Dose limits - radiation protection

ICRP - International Commission on Radiological Protection.

Established in 1928 as an idependent foundation, but with close contacts to other relevant international organisations.

Gives recommendations for dose limits to humans by exposure to ionising radiation

Has not worked extensively with effects of radiation on the environment in previous years, but has started with that comcept.

Radiation biology

UNSCEAR - United Nation's Scientific Committee on the Effects of Atomic Radiation

BEIR - Committee on the Biological Effects of Ionizing Radiation, National Research Council (USA)

Systematise and draw conclusions about radiation biologic effects. Stand for much of the data basis for ICRP.

Reactor safety

IAEA - International Atomic Energy Agency

Responsibility for reactor controls and surveillance of stratetic nuclear material

Health effects of ionising radiation

A central source of material for Ra production 100+ years ago was Jáchymov (St.Joachimstal) in Northern Bohemia, close to the German border. In this region, there has been extensive mining since about 1520.

It is clear that miners in this and adjacent regions through centuries were exposed to high radiation doses from radon, resulting in serious diseases whose origin was unidentified at the time.

Health effects of ionising radiation

In 1527, Georg Bauer "**Agricola**" (1494-1555) became town physician in Jáchymov. He became interested in these problems, the miner disease *Bergsucht* or *Schneeberger Krankheit*. In his book "On Metals" (1555), he documents this in the following way:

....it eats away the lungs and implants consumption in the body. Hence, in the mines of the Carpathian Mountains, women are found who have married seven husbands, all of whom this terrible consumption has carried off to a premature death.

It seems likely that the reason for this condition was exposure to very high radon content in the air over years, probably amounting to several hundred thousand Bq/m^3.

Pre-Becquerel use of radioactive material

Miners in Bohemia had problems with “Pechblende”, a substance used by Klaproth in his discovery of uranium (1789). In the early 1800's uranium got into use for colouring of glass and porcellain, particularly from 1840 and onwards.

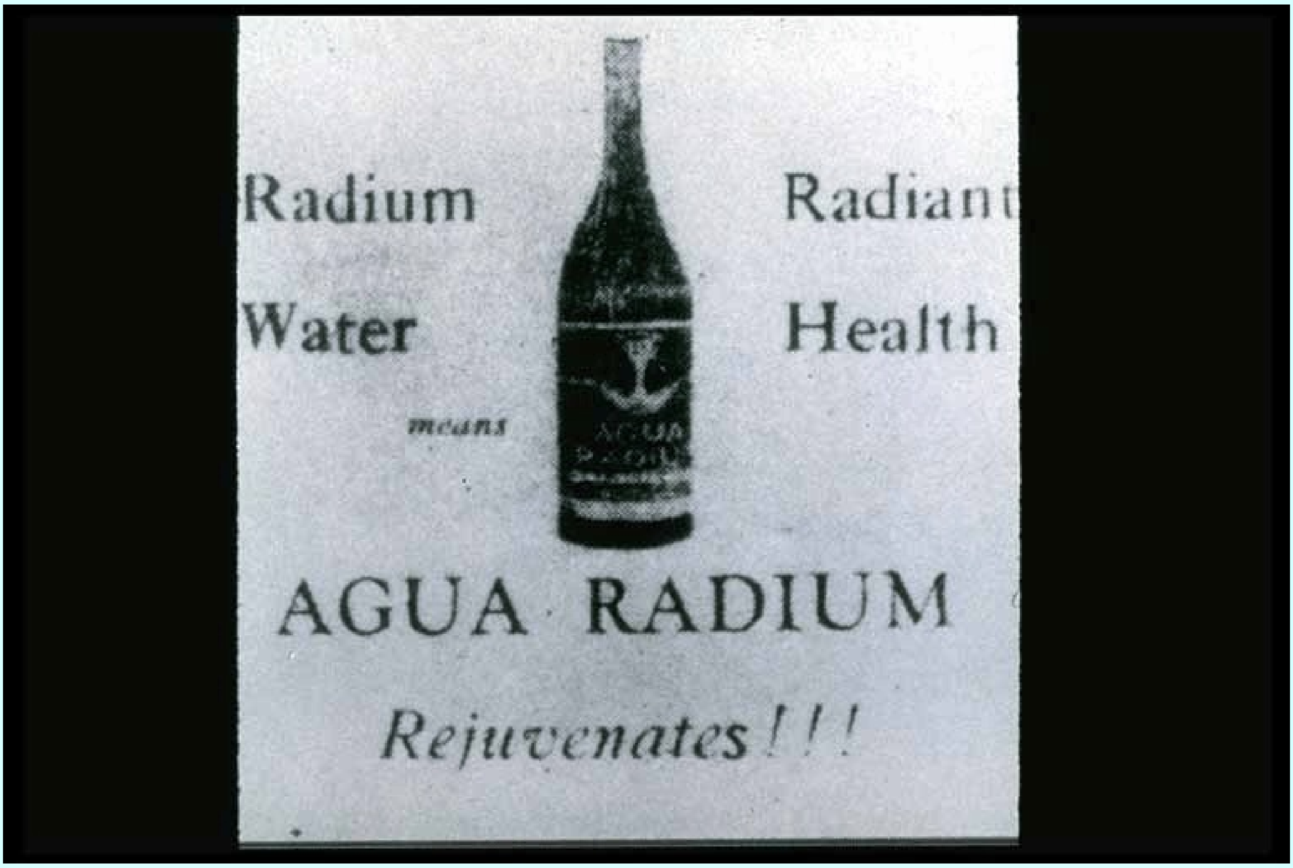
Nobody could in these days foresee that there was a special phenomenon connected to uranium which was not present in other types of dyes used for similar purposes.

