-1})$$

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

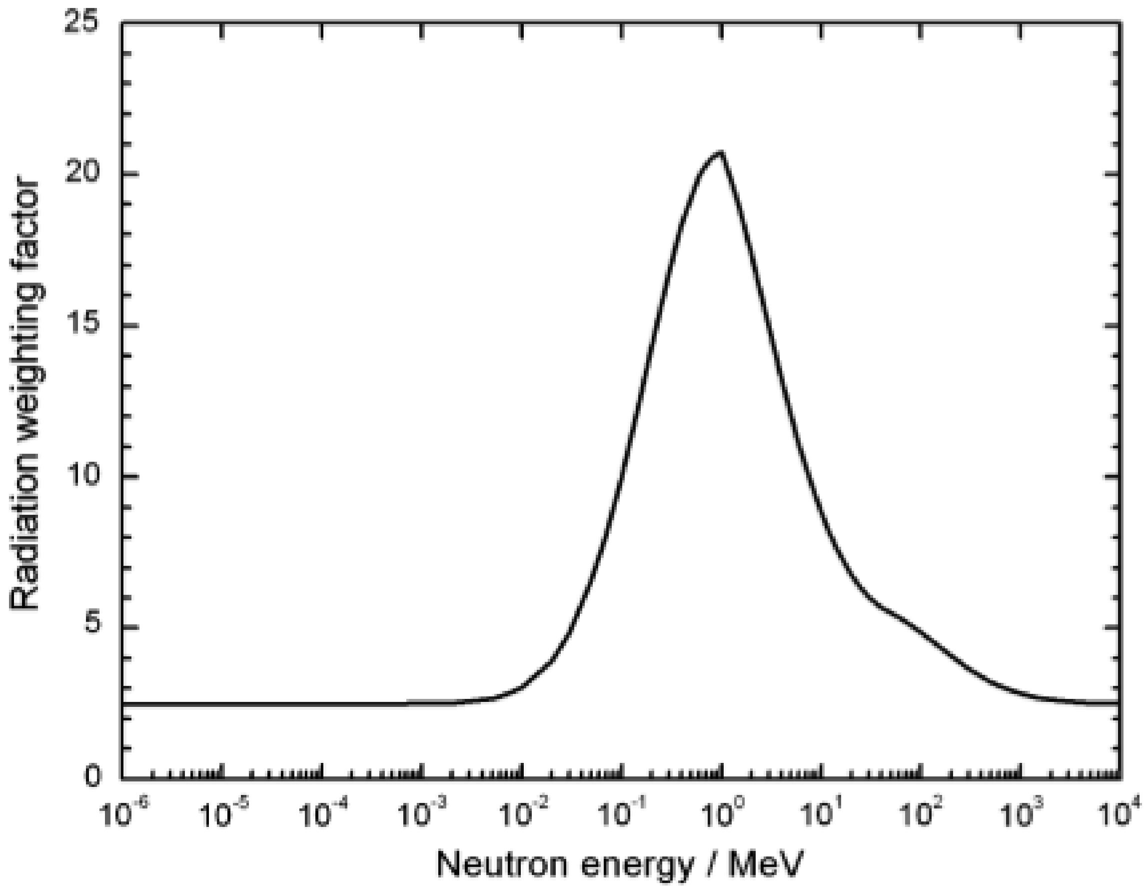


Fig. 1. Radiation weighting factor, w_R, for neutrons versus neutron energy.

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

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

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 lynfatic-hemapoietic (leukemia) and solid tumours are initiated by damaged cells that are propagated incorrectly .

