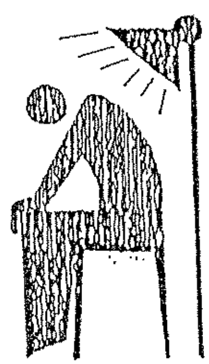
I.

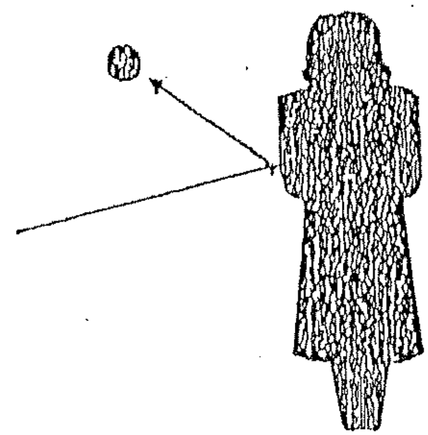
RADIATION BASICS

(A.) Understanding Radiation

What is radiation?

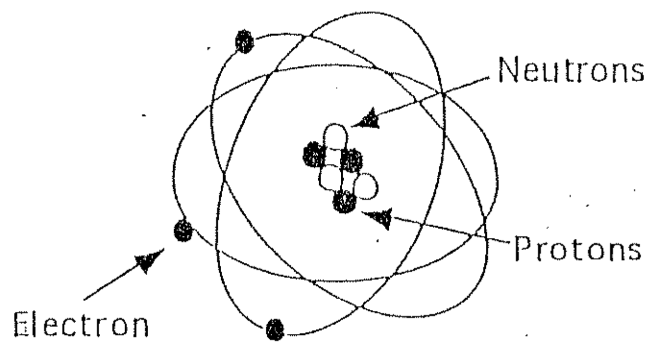
- Radiation is energy transferred from one place to another.
- Radiation is like the heat transferred from a bright light to your body.
- Radiation can also be like the energy transferred to your body when you are hit by a rock that is thrown at you.
- Some atoms (called radionuclides) produce radiation.





What is the atom?

- Atoms are the particles of which all matter is made.
- The nucleus of the atom is made up of protons and neutrons. Electrons surround the nucleus.



- The term atomic number refers to the number of protons within the nucleus of an atom.
- The term atomic weight, or mass number, refers to the number of neutrons plus protons in the nucleus of an atom.
- Isotopes are elements with the same atomic number but different atomic weights. E.g., uranium^{235} and uranium^{238} are isotopes of the element uranium. Uranium^{235} has 235 neutrons and protons; uranium^{238} has 238 neutrons and protons (i.e., three more neutrons).
- Too many or too few neutrons in a nucleus make the atom unstable. An unstable atom gives off energy as it tries to become stable. Radiation is this release of energy in the form of particles and rays.

What are radionuclides?

- Radionuclides are atoms which produce radiation (e.g., iodine131, cesium137, strontium90, and plutonium240).
- Some radionuclides release only alpha particles while others release only beta particles or gamma rays. Some radionuclides release various combinations of all three types of radiation at different energies.
- When radionuclides release radiation they turn into another type of atom. This process is called radioactive decay.
- Neutrons are uncharged particles in the nucleus of an atom. Neutrons are not normally released during radioactive decay. They are released during nuclear fission (e.g., in nuclear reactors, atom bombs).

Types of radiation

Radionuclides can produce different types of radiation.

- Alpha and beta radiation are particles.

- Gamma radiation is a wave (like light and heat)

Alpha and beta particles

<u>Alpha Particles</u> (2 neutrons and 2 protons)

- have a large mass and are easily slowed down*.
- can be stopped by a few inches of air or a piece of paper.
- cannot penetrate the human skin.
- do damage if they are inhaled or ingested in the body (where there is no skin to stop them).

Plutonium, uranium, and radon give off alpha particles. They are called alpha emitters.

<u>Beta Particles</u> (1 electron)

- have less mass than alpha particles.
- can be stopped by a sheet of metal or heavy clothing.
- can penetrate and damage the under layers of skin.
- are dangerous when ingested or inhaled.

Tritium, strontium^{90} and iodine^{131} are beta emitters.