1945-1960, miners were again exposed to Rn when Soviet rulers used prisoners for uranium mining, but this time the exposure was deliberate.

Early days....

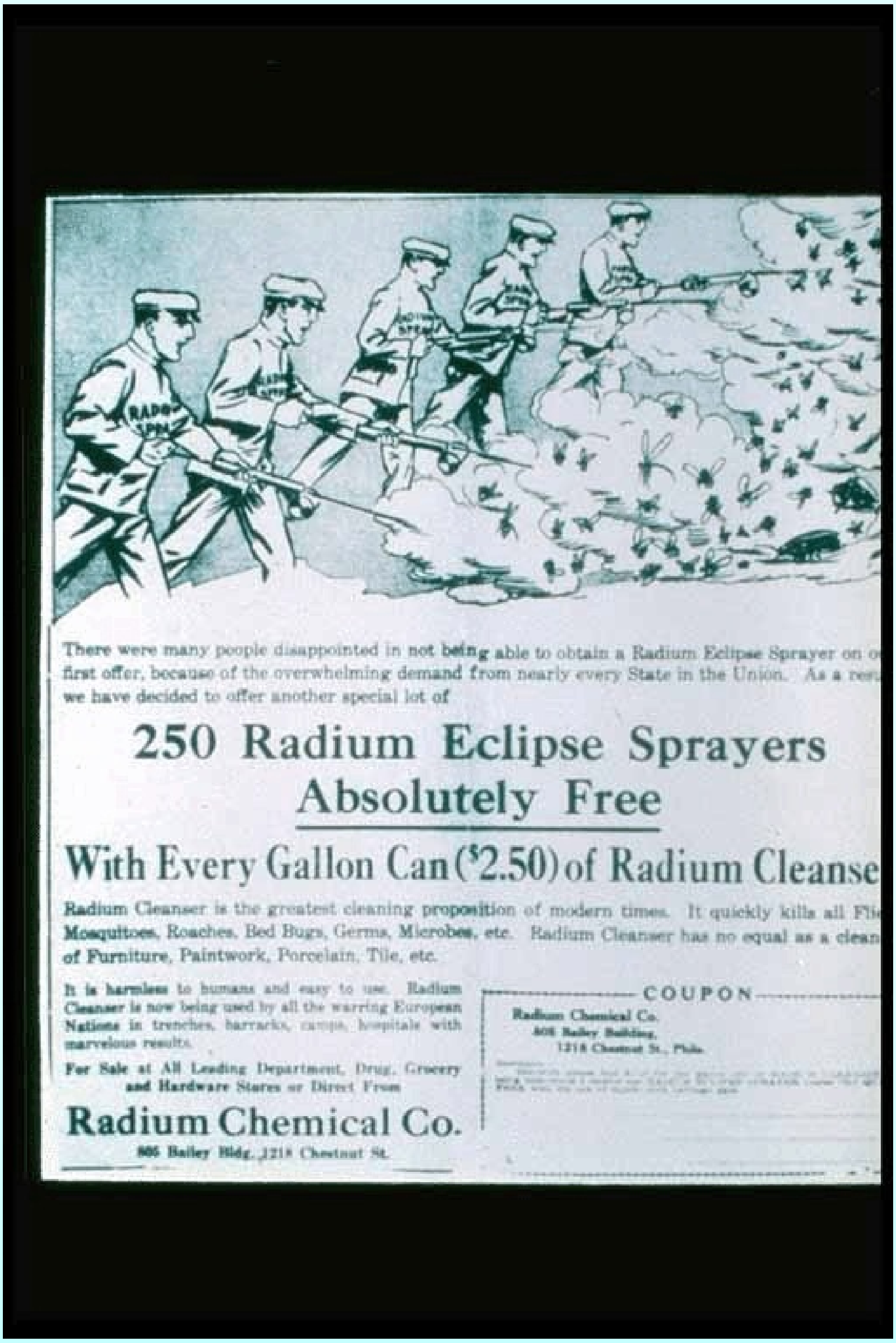
Factory where uranium-containing paint was applied on watches or china (uncertain what exactly these women were doing)

Early days....


Radium
Radiant
Water
Health
means
AGUA RADIUM
Rejuvenates!!!

Early days....

Early days....