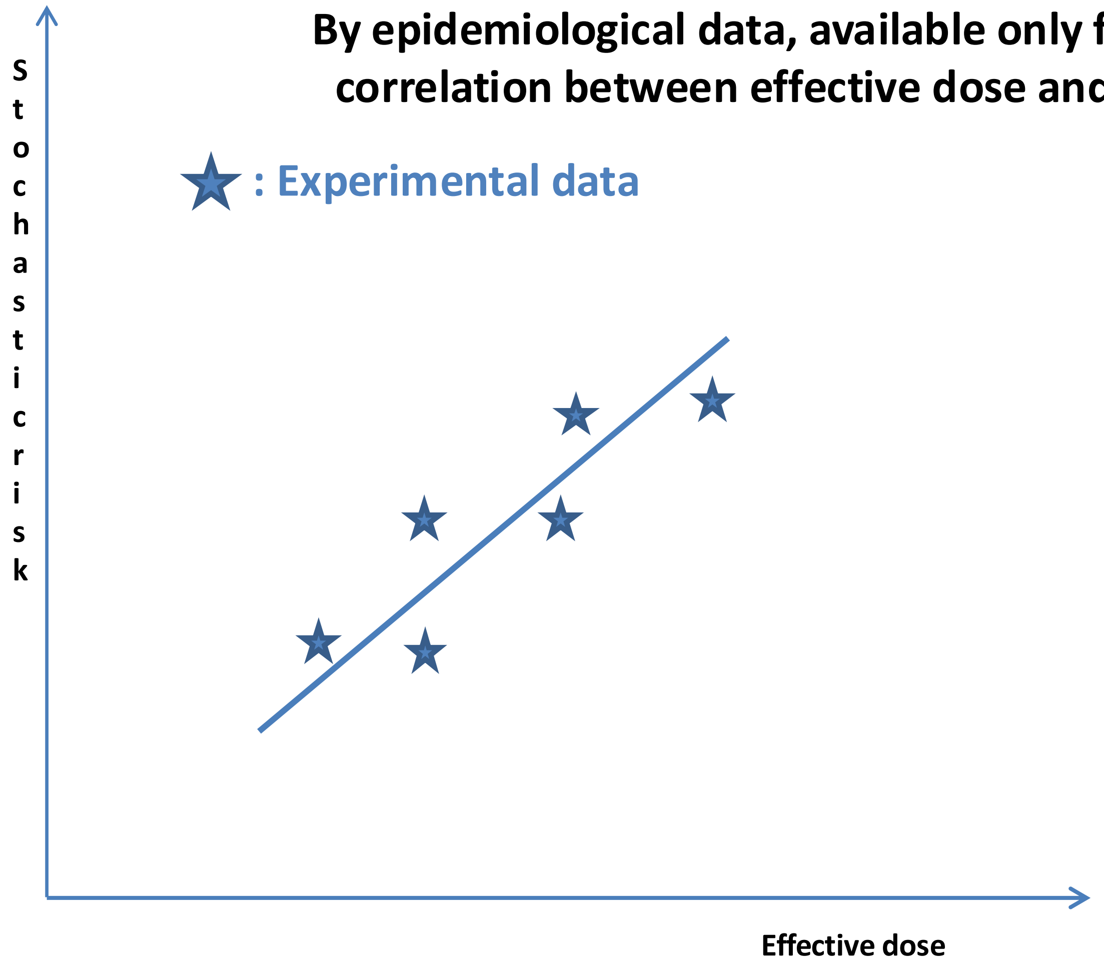
The ionizing radiation can promote development but not the growth, of carcinogenesis

