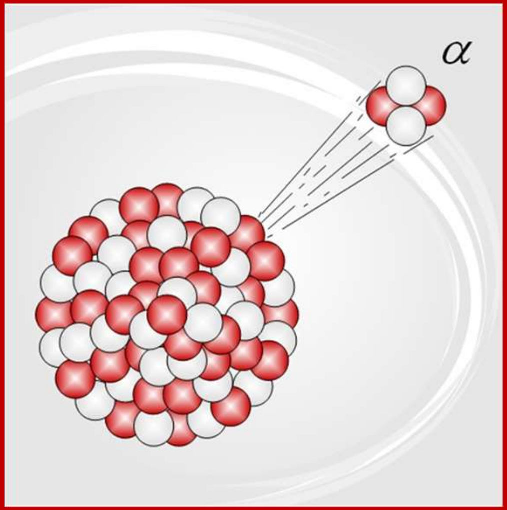
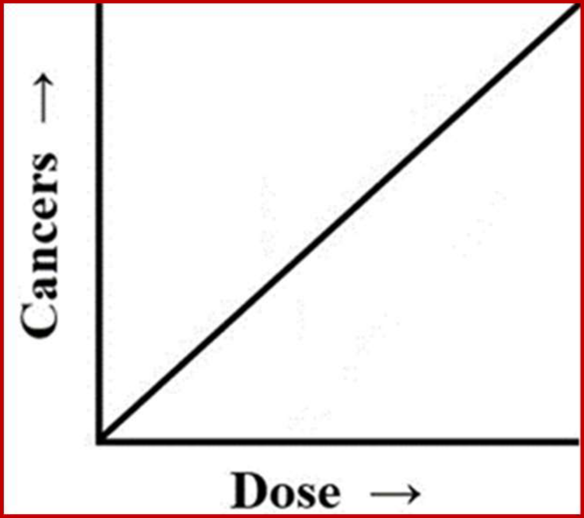
Decay, Background Radiation and Risk of Exposure





Radioactive Decay and Measurement

A curie (Ci) is 3.7×10^{10} disintegrations per second. A pico is 10^{-12}

pCi/L and pCi/g are often used in radiochemical/radiological studies.

The SI unit (International System of Units) of radioactivity is the becquerel (Bq). One Bq is 1.0 disintegration per second. One pCi = 0.037 Bq

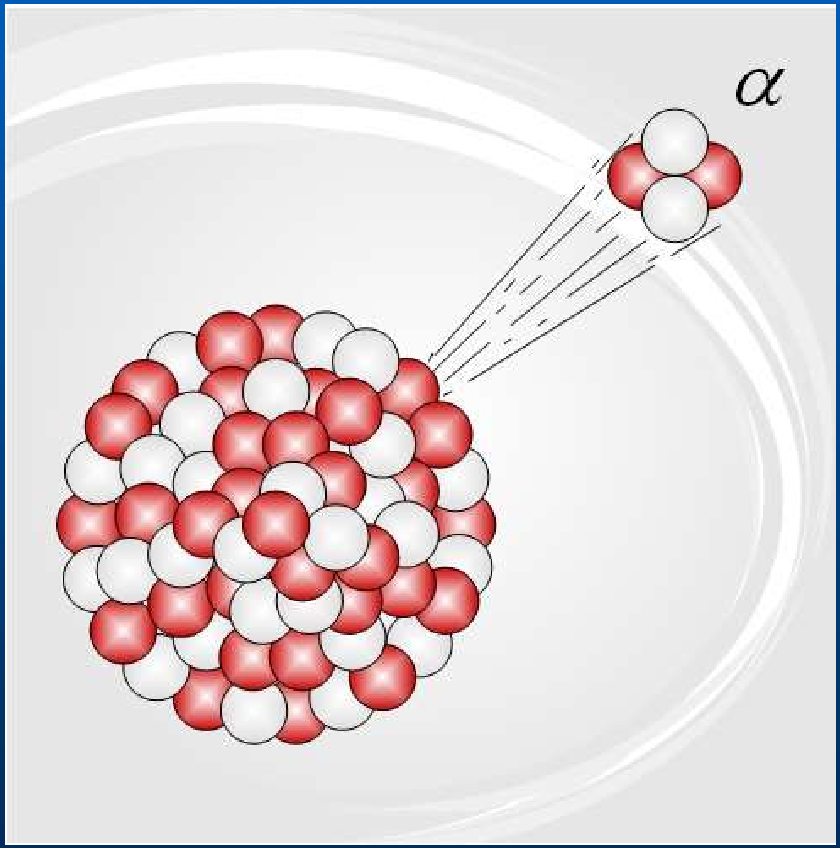
One tera is 10^{12}

One terabecquerel (TBq) = 27 Ci

Modes of decay: α

During radioactive decay, charged particles are emitted:

Alpha radiation is two protons and two neutrons (He^{2+}).



Polonium-210:

$$^{210}Po_{84} \rightarrow {}^{206}Pb_{82} + \alpha$$

Modes of decay: β^-

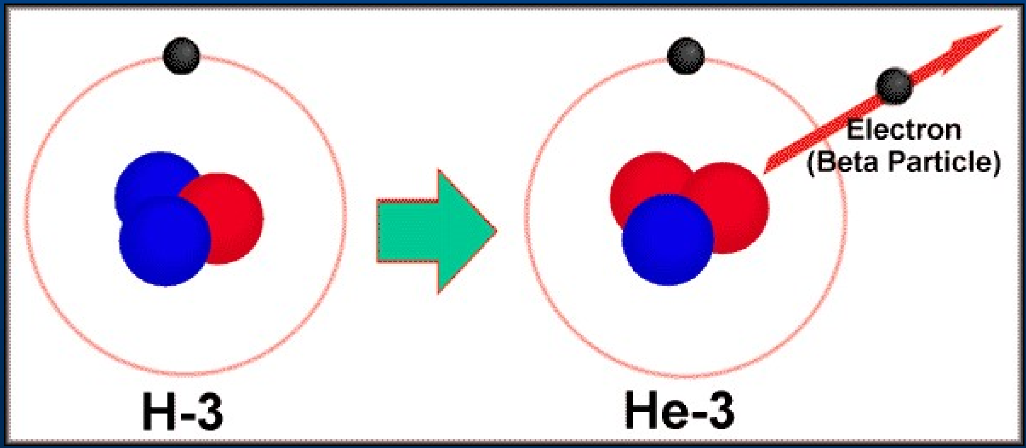
Beta radiation consists of electrons or positrons.