There were many people disappointed in not being able to obtain a Radium Eclipse Sprayer on o
first offer, because of the overwhelming demand from nearly every State in the Union. As a res
we have decided to offer another special lot of
250 Radium Eclipse Sprayers
Absolutely Free
With Every Gallon Can ($2.50) of Radium Cleanse
Radium Cleanser is the greatest cleaning proposition of modern times. It quickly kills all Fli
Mosquitoes, Roaches, Bed Bugs, Germs, Microbes, etc. Radium Cleanser has no equal as a clean
of Furniture, Paintwork, Porcelain, Tile, etc.
It is harmless to humans and easy to use. Radium Cleanser is now being used by all the warring European Nations in trenches, barracks, camps, hospitals with marvelous results.
For Sale at All Leading Department, Drug, Grocery and Hardware Stores or Direct From
Radium Chemical Co.
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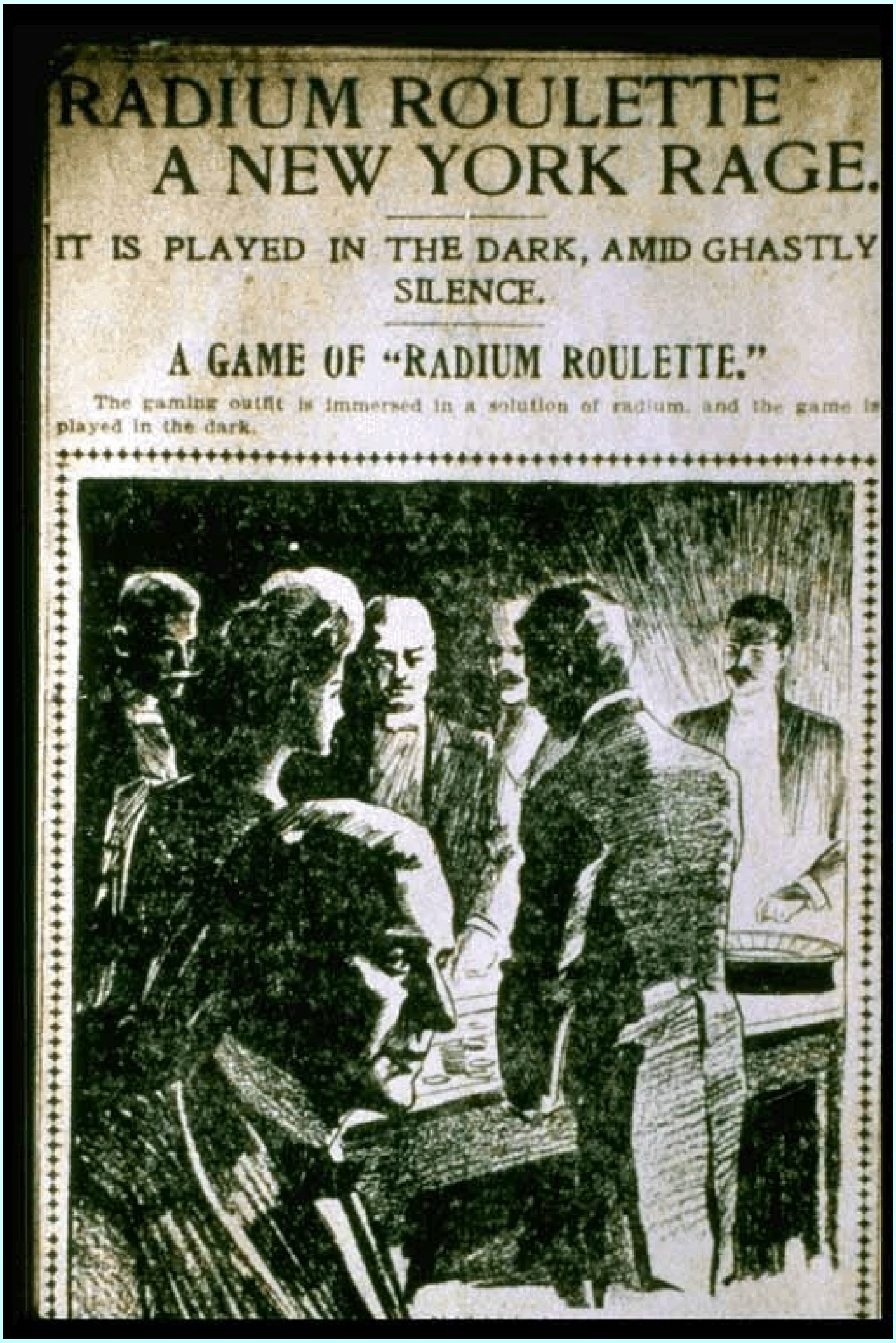
COUPON
Radium Chemical Co.
806 Bailey Building,
1218 Chestnut St., Phila.

Early days....



RADIUM ROULETTE A NEW YORK RAGE.

IT IS PLAYED IN THE DARK, AMID GHASTLY SILENCE.

A GAME OF "RADIUM ROULETTE."

The gaming outfit is immersed in a solution of radium, and the game is played in the dark.