Very often the cellular damage are resolved by cell repair mechanisms

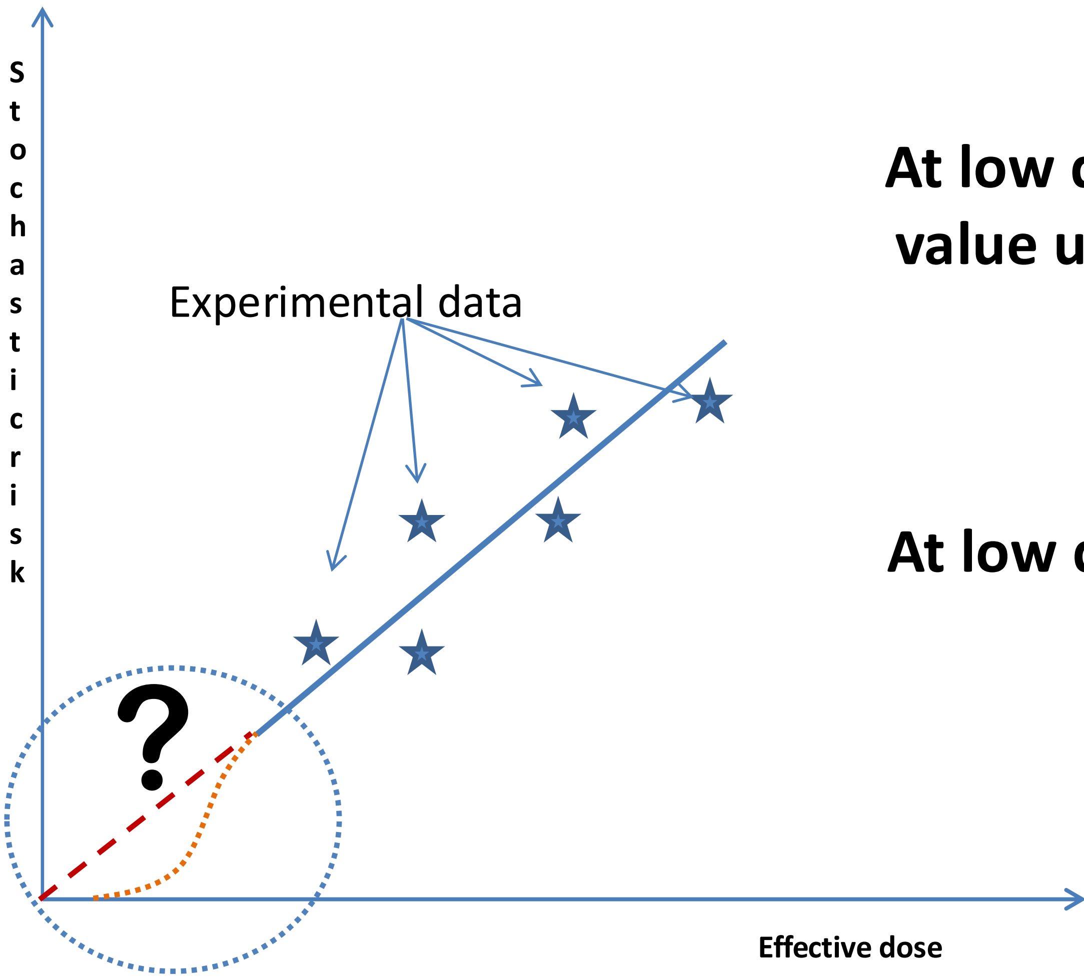
Carcinogenesis and hereditary effects

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)

By epidemiological data, available only for high doses, correlation between effective dose and risk is linear



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]	*Publ. 60*	Present[1]	*Publ. 60*	Present[1]	*Publ. 60*
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.

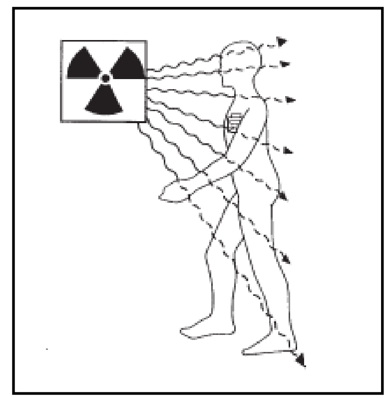
External irradiation

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

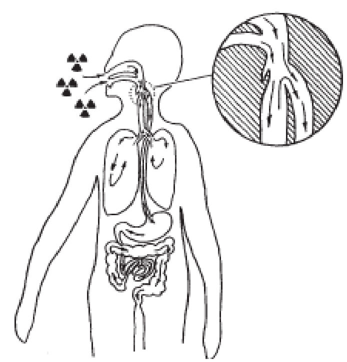
- Internal irradiation is due to radionuclides intake: inhalation of natural or artificial radionuclides, environmental contamination, nuclear medicine applications, etc.
- External irradiation is due to sources placed outside human body, e.g. and X-ray tube, a gamma source, etc…