An unstable atomic nucleus with an excess of neutrons may undergo β^- decay, where a neutron is converted into a proton, an electron, and an antineutrino:

$$n \rightarrow p + e^- + \bar{\nu}_e$$

Berylium-10:

$$^{10}Be_4 \rightarrow {}^{10}B_5 + e^-$$



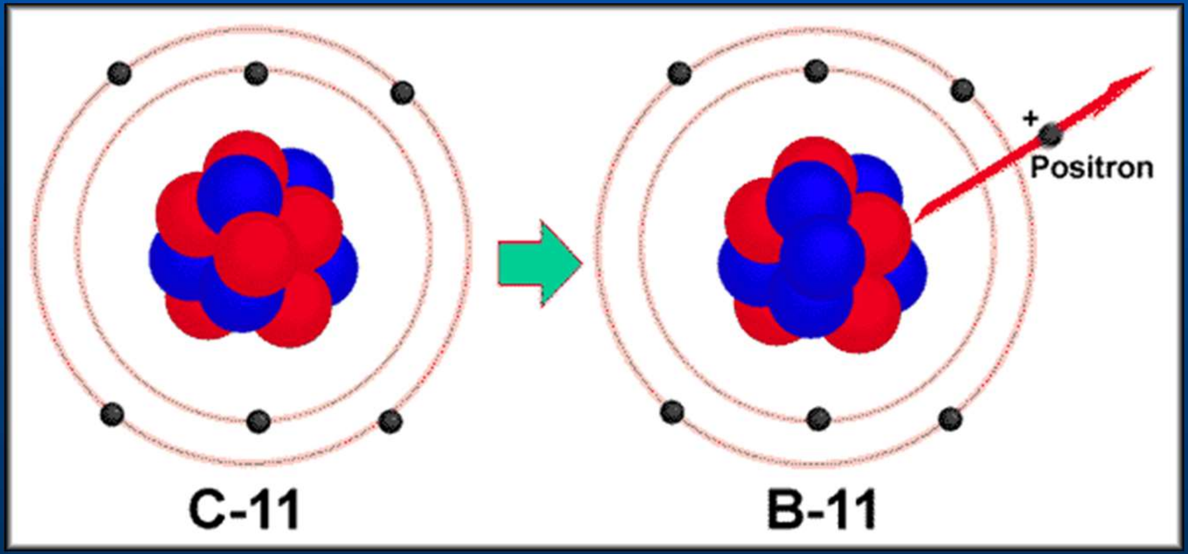
Modes of decay: β^+

An unstable atomic nucleus with an excess of protons may undergo β^+ decay, where a proton converted into a neutron, a positron, and a neutrino:

$p \longrightarrow \eta + e^+ + \nu_e$

Rubidium-82:

$^{82}Rb_{37} \longrightarrow {}^{82}Kr_{36} + e^+$



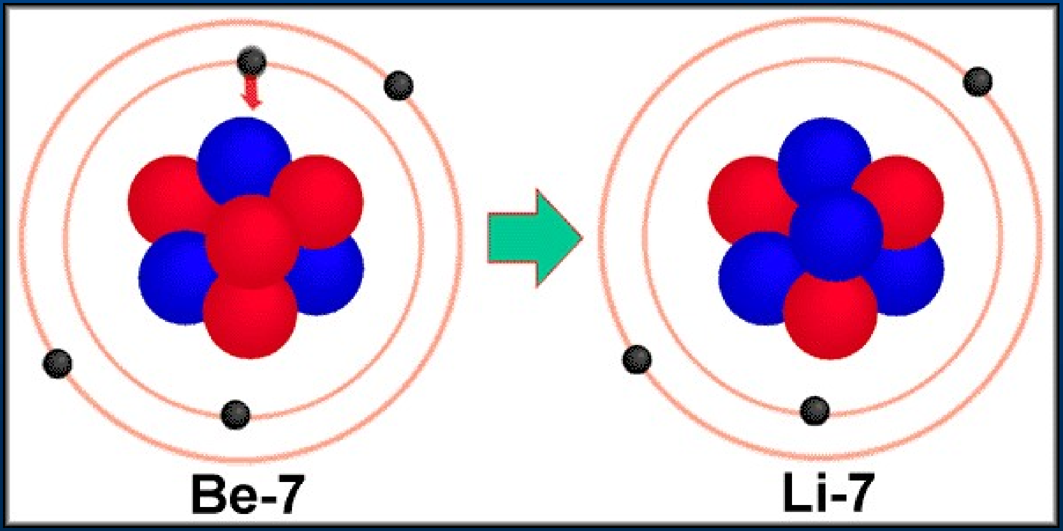
Modes of decay: electron capture

An atomic nucleus absorbs an inner electron, changing a proton into a neutron yielding a neutrino, and in some cases photons and electrons.