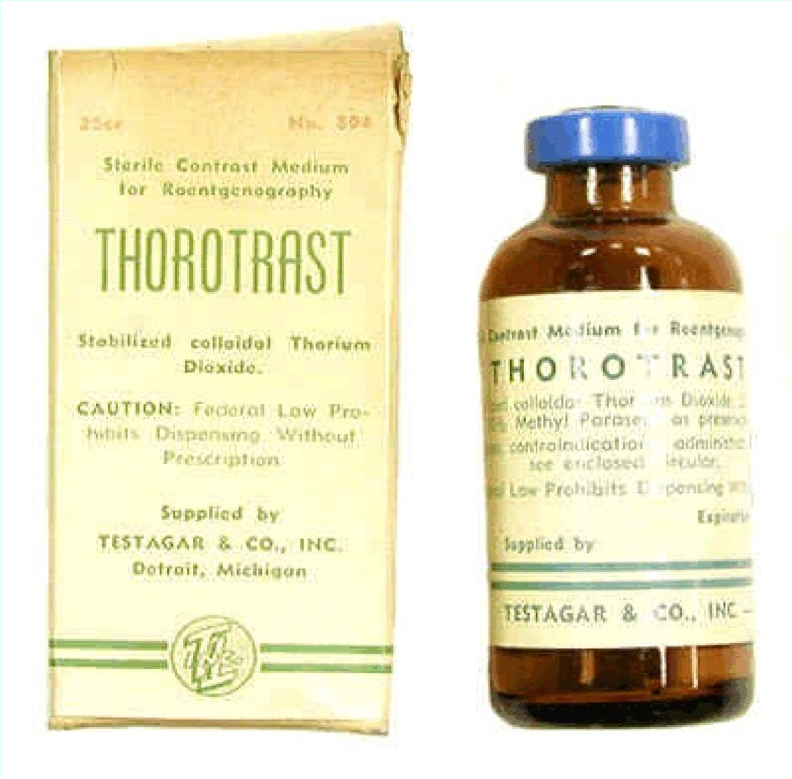
Early days....

The text reads: *radon removes harmful substances and makes the smoke softer and milder*

Early days....

Radioactive suppositories (stikkpiller)....

Thorotrast, a skeleton in the closet



Thorotrast is a suspension av colloidal ThO_2, stabilised with 15-20 % dextrin and a little p-hydroxy-benzoic acid.

Thorotrast

The presence of thorium made thorotrast very suitable as contrast medium for different types of soft-tissue x-ray investigations (very high Z) The earliest contrast media were often iodine-based and could lead to serious side-effects, allergic reactions, sometimes even death.

Thorotrast gave strongly improved picture quality and short-term side-effects were absent. It therefore got very popular quickly in the 1930's, particularly in Japan, USA and Germany.

Thorotrast in cerebral arteriography was introdused by Antonio Egas Moniz, today also notoriously known as the inventor of frontal lobotomy.

Even if short-term side-effects were absent, it was very different with the long-term ones.......

Thorotrast

Thorotrast achieved widespread use, it is estimated that 2.5 - 10 million patients were injected with it in 1930-1955, when it slowly went out of use. The first report of radiation induced cancer (leukemia) in a patient came in 1942 i Switzerland.

It was assumed that the weak radioactivity of Th was biologically uninmportant. In reality, this compound is enriched in spleen, liver, bone warrow and lymph nodes with a biologic half-life estimated to 400 years.

The orgqan doses are very individual and depend of course on the amounts injected, but they may have been of the order of 100 - 700 mGy pr.year.

At the time, knowledge about the biologic effects of high LET radiation was sparce.

Thorotrast

Thorotrast is one of the most carcinogenic compounds ever used medically. This could happen because the effect did not appear before 20-30 years had passed. In particular, the liver cancer incidence (and type) was astonishing.
First report of primary liver cancer for a thorotrast-injected person came in 1947, at that time the damage had already happened.

In Denmark, 584 thorotrast-victims lived 15 years after the injection. 136 of these later developed primary liver cancer, all of them with terminal result.

Thorotrast

Consequences of thorotrast may be:

- Liver cancer
- Mesotelioma
- Leukemia
- Serious benign lesions

It is reported in litterature about more than1000 cases of thorotrast-related liver cancer and 175 cases of thorotrast-related leukemia. Evidently, there are large dark numbers.

Exact numbers are hard to estimate, but is is certain that the number of thorotrast-induced deaths is much higher than the number of deaths attributable to cancer induced by ionising radiation (not to be confused with the total number) after the bombs on Hiroshima and Nagasaki.

Umbrathor

Umbrathor was a ThO_2-based contrast agent used perorally and used for X-ray imaging of the gastro-intestinal-system. Due to a different type of intake, The negative effects were much less than for thorotrast, which was injected.

Because no other group of people have been expsed to this much high LET radiation, it is today possible to extract valuable information from the thorotrast scandal.

Early use of radioactivity

From examples like these and others, an important principle for the use of ionising radiation materialised:
All use of ionising radiation shall be useful, and the ionising radiation shall have a clear advantage over alternative technology.

From that principle, X-rays are acceptable, but not radioactive roulette.