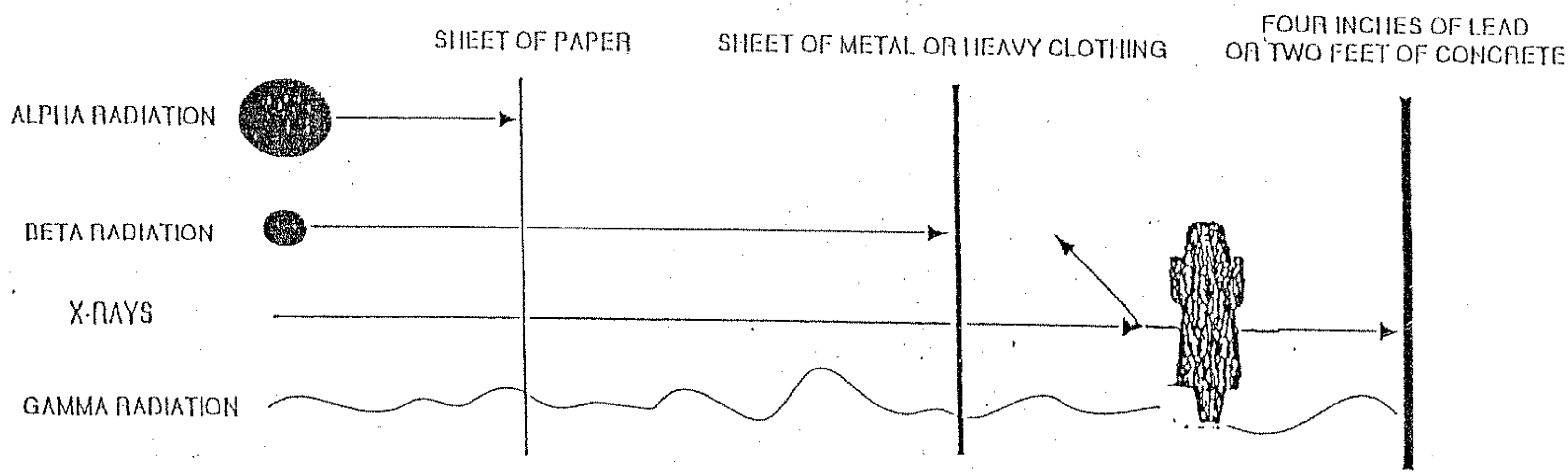
* Mass is defined as the weight of an object. A baseball is roughly the same size but heavier than a tennis ball. It has more mass.

Gamma radiation and x-rays

Gamma Radiation

- is a form of wave energy similar to light and heat but of much *shorter wave length and higher frequency*.
- will often pass through the body sometimes without doing damage.
- can be stopped by four inches of lead or several feet of concrete.

Many radionuclides, such as strontium, plutonium, and iodine emit gamma rays, along with their release of alpha or beta radiation.



ONLY GAMMA AND X-RAYS WILL PASS THROUGH THE HUMAN BODY

X-Rays

- are like gamma rays but of much *larger wave length and lower frequency*.
- a less penetrating form of radiation.
- will penetrate soft tissue not bone, making them useful for medical imaging.

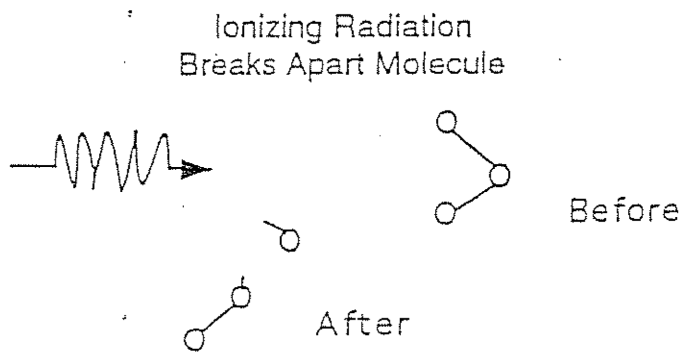
Radiation types by effect

Radiation may be ionizing or non-ionizing.

Ionizing Radiation

Alpha, beta, gamma and x-radiation are types of ionizing radiation. Ionizing radiation transfers energy to the substances it strikes. This transfer of energy is special because it damages the molecules within the cell.

Ionizing radiation breaks apart molecules. The greater the energy transferred, the greater the injury. Ionizing radiation consists of either waves of energy or tiny particles.



Examples of ionizing radiation include:

- Radiation releases from nuclear power plants
- Medical X-rays
- Naturally occuring background radiation
- Ultraviolet radiation from the sun

Non-ionizing Radiation

Non-ionizing radiation energizes or shakes up molecules, without breaking them apart.

Examples of sources of non-ionizing radiation include:

- Power lines
- Televisions
- Radar
- Toasters and other electrical appliances
- Microwaves
- Heat from the sun

I.

RADIATION BASICS

(B.) Radiation Measurements and Exposures

How is radiation measured?

Typically radiation is measured by its rate of decay and by the damage it can do to humans or matter.

Measuring Rate of Decay:

- As an individual radionuclide ages, it disintegrates or "decays", losing energy in the form of alpha and beta particles and gamma rays and changing to a new type of atom.
- Thirty-seven (37) billion decays per second is called one Curie. One decay per second is a Becquerel.
- Curies and Becquerels are measures of the rates of decay of radionuclides.
- The rate of decay is measured by a geiger counter or another instrument.

Measuring Absorbed Energy:

- A rad is the dose or amount of radiation absorbed by a material. Rad stands for Radiation Absorbed Dose.