$$p + e^{-} \rightarrow \eta + \nu_e$$

Iron-55:

$$^{55}Fe_{26} + e^{-} \rightarrow {}^{55}Mn_{25}$$

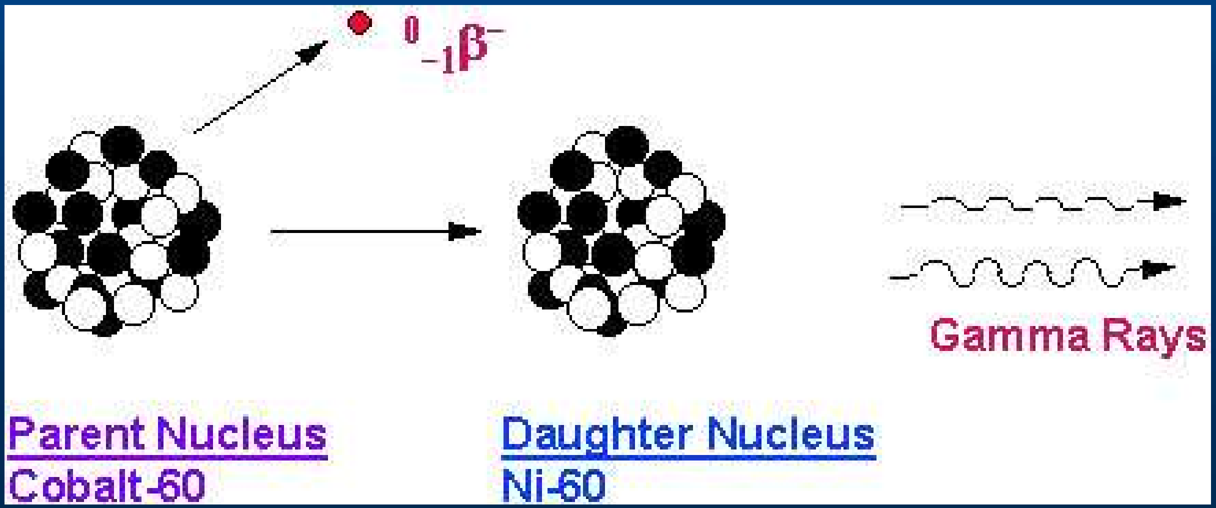


Modes of decay: γ

Unstable nucleus releases electromagnetic energy. Gamma ray emission frequently follows beta decay, alpha decay, and other nuclear decay processes.

Cobalt-60:

$$^{60}Co_{27} \rightarrow {}^{60}Ni_{28} + e^{-} + \gamma$$



Modes of decay: isomeric transition

Nucleus in an excited, metastable state emits a gamma ray. No change in number or protons or neutrons.

Technitium-99m: $^{99m}Tc_{93} \rightarrow {}^{99}Tc_{93} + \gamma$

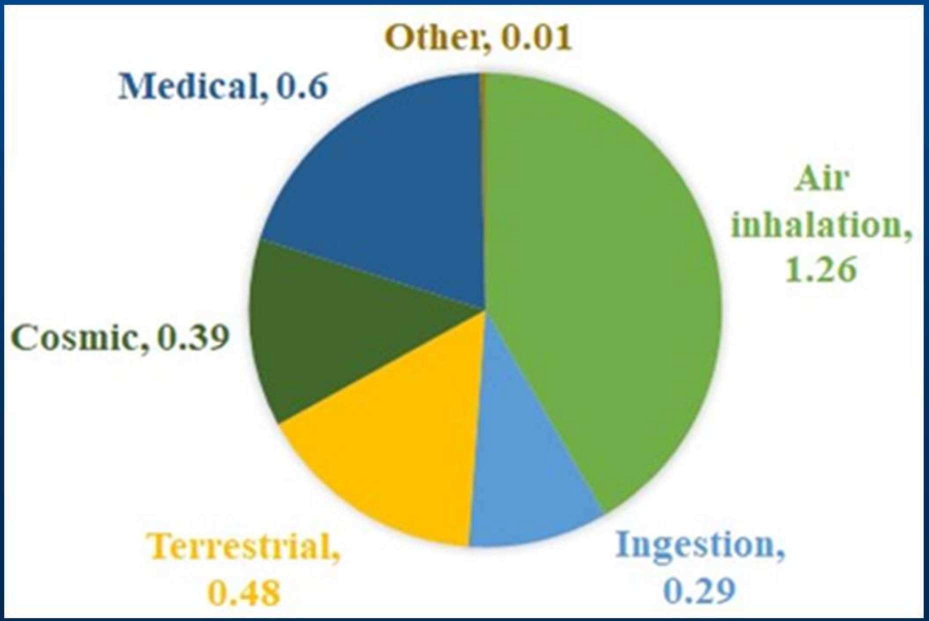
spontaneous fission

Characteristic of very heavy isotopes (atomic numbers greater than 93.

Curium-250: 11% α (^{246}Pu), 9% β^- (^{250}Bk), and 80% SF (various daughters)