Irradiation

- **external**



- **internal**

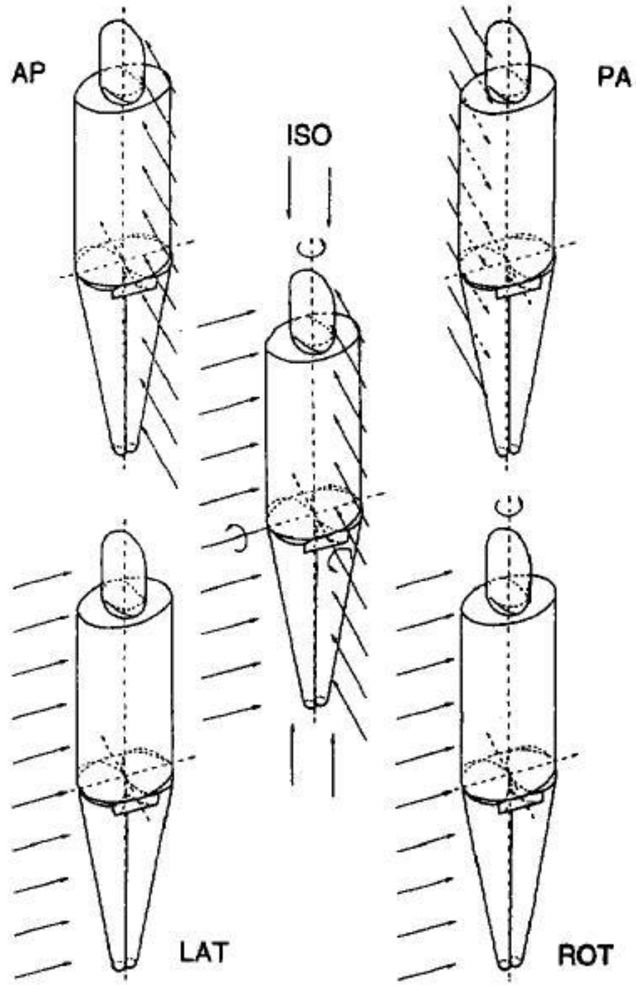


Radiation type	Energy	Position of dose equivalent maximum
beta and electrons	≤ 4 MeV	Within the first centimetre of soft tissue
	〉4 MeV	Greater and greater depths. For some GeV the depth is larger than 30 cm (average thickness of human body)
gamma	〈 1 MeV	Under germinative layer
	1 MeV 〈 E 〈 2 MeV	About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