Measuring Damage:

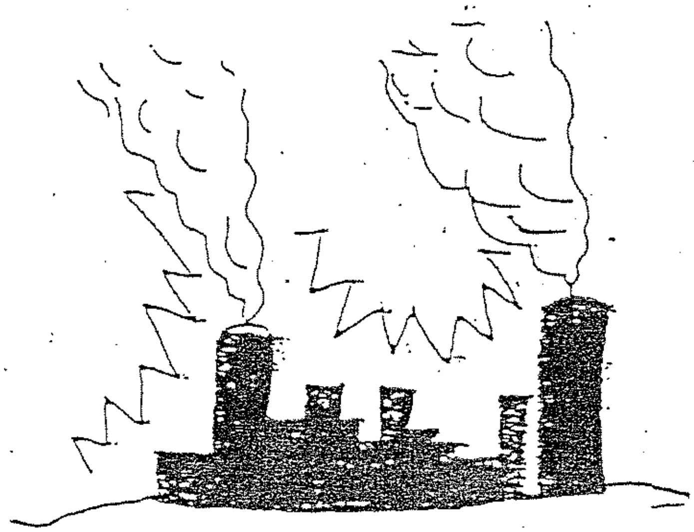
- Radiation damage is measured in doses.
- The rem measures the dose (amount) of damage to a human from radiation. Rem stands for Radiation Equivalent in Man.
- The rad and rem can be calculated from the Curie or measured with an instrument like a film badge.

Are rad and rem related?

- A rad and a rem are related depending on the type of radiation produced.
- One rad is equal to one rem for gamma and beta radiation.
- One rad is typically equal to 10 to 20 rem for alpha radiation. This is because alpha radiation can damage localized tissue more effectively than beta and gamma.

Examples of radioactive emissions

- 14 Curies from radioactive iodine were released during the accident at Three Mile Island in 1979.
- Hanford Nuclear Complex in Washington, released 730,000 Curies of $iodine^{131}$ between the years 1944 and 1992.
- The Sedan Test, in 1962, released 15 million Curies at the Nevada Test Site ($cesium^{137}$, $iodine^{131}$)
- 50 million Curies ($cesium^{137}$, $iodine^{131}$) were released during the accident at Chernobyl in 1984.



Curies, rads and rems can be measured as fractions

- 1 thousandth of a rem is a millirem or mrem.
- 1 millionth of a rem is a microrem or μrem.
- 1 billionth of a rem is a nanorem or nrem.
- 1 trillionth of a rem is a picorem or prem.

One can measure millirads, picocuries, etc.

Radiation Measurements

U.S. Terms

Curies
picocurie (pCi)-1 trillionth, 10^{-12}
nanocurie (nCi)-1 billionth, 10^{-9}
microcurie (µCI)-1 millionth, 10^{-6}
millicurie (mCi)-1 thousandth, 10^{-3}
curie (Ci)-1 curie

Rads
microrads (µr)-1 millionth, 10^{-6}
millirads (mr) - 1 thousandth, 10^{-3}
centirads (cr) - 1 hundredth, 10^{-2}
rad (r) - 1 rad
kilorads - 1 thousand rads, 10^{3}

Rems
microrem - 1 millionth, 10^{-6}
millirem - 1 thousandth, 10^{-3}
rem - 1 rem
kilorem - 1 thousand, 10^{3}

International Terms

Becquerels
tera becquerels - 1 trillion, 10^{12}
giga becquerels-1 billion, 10^{9}
mega becquerels - 1 million, 10^{6}
kilo becquerels - 1 thousand, 10^{3}
becquerel-1 becquerel
millibecquerel-1 thousandth, 10^{-3}
microbecquerel-1 millionth, 10^{-6}
nanobecquerel-1 billionth, 10^{-9}
picobecquerel-1 trillionth, 10^{-12}

Grays
microgray (µGy) - 1 millionth, 10^{-6}
milligray (mGy) - 1 thousandth, 10^{-3}
centigray (cGy) - 1 hundredth, 10^{-2}
gray (Gy) - 1 gray
kilo gray (kGy) - 1 thousand, 10^{3}

Sieverts
microsievert (µSv) - 1 millionth, 10^{-6}
millisievert (mSv) - 1 thousandth, 10^{-3}
sievert (Sv) - 1 sievert
kilosievert (kSv) - 1 thousand, 10^{3}

Scientific Notation

10^{12}	(1.0 E 12)	1,000,000,000,000	1 trillion	Tera-
10^{9}	(1.0 E 9)	1,000,000,000	1 billion	Giga-
19^{6}	(1.0 E 6)	1,000,000	1 million	Mega-
10^{3}	(1.0 E 3)	1,000	1 thousand	Kilo-
10^{0}	(1.0 E 0)	1	one	
10^{-3}	(1.0 E -3)	0.001	1 thousandth	Milli-
10^{-6}	(1.0 E -6)	0.000001	1 millionth	Micro-
10^{-9}	(1.0 E -9)	0.000000001	1 billionth	Nano-
10^{-12}	(1.0 E -12)	0.000000000001	1 trillionth	Pico-

CONVERSIONS

1 rad = 1 rem

0.1 rad = .1 rem

0.01 rad = .01 rem

0.001 rad = .001 rem

(These conversions are for gamma and beta radiation only)

1 gray = 100 rads

0.1 gray = 10 rads

0.01 gray = 1 rad

0.001 gray = .1 rad

1 gray = 100 rad = 100 rem = 1 sievert*

0.1 gray = 10 rad = 10 rem = 100 millisieverts

0.01 gray = 1 rad = 1 rem = 10 millisieverts

0.001 gray = 0.1 rad = 0.1 rem = 1 millisievert

(* these equations hold true only for types of gamma and beta radiation. For alpha radiation you must multiply rads (or grays) by 20 to determine rems (or sieverts))