Radiation dose in a normal population

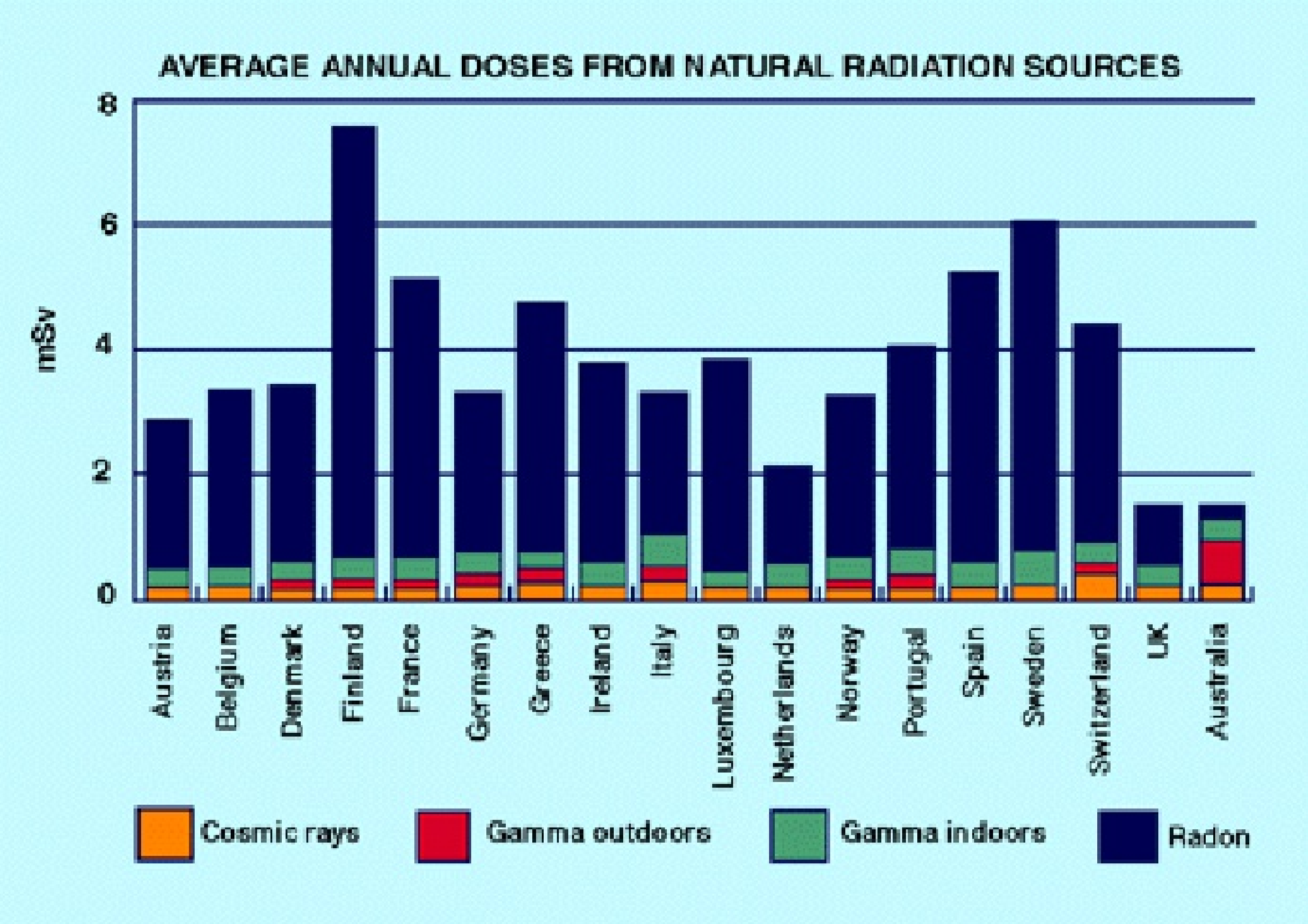
Kilde: Statens Strålskyddsinstitut (SSI)

Rn - varies with ground condition, ventilation, buildings, climate and smoking

X_rays 75 %; Nuclear medicine 25 %
Variees with local methods and practice.
Therapy not included

Internal β and γ 40 %; external γ 30 %
cosmic 30 %. Depends on ground, building materials, altitude etc.

Dose profile



Extremes

Extremely high natural background in some areas:

Tahesh Mahaleh - Ramsar, North Iran

Local areas with very high radiation level due to radium-containing springs. Natural doses to single individuals up to 240 mSv pr.year

Stable population (over centuries) with relatively good standard of living. Stable conditions.

Traces of radiation damages are observed, but no indications of increase in sickness

Certain indications to “adaptive response”, i.e. increased resistance to radiation damage in populations subjected to radiation for many generations

Extreme conditions

A large extreme area is a coastal region in Kerala, India, where natural radioactivity in the sand gives a background dose of 13 mSv per year for a larger population.

This is mostly external, low LET radiation.

There does not seem to be significant effects of that background level, the region is relatively poor with low living conditions, so effects are difficult to observe.

Extreme conditions

Extreme conditions, Rn.
The problem of radon houses was focused after an employee on an American nuclear power plant was stopped by a control monitor on the way into work in the morning (!)
A control showed that his house had a radon level above 50000 Bq pr.m^3.

In Norway even higher values than that have been measured. In some underground defence facilities, it was measured 200 000 Bq pr.m^3.

Definition of radiation dose

The radiation dose **D** is a measure of the burden of radiation a medium is subjected to, and expresses the amount of absorbed radiation energy pr. Mass unit in the material:

$$D = E/m$$

where
E = absorbed radiation energy (joule)
m = the mass where E **is absorbed**

unit of radiation dose: 1 gray (Gy)
1 Gy = 1 J kg^{-1}.
(One joule absorbed radiation energy per. kg material)

Doserate is measured in units e.g. Gy/h

Quality factor

Diferent types of radiation lead to different damage in bioogic systems, even at the same dose.

This is correct by assigning to each radiation **type** a **quality factor (Q)**

A dose given by e.g.α-particles lead to higher radiation damage in biologic material than the same dose given by e.g. β,γ or X-rays.