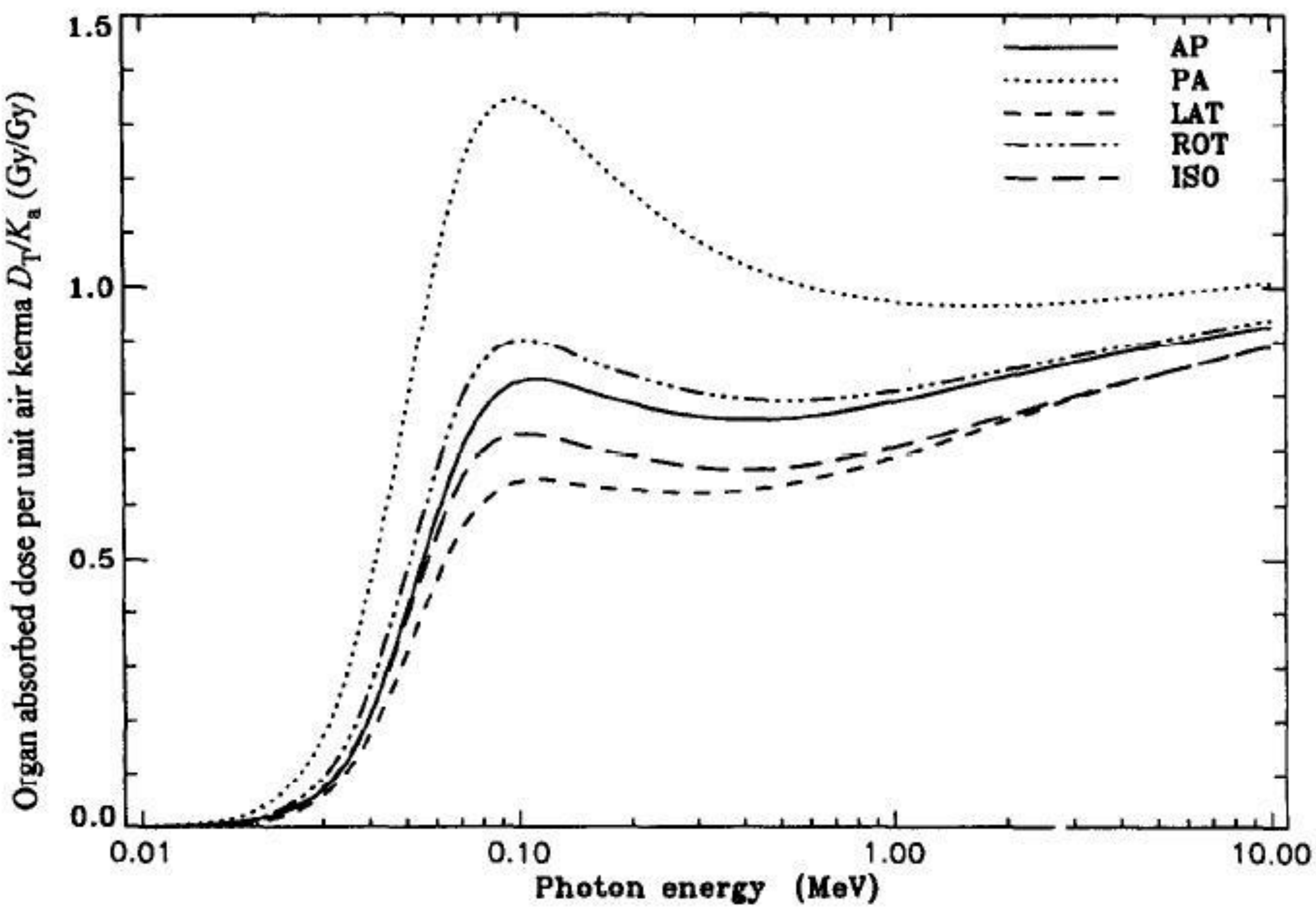
Average depth of some organs (measured from cutaneous surface)



AP: Antero-Posterior
PA: Postero-Anterior
LAT: Lateral
ROT: Rotazional
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