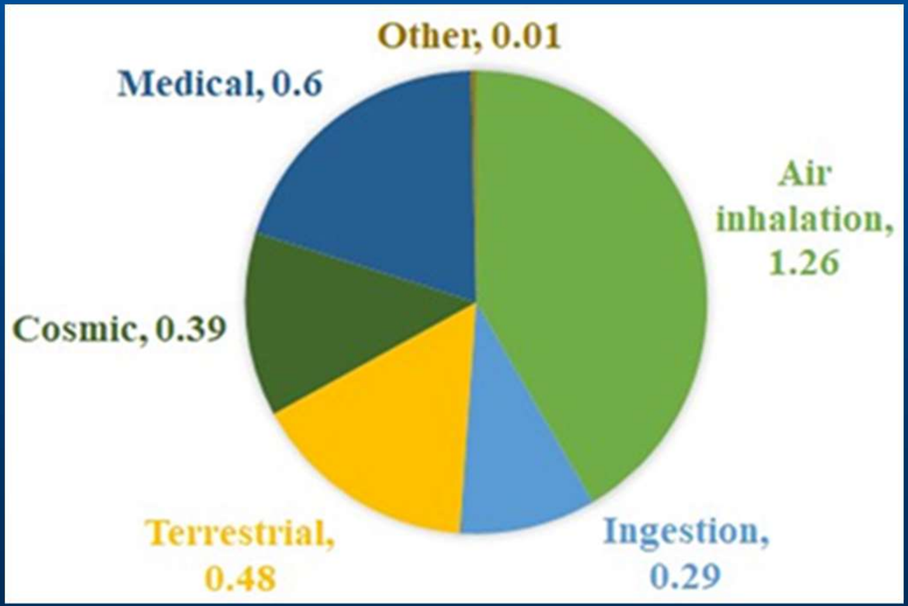
Global background radiation

Global background ionizing radiation 3.01 mSv/year per person (301 mrem/year). Air inhalation = radon. Ingestion is consumption of foods and water containing K-40, C-14, U-238 and others.

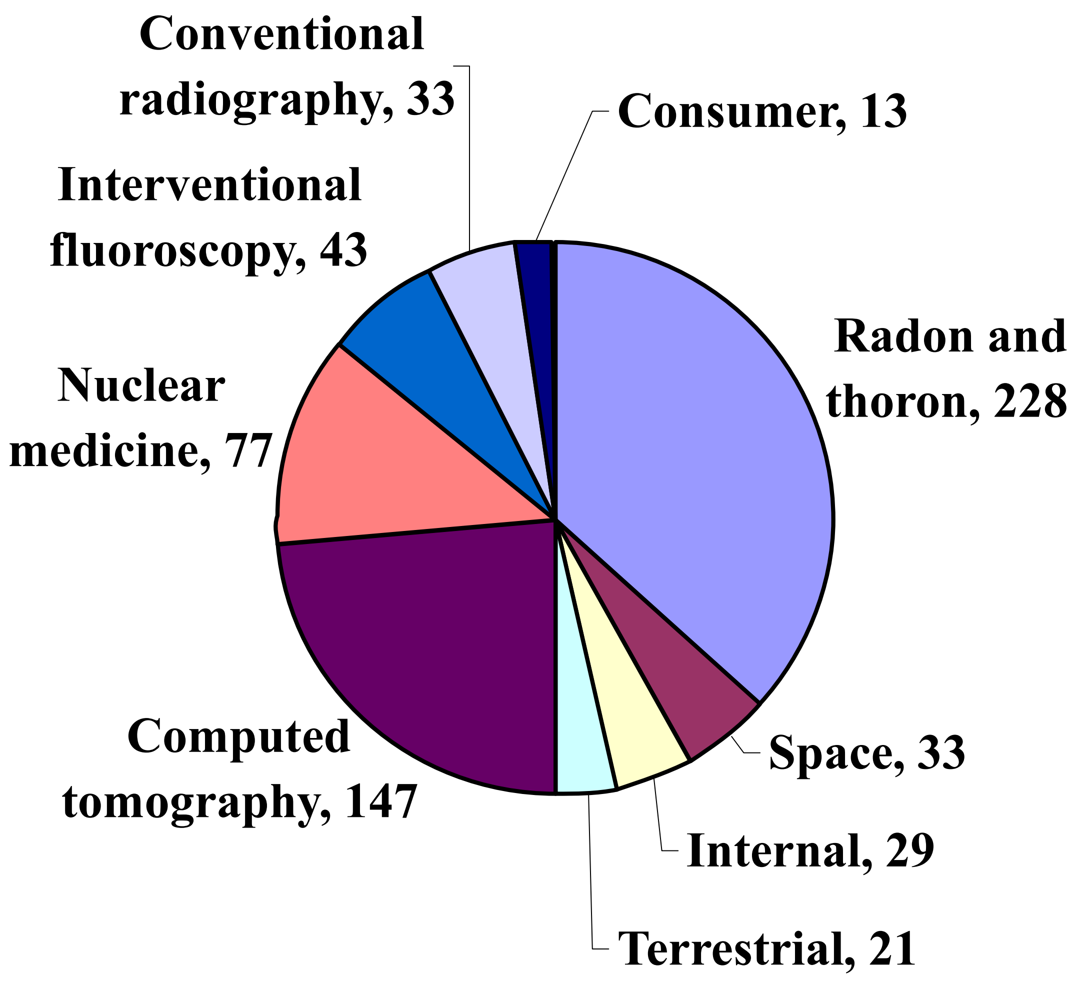


Global background radiation

Terrestrial = radiation from soil, rocks, and building materials. Other is atmospheric testing of nuclear weapons, occupational exposure, the nuclear fuel cycle, and the Chernobyl accident.



Sources of background radiation (about 620 mrem/year or 6.2 mSv/year) in the U.S.



Consumer products
(13 mrem/year or 0.13 mSv/year)

Older (c. 1930s) Fiesta ware (U)

Antique glass (U)

Bathroom tile (U)

Jewelry (U)

Camera lens (Th)

Smoke detectors (Am)

Fertilizer (^{40}K, U, Th, Ra)

Consumer products (13 mrem/year or 0.13 mSv/year)

Watches and clocks (^{3}H, ^{226}Ra)

Bricks

Cement blocks

Granite counter tops (U, Th, Ra)

Kitty litter (^{40}K, Th, U)

Food and water

Radioactivity in food

Carrots contain 2.4 pCi of uranium per pound (196 mBq/kg)

Beef contains about 4.3 pCi U/pound (350 mBq/kg)

Table salt: 12 pCi U/pound (979 mBq/kg)

Radioactivity in food

Bananas (1,140 pCi/lb) [93 Bq/kg]
Potatoes (1,955 pCi/lb) [159 Bq/kg]
Chicken (955 pCi/lb) [78 Bq/kg]
Orange juice (1,800 pCi/L)
[67 Bq/L]

All contain ^{40}K
Why? Because 0.012% of all potassium is radioactive ^{40}K.
$^{40}K \rightarrow {}^{40}Ca$ + beta radiation
Half-life = 1.3 billion years.