Quality factors:

Photons:	1
Electrons	1
α-particles, heavy ions	20
neutrons	5 - 20 (energy dependent)
protons, pions:	2

Equivalent dose

The equivalent dose (**H**) is a concept used only about biologic systems:

$$H \equiv DQN$$

where
D = Radiation dose
Q = Quality factor
(N= geometry factor, can normally by put to 1)

Q-values:
β± : 1 γ: 1 X-rays: 1
α : 20 neutrons: 2-10 (energydep.)

Unit equivalent dose: 1 sievert (Sv)

Quality factor - RBE

The concept **Relative Biologic Effektiveness (RBE)** expresses the difference between the effects of two different radiation qualities in a well defined experimental or concrete situation. The concept is closely related to that concrete situation and cannot be sued disconnected from that.

The dose D with a certain type of radiation (e.g. external γ) is needed in order to get a certain biologic effect. In order to get the same effect with another type of radiation (e.g. a source giving α-radiation), the dose D' is needed. Then RBE = D/D' for that system, that defined effect og those forms of exposure.

Quality factor - RBE

Example: If cells in culture are irradiated with external γ or X-rays, one gets a homogeneous, well defined low-LET radiation field.

An α-active source gives high-LET radiation. The radiation has short range, 50 - 100 μm, hence the micro-dosimetry on the cellular level is of importance for RBE.

Does the source enter the cell ?
Is it deposited on the surface ?
Is it deposited in an intercellular matrix ?
Does it bind to DNA ?

The quality factor is a sort of “average, practical RBE” assigned from scientific and administrative criteria, because the level of detail must not be too high in a practical setting.

Effective (equivalent)dose

Very often only a part of the body will receive radiation dose, this is true both for external and internal irradiation.

There may be several reasons for this, e.g. the shape of the radiation field by an external irradiation, absorption on the way in, and different chemical properties of radionuclides by intake (f.ex. Rn to lungs and iodide to the thyroid)

Every organ is assigned a weight factor w_T according to the degree of radiation sensitivity, and an effective dose $\mathbf{H_{eff}}$ is calculated:

$$\mathbf{H_{eff}} = \sum w_T H$$

summed over all organs

H_{eff} is also measured in Sv

Weight factors (ICRP)

Table B.2. Tissue weighting factors, w_T, in the 2007 Recommendations.

Organ/Tissue	Number of tissues	w_T	Total Contribution
Lung, stomach, colon, bone marrow, breast, remainder	6	0.12	0.72
Gonads	1	0.08	0.08
Thyroid, oesophagus, bladder, liver	4	0.04	0.16
Bone surface, skin, brain, salivary glands	4	0.01	0.04

1. The w_T for gonads is applied to the mean of the doses to testes and ovaries.
2. The dose to the colon is taken to be the mass-weighted mean of ULI and LLI doses, as in the *Publication 60* formulation.

The specified remainder tissues (14 in total, 13 in each sex) are: adrenals, extrathoracic tissue (ET), gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (♂), small intestine (SI), spleen, thymus, uterus/cervix (♀).

Revised weight factors from ICRP 2007 (Publication 103)

ALI - Annual Limit of Intake

From the biologic properties of different radionuclides, values are defined for how much intake one is allowed before one passes the allowed dose -ALI (Annual limit of intake).

The values distinguish between intake by inhalation and ingestion (eating and drinking). A third special case is injection, a fourth transcutaneous intake.

ALI-values depend particulary on:
Radiation energy
Radiation type (α,β,γ)
Speed and efficiency of uptake
Speed of excretion
Organ affinity
Chemical status of the radionuclide

ALI - Annual Limit of Intake

There are large variations in ALI-values, the lowest values are found for inhalation of poorly soluble, longlived α-emitters (e.g $^{238\text{-}240}$Pu), or for longlived α-emitters with high and specific organ affinity and long biologic halflife (e.g. ^{226}Ra).

The dose may often come from a daughter-nuclide (f.ex. ^{210}Pb, where the dose comes from α in the decay of ^{210}Po)

If the biologic halflife is short, the radio-toxicity even of longlived radionuclides may be low (e.g. ^{99}Tc (213 000 yr) as TcO_4^-, excreted after only a few days)

Committed dose

Comitted dose is a concept giving the total dose (formally over 50 years) to a certain organ from intake of a radionuclide.
The concept is particularly useful to calculate dose from radionuclides which
1) have long physical halflife
2) are slowly excreted.

Good examples are the boneseekers ^{90}Sr (30 yr) and ^{226}Ra (1600 yr). These radionuclides use several years out when they have got stuck in bone matrix.

Another example is ^{131}I, which goes to the thyroid unless it is bound chemically to a compound acting differently.

Committed effective dose

The committed effective dose is calculated when the committed dose to single organs is multiplied with their respective weight factors and summed over alle organs.

It is often the “committed effective dose” which it is referred to in popular text about the “doseburden” in some connection.

Radiation doses (f.ex.from Rn), frequently refer to yearly dose from a particular source, whereas committed dose gives the dose from a certain exposure, point exposure or continuous

Collective dose

The collective dose (collective equivalent dose) is the product of the average equivalent dose to a group of individuals and the number of individuals in the group

Unit: man-sievert or person-sievert

collective effective dose:
Product of average effective dose to a group of individuals and the number of individuals in the group
Same units

It is the collective effective dose which is used e.g. in estimates of cancer risk after accidents or releases.