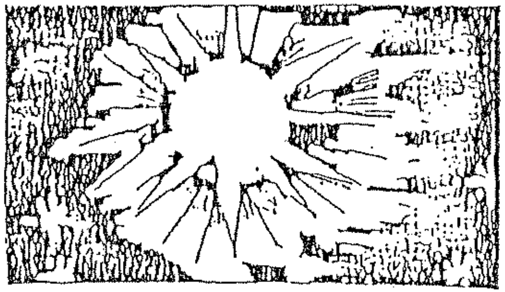
1 curie = 37 billion becquerels (37×10^9)

24.32 curies = 9 terabecquerels (9×10^{12})

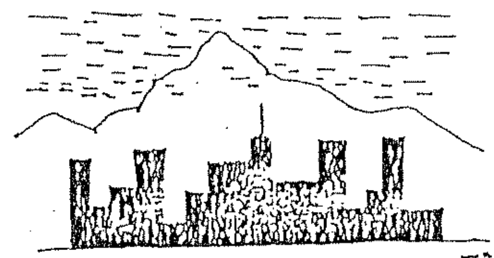
243,243,243 curies = 9000 terabecquerels (9×10^{15})

Typical sources of radiation and estimated doses

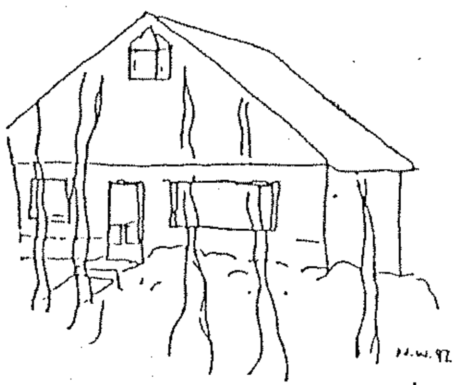
Natural Background Radiation totals 100 to 300 millirem per year.



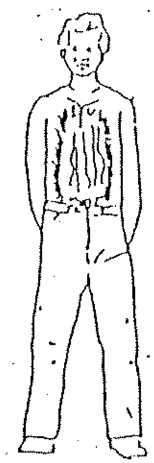
Cosmic Radiation
(sun, stars)
27 millirem/year
(alpha, beta, gamma-)



Terrestrial Radiation
(soil, rocks, minerals)
28 millirem/year
(gamma-)



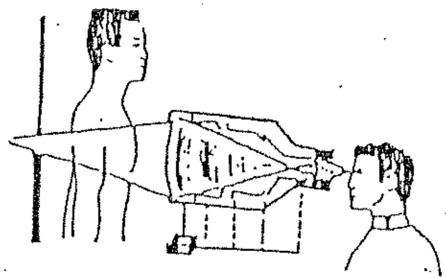
Indoor and Outdoor Radon
(seeps up from the earth)
200 millirem/year
(alpha-)



Internal Emitters
(carbon, phosphorus)
40 millirem/year
(alpha, beta, gamma-)

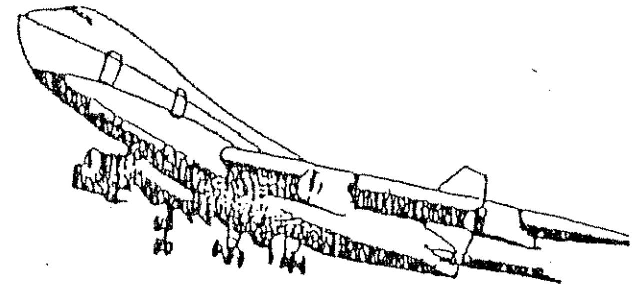
Other sources of radiation

Other Sources (amounts indicate average exposure)



Medical X-Rays

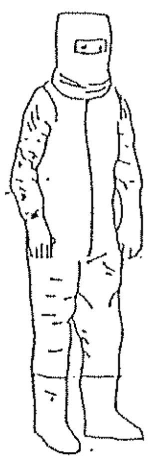
x-ray = 10-15 millirem
mammogram = 400 millirem
dental x-ray = 5 millirem



Air Travel

New York to Los Angeles
2.5 millirem

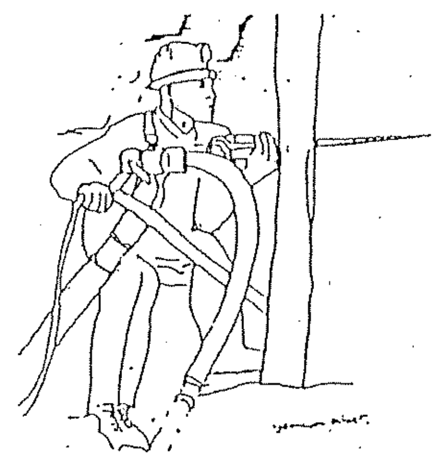
Occupational Sources of Radiation (amounts indicate allowable limits)