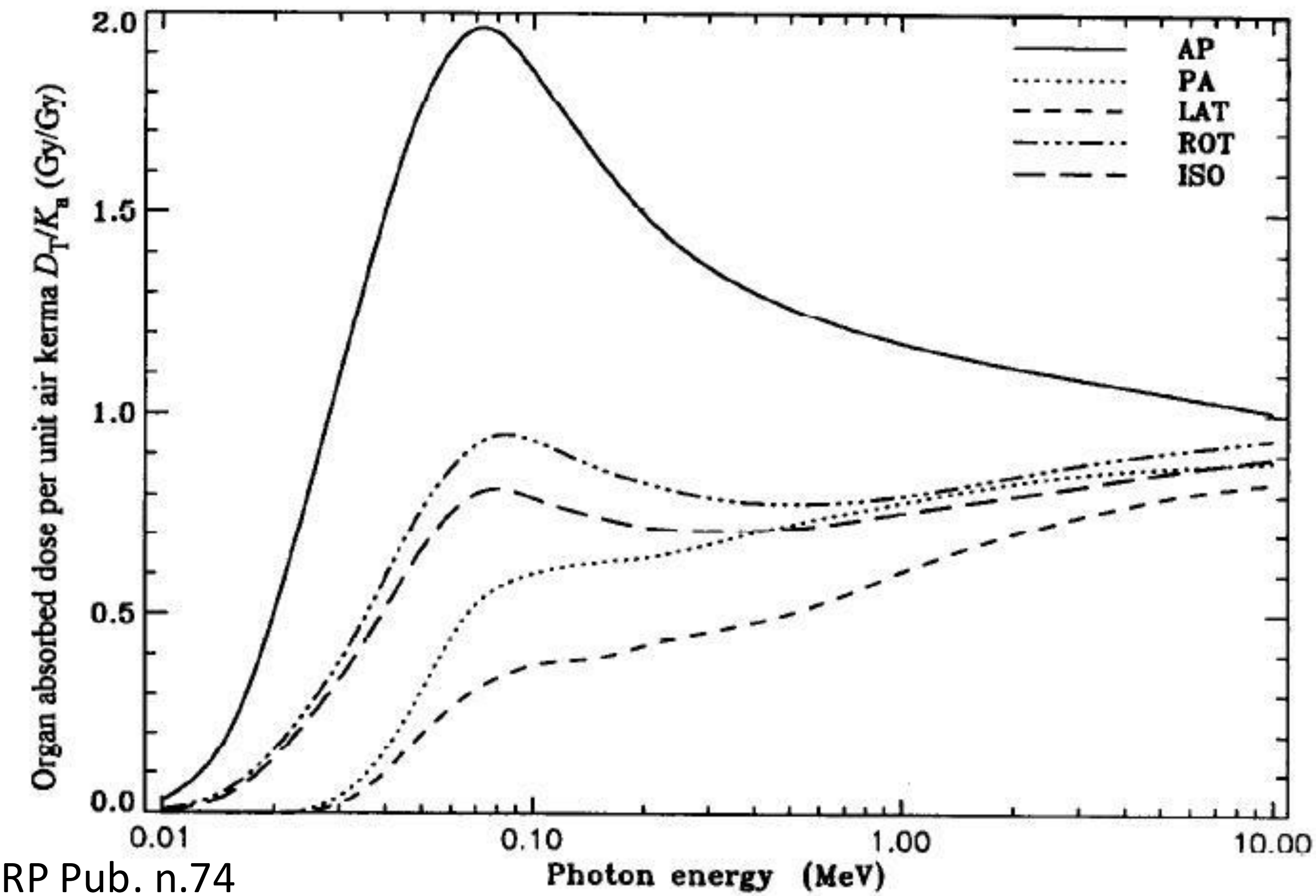


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Fig. A.7. Gonads, male (testes) absorbed dose per unit air kerma free-in-air.