Nuclear medicine (77 mrem/year or 0.77 mSv/year)

Using radionuclides in diagnosis and treatment of cancers.

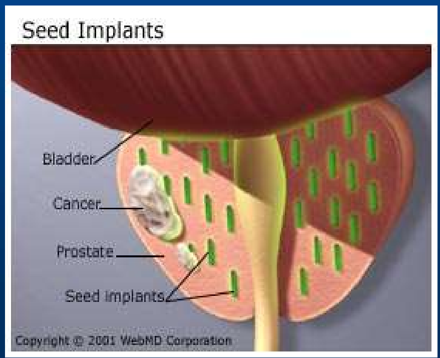
Injections of ^{99m}Tc for cancers.

Injection of tracers.

Nuclear medicine (77 mrem/year)

Diagnostic X-rays.

Radioactive pellets (seeds) containing ^{125}I and ^{89}Sr for breast, prostrate and bone cancer.



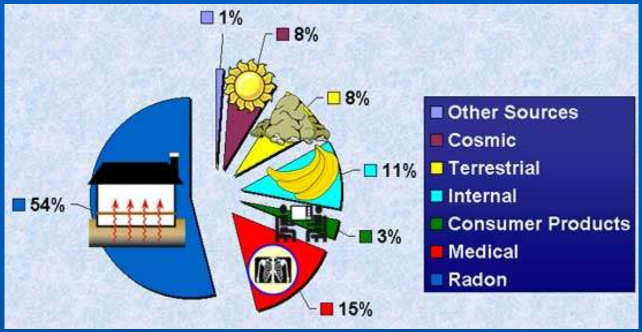
radioactive prostate seed

Internal radiation in the human body (29 mrem/year or 0.29 mSv/year)

From food: ^{40}K, U, Th, ^{14}C

Water: ^{40}K, Rn, U, Th, ^{3}H

Air: Rn



^{40}K has a biological half-life of 30 days.

The ^{40}K content in the body is constant, with an adult male having about 100,000 pCi.

This isotope yields a dose of about 18 mrem to soft tissues of the body and 14 mrem to bone per year.

Radon and Thoron (228 mrem/year or 0.23 mSv/year)

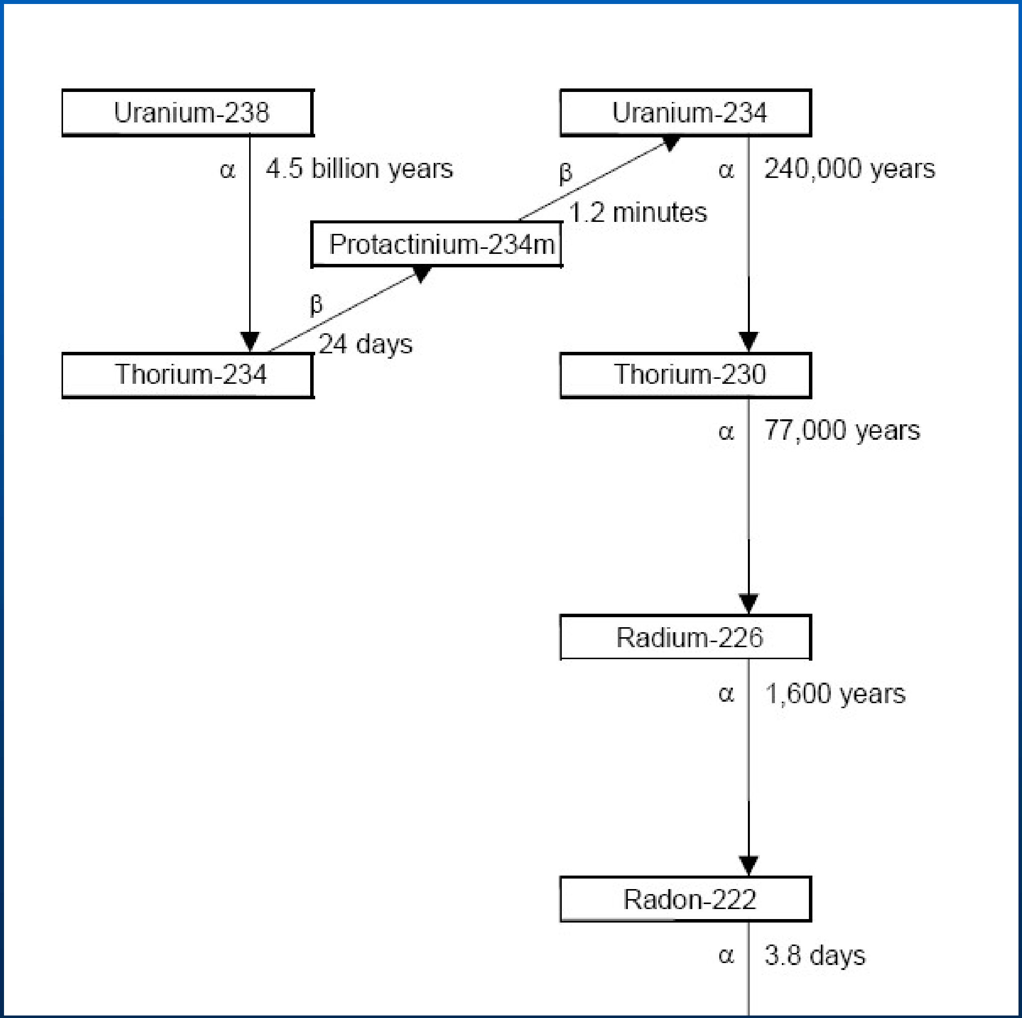
Radon (^{222}Rn)

A naturally occurring radioactive gas.