Nuclear Worker

United States = 5 rem per year
United Kingdom = 1.5 rem per year
ICRP proposal = 2 rem per year

ICRP = International Commission for Radiological Protection



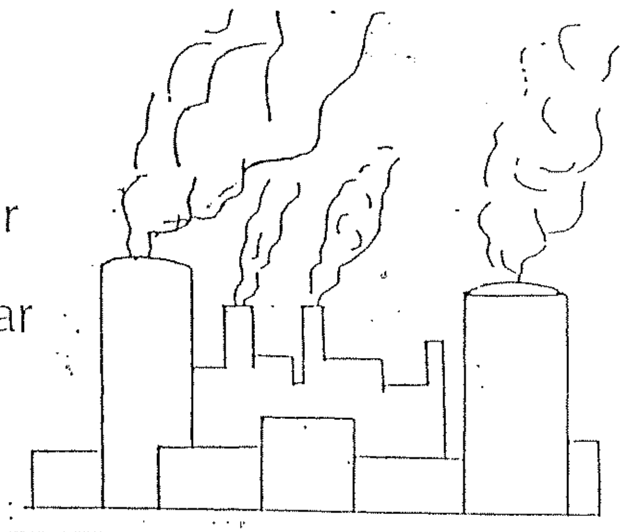
Uranium Miner

4 WLM per year**
0.7 WLM pref. by unions

** 1 WLM is approximately 100 picocuries per liter of air per month measured in mines (WLM is Working Level Month)

Limits for public exposure to radiation

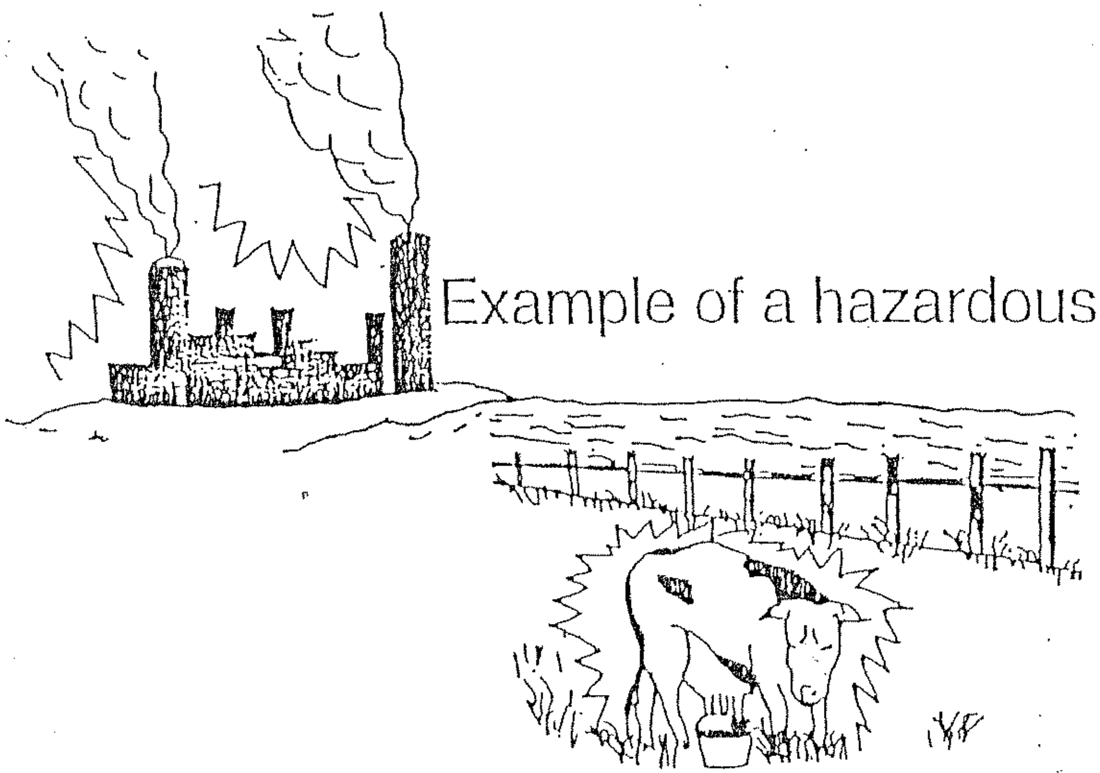
Nuclear Power Plants



Environmental Protection Agency (EPA) = 25 mrem per year

Nuclear Regulatory Commission (NRC) = 100 mrem per year

(NRC and Department of Energy (DOE) consider up to 500 mrem acceptable in special conditions)



Example of a hazardous release in Hanford, Washington

est. dose received = 1200 to 12,000 mrem to thyroids of the "Hanford Downwinders," especially infants

Chronology of radiation exposure limits

Radiation standards for workers and the general public consistently have been lowered over the years.