External irradiation - photons

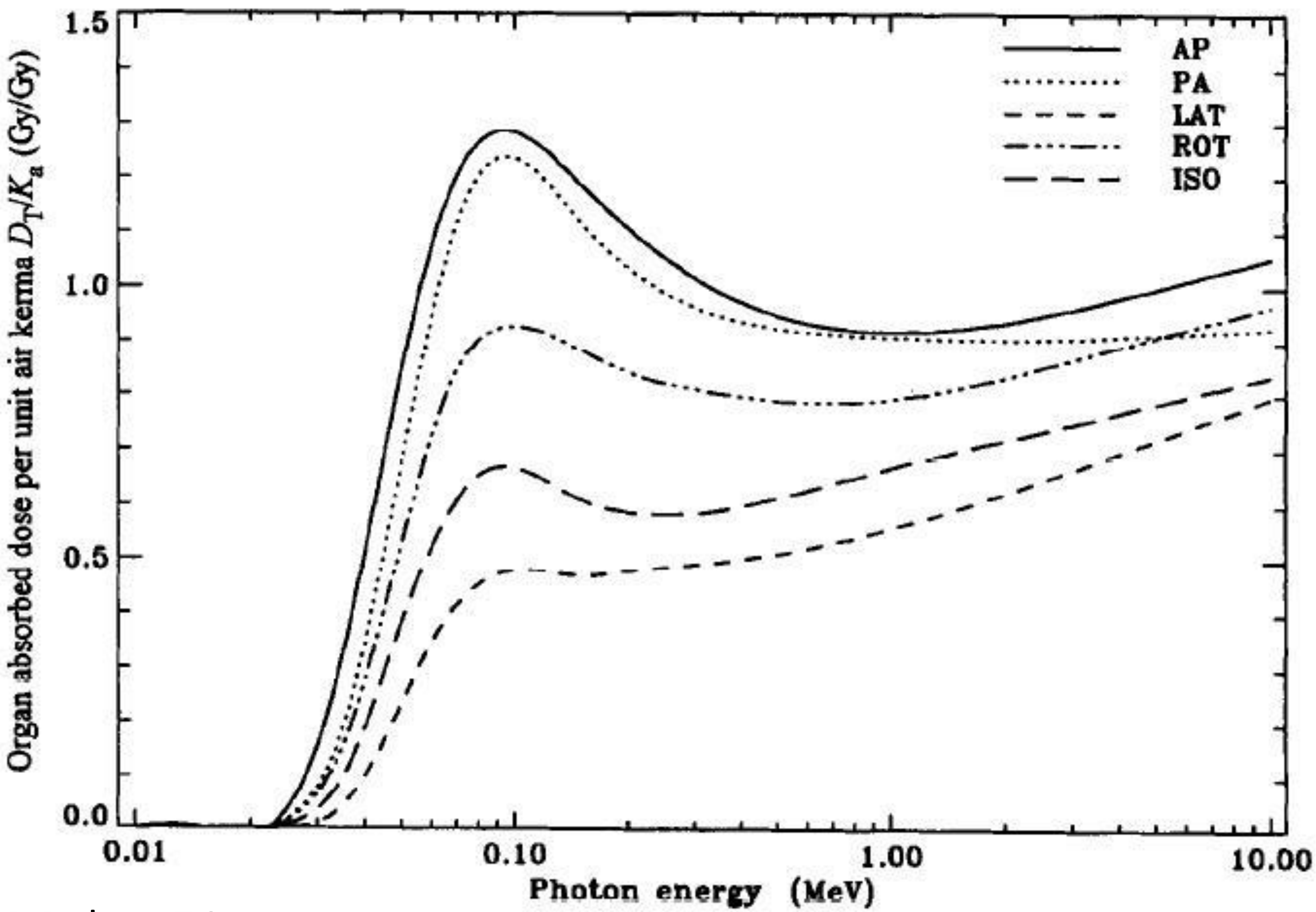

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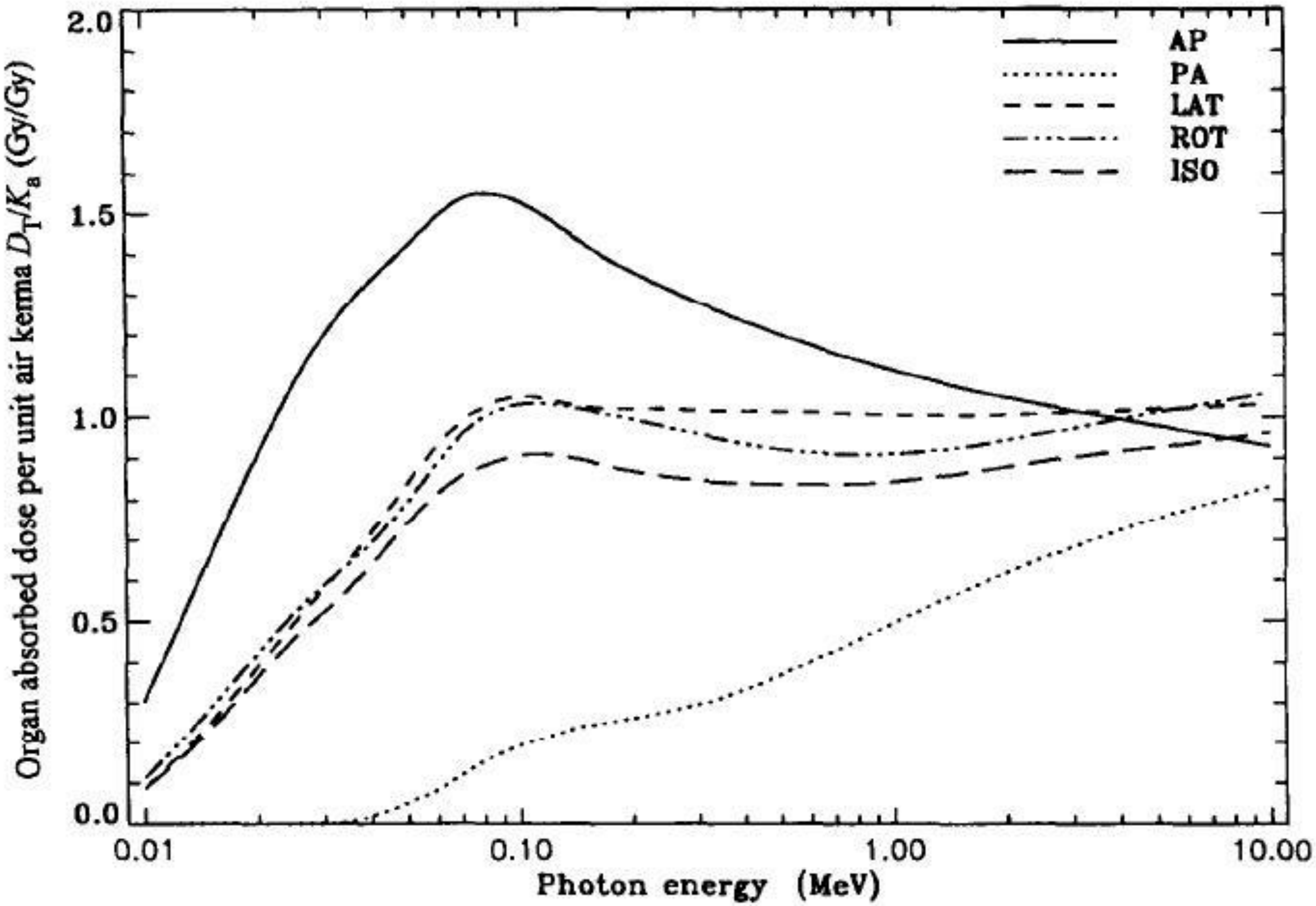
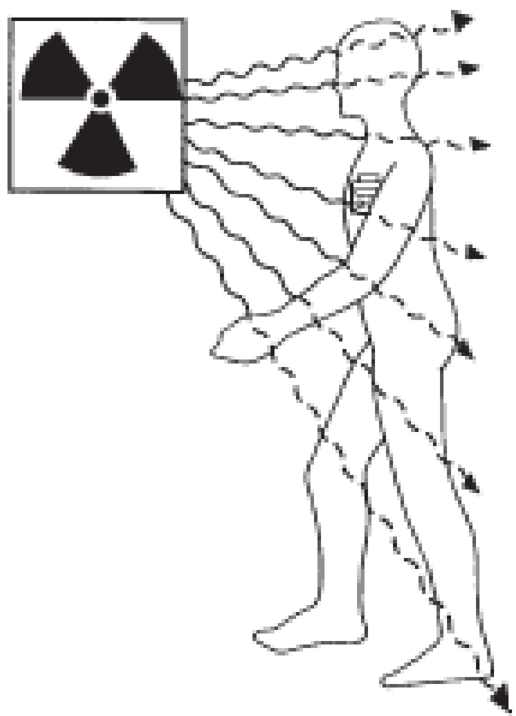
Fig. A.6. Gonads, female (ovaries) absorbed dose per unit air kerma free-in-air.

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 μSv
- About 50% of the threshold of non radiological relevance (10 μSv a^{-1})

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