A decay product from ^{226}Ra

Causes lung cancer.

Thoron (^{220}Rn)



Radon in Illinois

Radon gas can diffuse from the ground and accumulate in homes.

Can move as a gas through the foundation.

Enter as a dissolved gas in water.

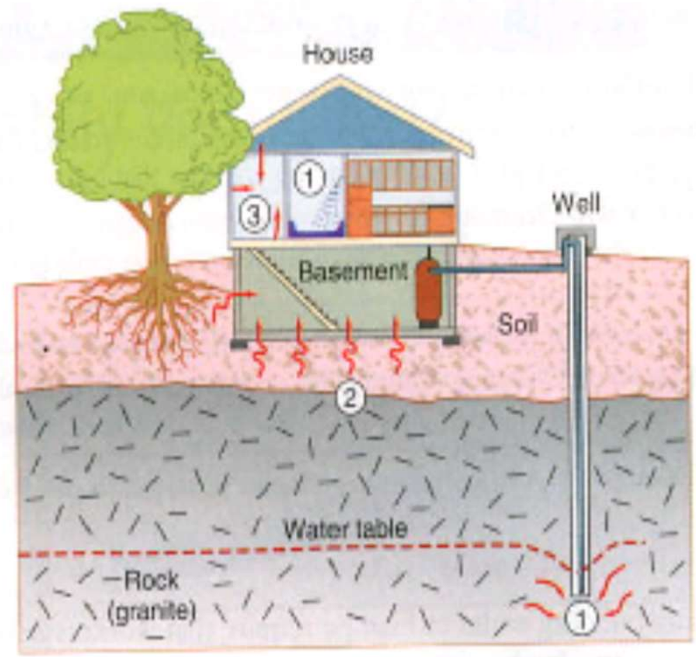


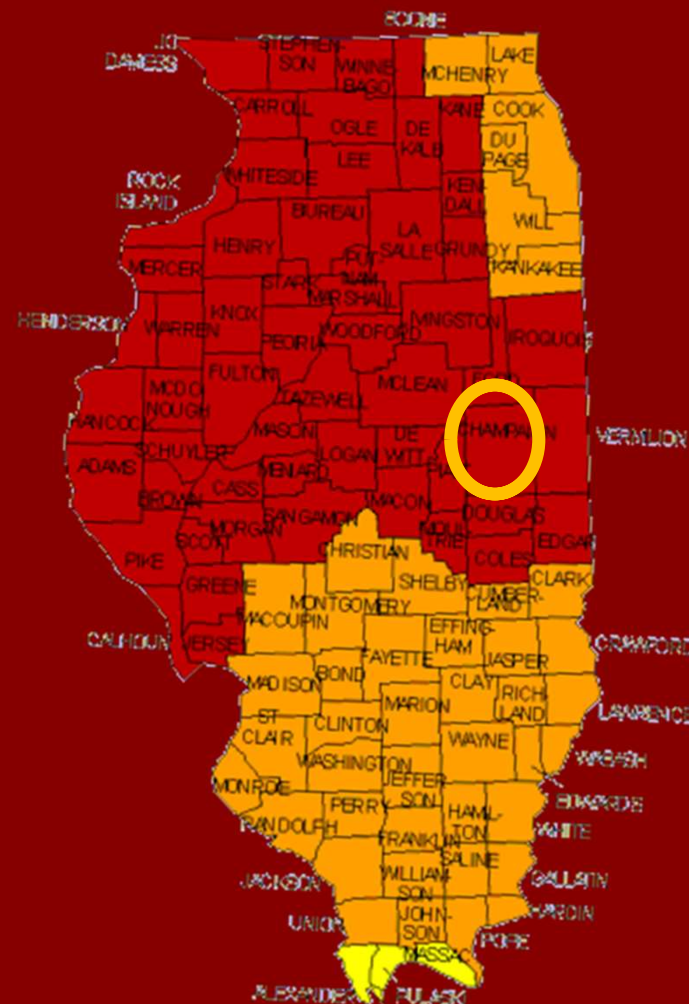
Figure 24.7 • How radon can enter homes. (1) Radon in groundwater enters a well and goes to a house, where it is used for water supply, dishwashing, showers, and other purposes. (2) Radon gas in rocks and soil migrates into a basement through cracks in the foundation and pores in construction. (3) Radon gas is emitted from construction materials used in building a house. (*Source:* Environmental Protection Agency.)

We are in an area of “high potential” for radon (> 4 pCi/L)

Zone 1 Highest Potential (greater than 4 pCi/L)

Zone 2 Moderate Potential (from 2 to 4 pCi/L)

Zone 3 Low Potential (less than 2 pCi/L)



Radon (cont)

Greater than 4 pCi/L is about 8.9 counts/min.

A high potential? Why?

Soils in this area contain 1 to 3 mg/kg uranium which is decaying to yield radon.

Because homes are built to be energy efficient, we might detect up to 6 pCi/L in a home in Urbana.

Is this a concern?

How to interpret a radon test

The accuracy of the testing devices commonly used is 6 $\pm$ 2 pCi/L.

If we think of the worst case (8 pCi/L), the level of radioactivity means that if you breath this air for 70 years and do not smoke, your chances of having cancer are 10 times the chance of dying in an airplane crash.