Nuclear Workers

1934	30 rem/year	Int'l Committee for Radiological Protection (ICRP)
1950	15 rem/year	ICRP
1956	5 rem/year	ICRP
1977	5 rem/year	National Committee for Radiological Protection (NCRP)
1987	1.5 rem/year	United Kingdom
1991	2.0 rem/year	proposed United States standard

General Public

1949	0.3 rem/year	10% occupational limit
1953	1.5 rem/year	10% occupational limit
1954	1.5 rem/year	ICRP
1956	0.5 rem/year	ICRP
1985	0.1 rem/year	ICRP-exceptions allowed to 0.5 rem/year
1995	0.025 rem/year	Environmental Protection Agency (EPA)

Radon (Mining)

1940	106 WLM	average exposure
1967	12 WLM	Federal Radiation Council (FRC)
1971	4 WLM	Mine Safety and Health Administration (MSHA)
1981	4.8 WLM	ICRP (union requested 0.7 WLM)

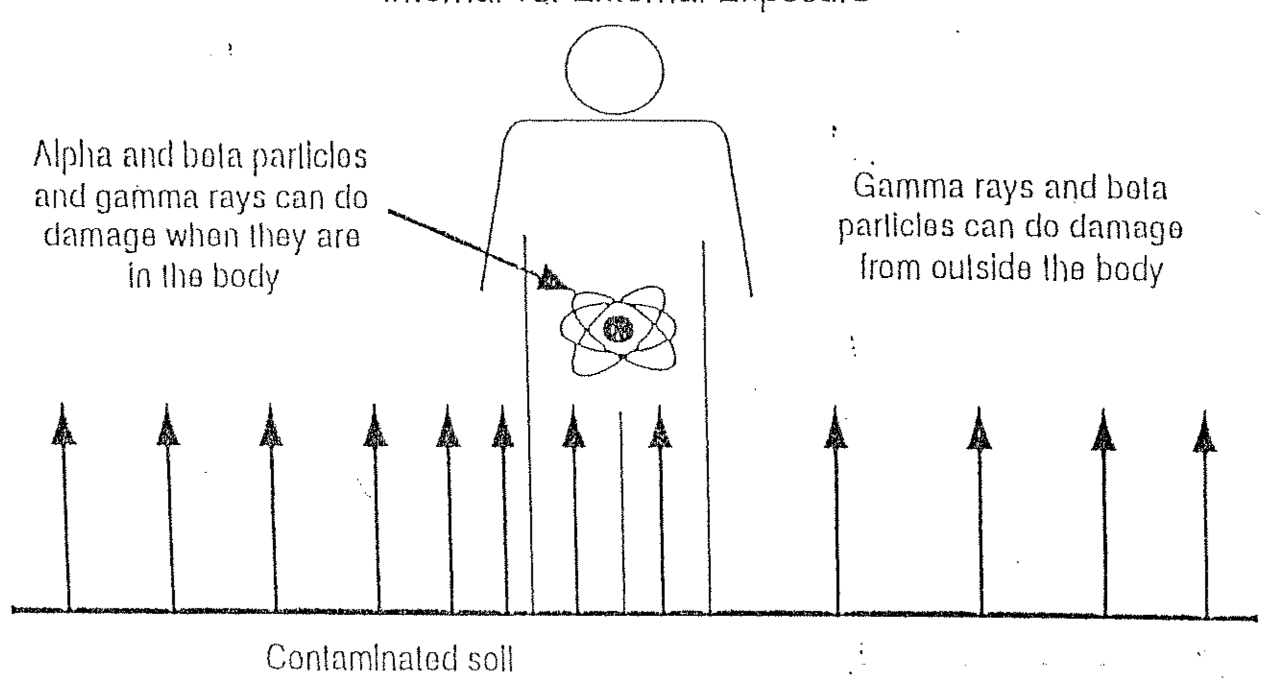
1 WLM = Working Level Month, which is approximately 100 picocuries per liter of air per month as measured in mines

How are we exposed to radiation?

We are exposed to external and internal radiation.

- Radiation can expose your body from both outside and inside.
- *External radiation* is radiation from outside of your body coming in. External radiation is primarily from gamma rays and beta particles. Think of getting sunburn from being out in the sun.
- *Internal radiation* is radiation that comes from radionuclides which are inside your body. TInternal radiation can come from all three types of radiation; gamma rays, beta particles and alpha particles.

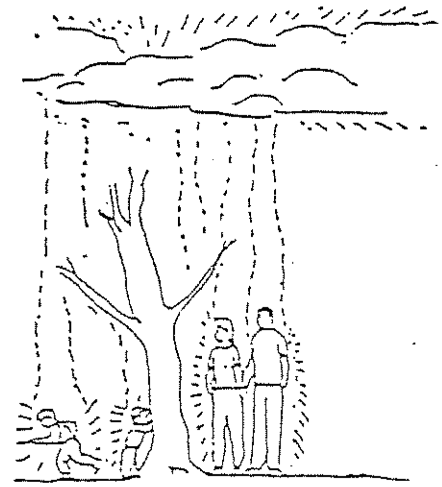
Internal vs. External Exposure



What are the typical pathways of radiation contamination?