Such estimates er often controversial because the risk data are based on much higher doses than those in question

Collective dose and cancer risk

ICRP states that the risk for cancer is 0.05 pr.man-sievert.
The risk for deadly cancer is 0.04.

These data are based on different studies, where particularly the weak increase in cancer incidence from the nuclear weapons used in Japan in 1945 has been important.

A difficulty here has been to extrapolate from an instantaneous dose to slow doses.

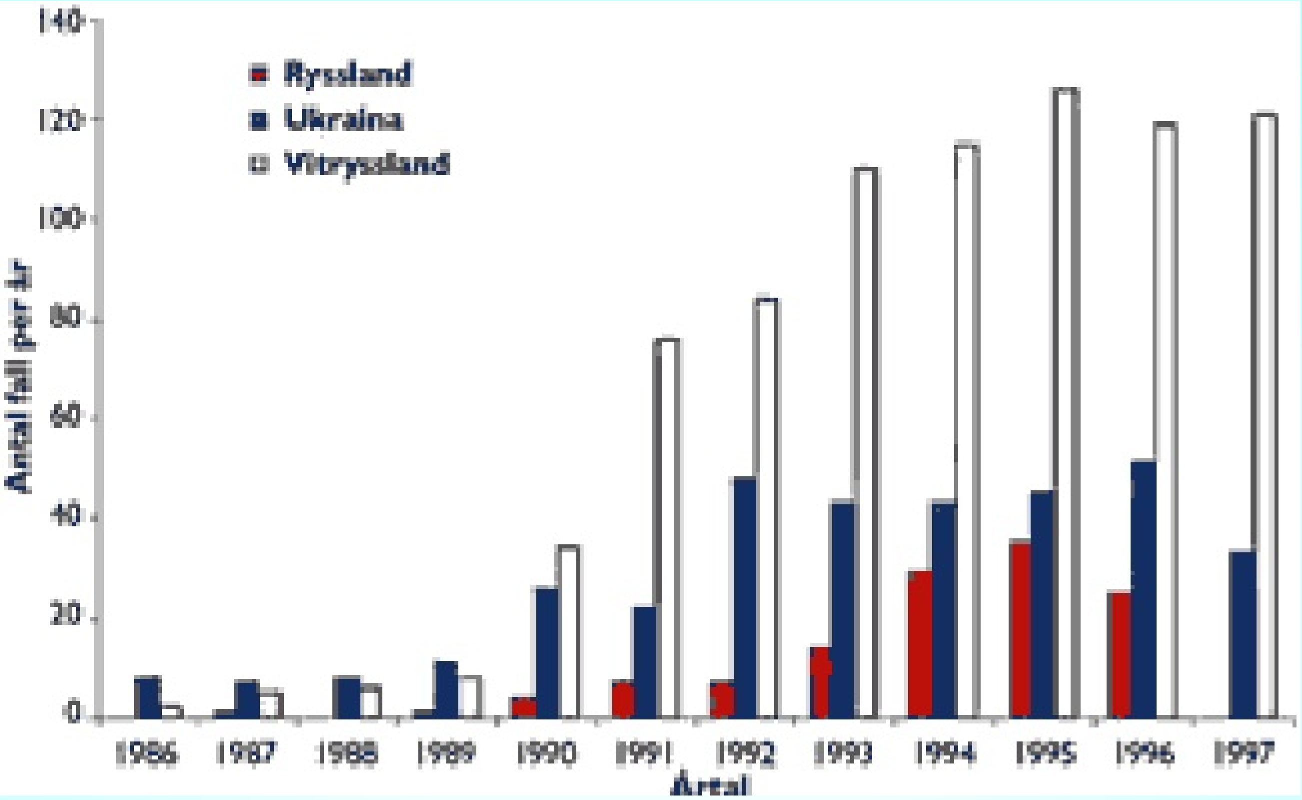
Different approaches are used in order to evaluate the effects of radon. It is today generally accepted that Rn causes lung cancer and that the effect has a strong synergy with smoking.

Collective dose and cancer risk

The given cancer risk (0.05) is a number valid for all cancer forms and for the entire population over a lifespan.

The risk may be considerably higher for certain cancer forms and vary strongly with age and sex. Example: Higher risk for breast cancer for women in the age 10 - 19 by the age of irradiation.Drops considerably with increasing age.

Cancer risk: Tsjernobyl



The thyroid is radiation sensitive in the early ages, illustrated by a strong increase in thyroid cancer for persons who were below 15 when the Tsjernobyl acident took place in 1986, clearly due to exposure to ^{131}I
Integrated increase by 2003 - 1800 cases.
This malignancy is almost never lethal (< 10 cases)
In 2005, IAEA reported about 2000 cases of this type.

Radon

Radon in houses gives the largest radiation dose to a normal population in almost all countries. Radon comes normally in through small cracks in the basement, but may also come in through the drinking water supply if this comes from wells directly down to the ground water.
The radiation dose does not come from Rn itself but from the Rn daughter, which stick to particles and remain in the lungs. Caracterisation of particles is therefore of importance in order to assess the effect of Rn, not only the Rn content in air.
Smoking increases the effect of Rn strongly.