Terrestrial Radiation
(21 mrem/year or 0.21 mSv/year)

The naturally occurring radioactive elements in rocks, soil, fresh water, and sea water.

Crustal abundance of ^{238}U: 1 pCi/g [37 mBq/g]
U.S. soils: 0.6 pCi ^{238}U/g [22 mBq/g]

Surface water in U.S.
0.01 to 582 pCi/L U [0.4 to 21,534 mBq/L]
0.1 to 0.5 pCi/L ^{226}Ra [0.4 to 18.5 mBq/L]

Terrestrial radiation example

A NPRE 397 (*Independent Study*) research project.

Atmospheric testing of nuclear weapon from 1945 to 1962 created radioactive fallout.

Could ^{137}Cs still be detected in undisturbed, surface soil samples in Champaign County?

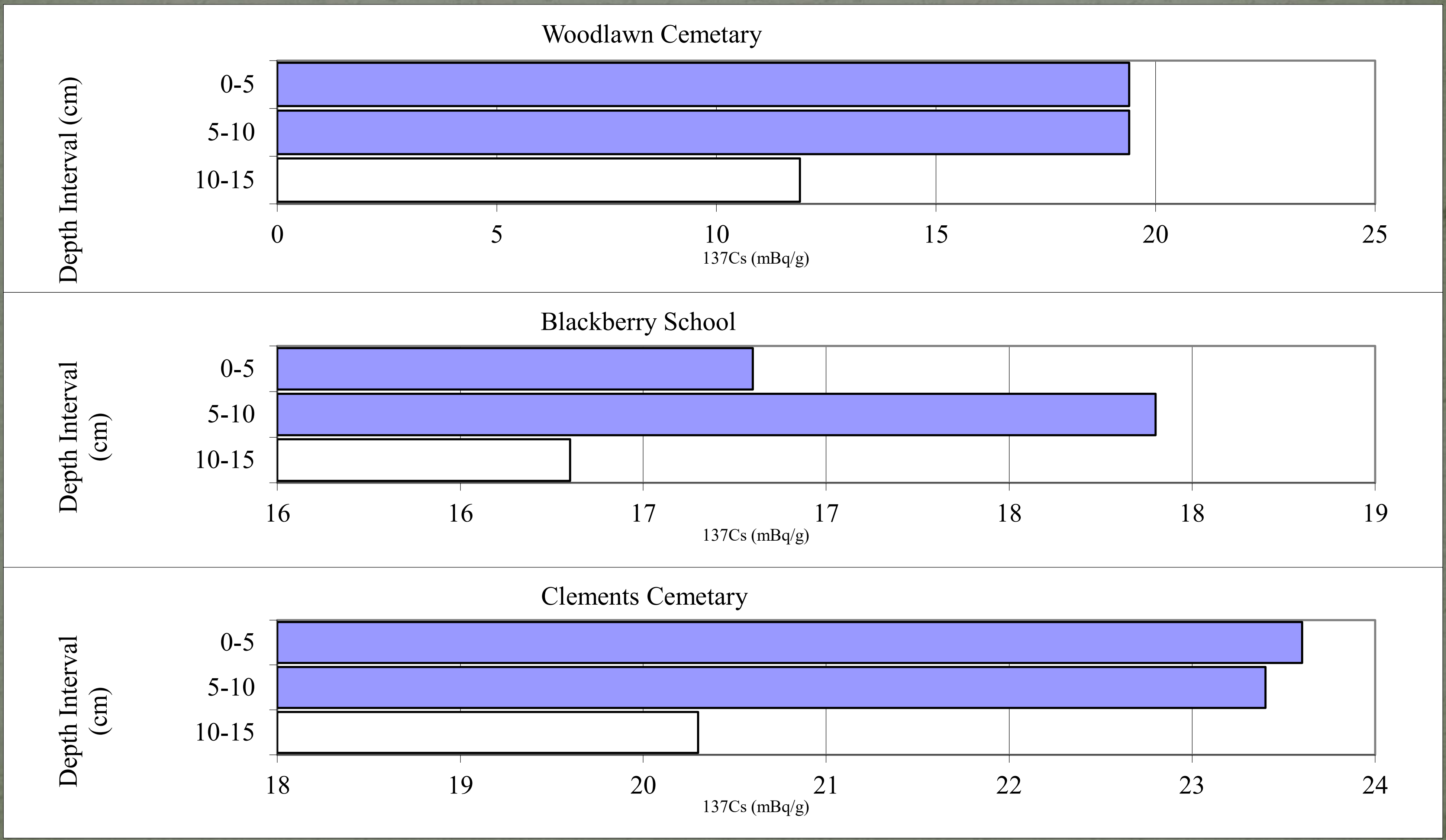
Experimental Procedures for NPRE 397

Christopher Demetriou
Engineering Manager at Constellation Energy Corp

Experimental Procedure

- After the soil samples dried:
  - Samples were sifted to separate out organic matter
  - 100 grams were placed into specialized beaker for radiation detection
  - A high purity Germanium Semiconductor Detector was used to detect any radioactivity within the sample over a two day time span
  - The detector was encased in lead bricks to shield from background radiation, but a background test was also taken