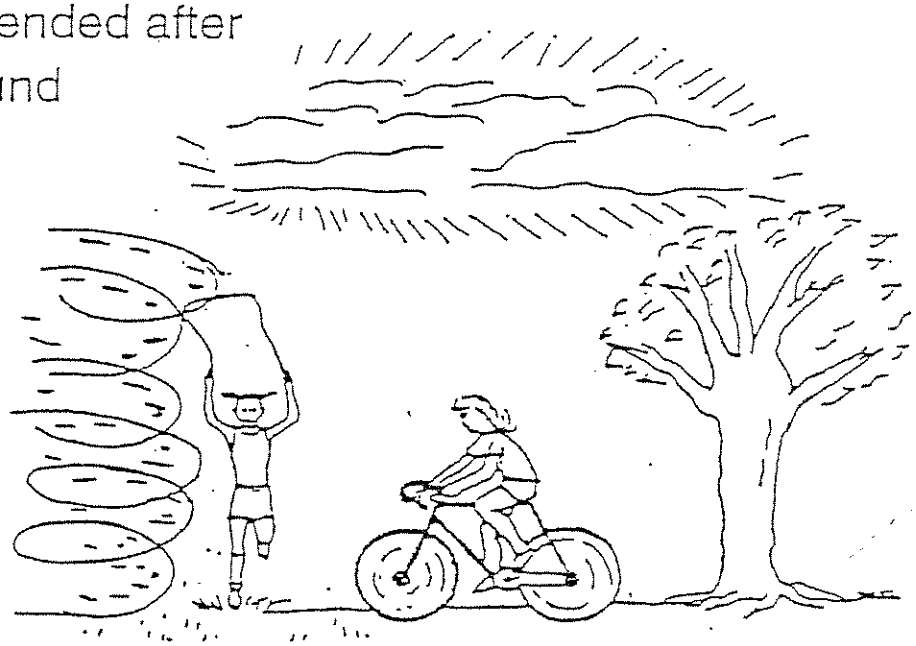
Direct radiation of the whole body

from gamma-emitting radionuclides in a cloud of passing over a population (e.g., Cesium^{137})



Inhalation of radioactive substances

from a passing cloud and from radionuclides re-suspended after deposition on the ground (e.g., Iodine^{131})



Properties of specific radionuclides

- Iodine^{131} concentrates in the thyroid and has a half life of 8 days. Thus essentially all of the iodine^{131} released in the 1950s is gone now.

- Cesium^{137} has a half life of 30 years. When cesium^{137} enters the body it is distributed uniformly throughout the body.

- Strontium^{90} has a half life of 28 years. Strontium concentrates in the bones of exposed people and animals. Some of the strontium^{90} from nuclear testing is still in the environment.

- Plutonium^{239} has a half life of 24,400 years. Essentially all of the plutonium from testing is still around. Like strontium, plutonium concentrates in the bone and damages bone more than other tissues.

Radionuclide organ distribution

Because of their chemical form,
radioactive forms of these elements "seek" these organs

Elements	Organs
Radium, Strontium, Yttrium, Promethium, Barium, Thorium, Phosphorous, Calcium, Plutonium	Bone
Ruthenium, Polonium, Uranium, Irridium	Kidneys
Polonium, Zinc, Cesium, Cerium	Liver
Any radionuclide inhaled and any insoluble radionuclide (not readily dissolved), e.g. Zirconium	Lungs and GI Tract
Potassium, Cesium	Muscle
Zinc	Ovaries
Zinc	Prostate
Polonium, Irridium, Cesium	Spleen
Iodine	Thyroid
Tritium, Carbon, Chromium, Sulfur, Cobalt (all forms), Cesium, Potassium, Zirconium	Uniform

Half-lives of common radionuclides

Radionuclide	Half-Life
Radon-222	3.8 days
Iodine-131	8.05 days
Thorium-234	24 days
Radium-226	1,600 years
Cobalt-60	5.27 years
Tritium (H3)	12.3 years
Strontium-90	28.1 years
Cesium-137	30 years
Americium-241	432 years
Plutonium-239	24,400 years
Technetium-99	213,000 years
Uranium-235	704,000,000 years (7.04×10^8)

Uranium decay series "daughters of uranium"

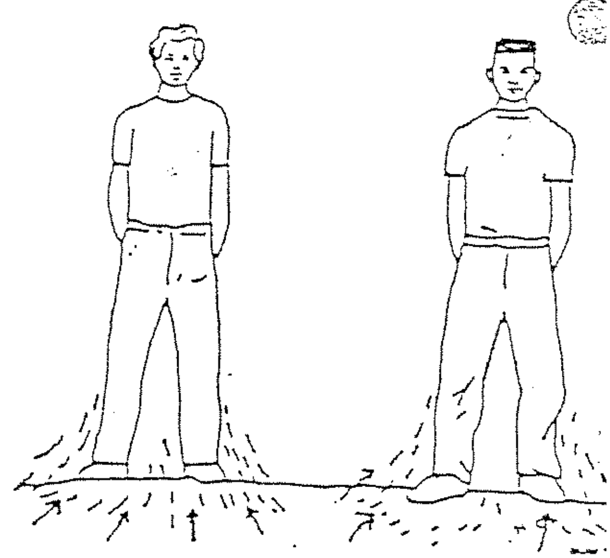
As uranium-238 decays*, it turns into other elements that are also radioactive. These elements are called "daughters of uranium."