Radon

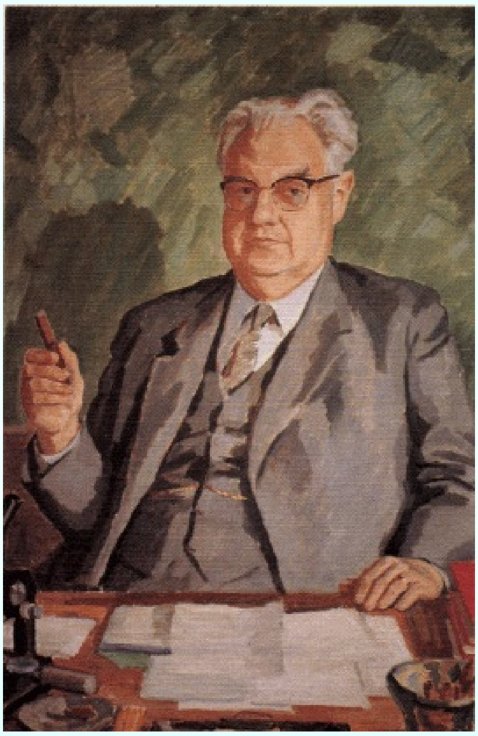
Uranium daughters other than Rn may also contribute. That is especially important for ^{210}Pb (22 yr) and ^{210}Po (138 d), which have long biologic halflife and is taken up in bone.

Depending on diet, there will be more or less extra dose from this source. It has been estimated that persons eating extremely much marine fish (>200 kg pr.year) get an extra dose of 148 μSv pr.year from ^{210}Po in seawater. Persons eating much reindeer meat also get a similar extra dose.

The advantages with a healthy diet are of course more important than this small extra dose.

FYS-KJM 4710

Louis Harold Gray (1905 - 1965)



Rolf M. Sievert (1896 - 1966)

Autumn 2008

Per Hoff

The enemy within

We contain ca 140 g K
^{40}K is radioactive, $T_{½} = 1.3 \cdot 10^{9}$ yr
Abundance: $1.2 \cdot 10^{-4}$

Disintegration rate:
$n_K = 140/39.10 = 3.58$ mol (mol K)

$N_K = n_K \cdot N_A = 3.58 \cdot 6.02 \cdot 10^{23} = 2.16 \cdot 10^{24}$ (K-atoms)

$N = H_{40} \cdot N_K = 1.2 \cdot 10^{-4} \cdot 2.16 \cdot 10^{24} = 2.59 \cdot 10^{20}$ (^{40}K atoms)

$D = N\,ln(2)/T_{½} = (2.59 \cdot 10^{20} \cdot ln(2))/(1.3 \cdot 10^{9} \cdot 3.16 \cdot 10^{7})$

= 4375 Bq

Radiation dose pr.year from ^{40}K

One disintegration ^{40}K gives in average 400 keV β-energy (we assume for simplicity that all γ leaves)

Deposited: 400•4375 keV pr.s
= $5.5 \cdot 10^{13}$ keV pr.yr (1 keV=$1.6 \cdot 10^{-16}$J)
= $8,8 \cdot 10^{-3}$ J pr.yr

Chemical properties: K is mainly found in muscles and soft tissues, a reasonable assumption is that m = the body weight. 140 g corresponds to the K content in a person of 70 kg.

Yearly dose:
$D=E/m = 8,8 \cdot 10^{-3} / 70 = 1.3 \cdot 10^{-4}$ Gy.

Typical doses (effective equivalent dose)

- 1µSv:
  - Eat as grown-up of 70 kg approximately 1 kg food at the EU limit for ^{99}Tc, 1250 Bq pr.kg
  - Being alive as average person 2-3 hours
- 10 µSv
  - Extra dose for cosmic radiation during a flight to the Canary Islands, one way
  - Being alive as average person 1 day
- 100 µSv
  - Assumed extra dose to average persons from man-made radiation (not including medical)
  - Eat 1 kg reindeer meat at 7000 Bq ^{137}Cs per kg.
  - Extra approximate yearly dose from ^{210}Po to people eating much seafish (> 100 kg pr.yr)
  - Approximate yearly dose extra to people living at 400 m altitude, compared to sealevel, due to cosmic radiation
- 1 mSv
  - Allowed extra dose to single persons in a population
  - Typical dose for several pictures in an X-ray examinations
- 3-4 mSv
  - Average background dose for sivilians in Noway per year. Slightly more that 50 % is due to radon.

Radiation protection

1. The use of ionising radiation shall be justified and have a clear value.

1a. Ionising radiation shall give a useful effect not obtainable with other technology at the same cost

2. ALARA - As Low As Reasonably Achievable. The doses and activity levels used should be kept as low as possible.

3. All use of radiation shall be within the limits of the regulatory rules.

In most contries the rules are in consistence with ICRP.

10 μSv dose over a year is considered as negligable("trivial dose")

Some Norwegian rules

Effective dose:	20 mSv pr.yr 50 mSv in 5 yrs
Eye lense	150 mSv/y
Skin	500 mSv/y
Hands,feet	500 mSv/y
At pregnancy	< 2 mSv locally

The reason for local dose limits is that e.g. hands and feet contribute little to the total effective dose, because the risk for stokastic effects is little for this organ. However, one can get undesired, local deterministic effects.