	Radionuclide	Half-life	Radioactive Emissions
start	Uranium-238	4.5 billion years	alpha
	Thorium-234	24.1 days	beta, gamma
	Protactinium-234	6.75 hours	beta, gamma
	Uranium-234	247,000 years	alpha, gamma
	Thorium-230	77,000 years	alpha, gamma
	Radium-226	1,600 years	alpha, gamma
	Radon-222	3.8 days	alpha, gamma
	Polonium-218	3 minutes	alpha, beta
	Lead-214	27 minutes	beta, gamma
	Bismuth-214	19.7 minutes	beta, gamma
	Polonium-214	164 microseconds	alpha, gamma
	Lead-210	21 years	beta, gamma, alpha
	Bismuth-210	5 days	alpha, beta
	Polonium-210	138.5 days	alpha
end	Lead-206	stable	

* This list represents the primary decay products.

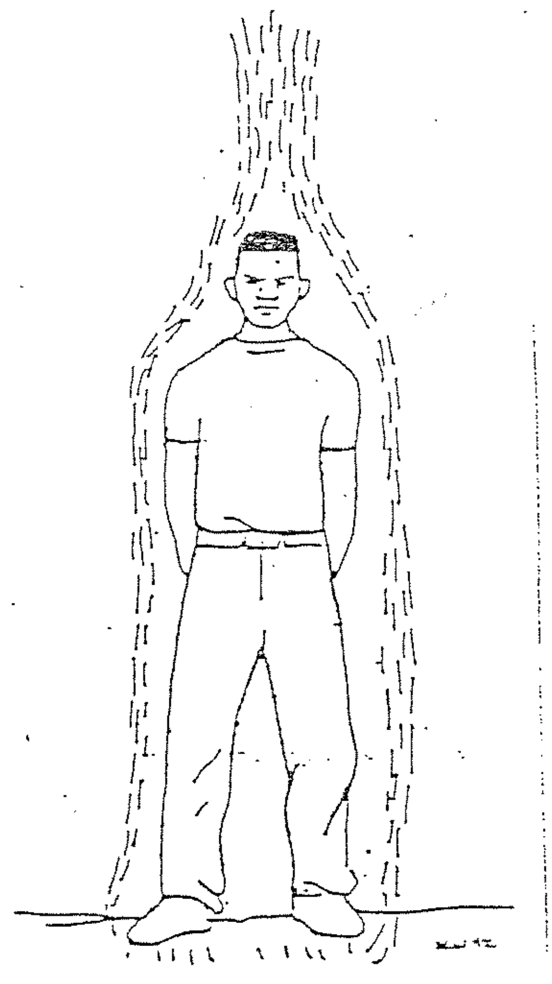
Direct external radiation

of the whole body by gamma rays or beta particles emitted from radionuclides deposited on the ground (e.g., Cesium^{137}, or other gamma emitters)



Whole body exposure

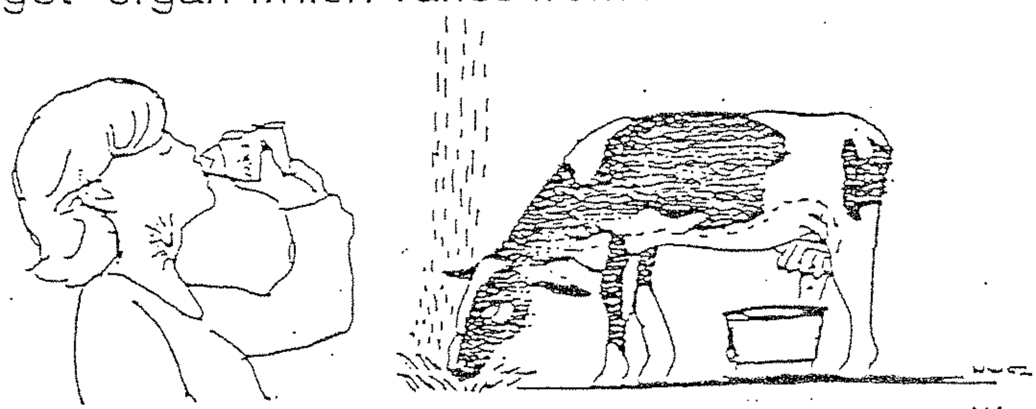
Exposure by external radiation can expose the whole body or part of it. However, for gamma or neutron radiation, we can assume that the whole body receives approximately the same dose.



Internal Exposure by Ingestion

of radionuclides with milk, water, meat, fruit, and vegetables
(e.g., uranium, and other alpha emitters)

Internal exposures: Radionuclides inside the body irradiate mainly their "target" organ which varies from radionuclide to radionuclide.



Major radio-sensitive body organs		Other radio-sensitive organs	
gonads	digestive tract	kidneys	pharynx
breasts	thyroid	bladder	liver
red bone marrow	lung	brain	biliary tract
bone surfaces		pancreas	nervous system
		skin	salivary glands

(Source: BEIR V - see page 51)