Results – Depth of the Cesium-137



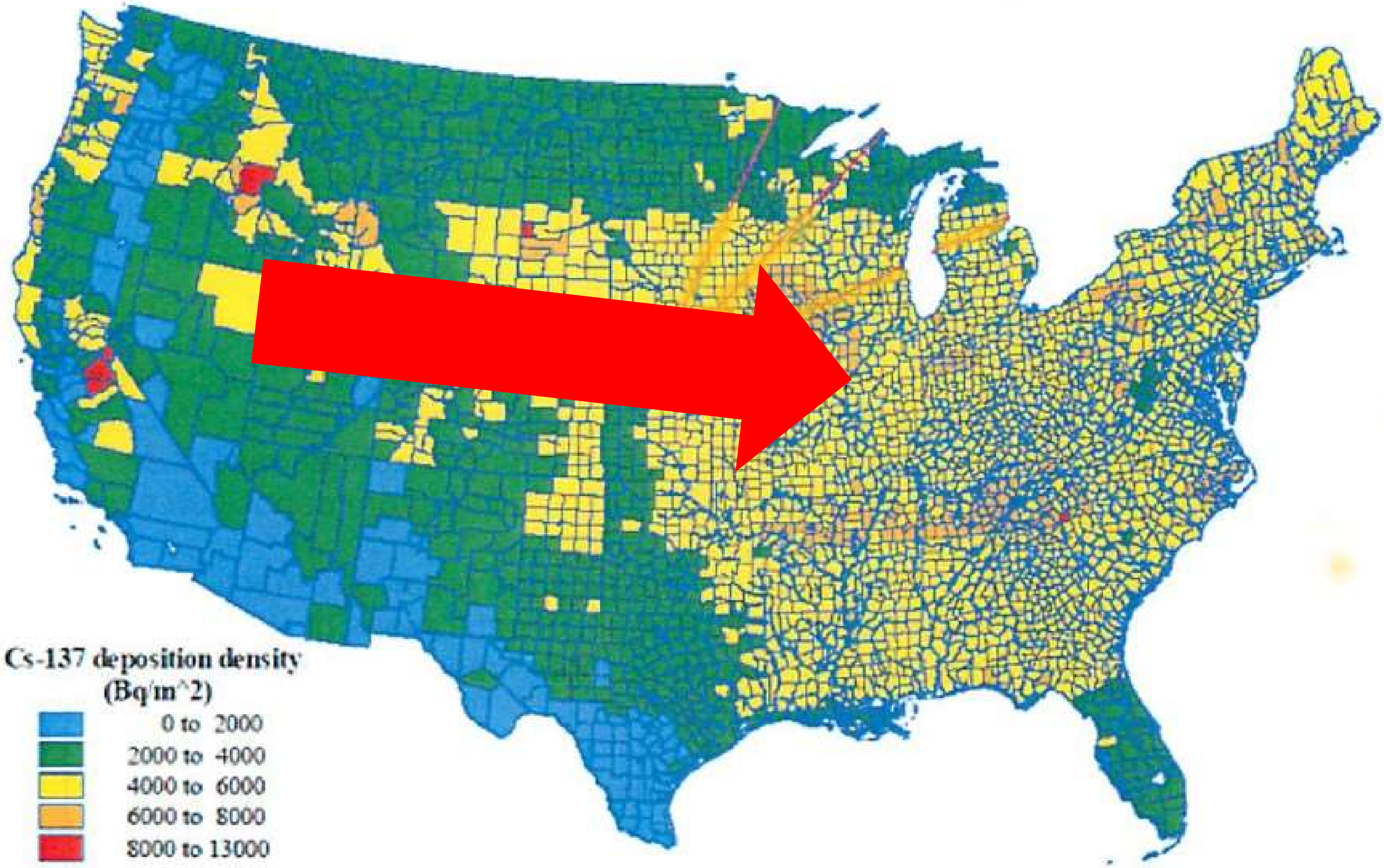


Figure 3- Cs-137 deposition from fallout and Nuclear Weapons Testing (Ref. 1, CDC-NCI, 2013)

Cosmic Radiation (33 mrem/year or 0.33 mSv/year)

High-energy particles (up to 10^{18} eV), and are mostly protons, with photons, and muons.

The amount of radiation depends on altitude: flying increase dose.

Cosmic radiation permeates all of space. The upper atmosphere interacts with cosmic radiation, and produces radioactive nuclides (cosmogenic).

Cosmic Radiation (33 mrem/year)

They can have long half-lives, but the majority have shorter half-lives than the primordial nuclides, and include ^{14}C, ^{3}H, ^{7}Be, ^{10}Be, ^{26}Al, ^{36}Cl, ^{80}Kr, ^{32}Si, ^{39}Ar, ^{22}Na, ^{35}S, ^{37}Ar, ^{33}P, ^{32}P, ^{38}Mg, ^{24}Na, ^{38}S, ^{31}Si, ^{18}F, ^{39}Cl, ^{38}Cl, ^{34m}Cl.

Half-Life Calculations

Chemical kinetics—the rate by which a chemical reaction occurs.

Zero-order reactions—the reaction rate is independent of concentration (adding more reactant will not speed up the reaction). These are rare. Often catalytic surfaces containing the reactant.

Half-Life Calculations

In a first-order reaction, the reaction rate depends on the concentration of one reactant.

That is, the more reactant, the faster the reaction. Conversely, less reactant yields a slower reaction.

Radioactive decay is a first-order reaction.

Half-Life Calculations

Keep in mind:

Other environmental contaminants such as lead, cadmium, and mercury do *not* degrade.

We must remind people that radionuclides *do* decay with time in a quantitative manner.

Some organic chemicals decay (chemical and biochemical), but the rate is uncertain and system-specific.

Half-Life Calculations

A biological half-life (T_{bio}) is the time required for the sum of all the available biological processes to eliminate one-half of the retained radionuclide.

The effective half-life (T_{eff}) is the time required for the activity of a radionuclide to be halved as a result of both radioactive decay and biological elimination.

$$T_{eff} = (T_{bio} \times t_{1/2})/(T_{bio} + t_{1/2})$$

Effective Half-Life

Table 2-2. Effective Half-Lives of Selected Radionuclides in Major Adult Body Organs

Radionuclide	Critical organ	Half-life		
		Physical	Biological	Effective
Tritium (^{3}H)[a]	Whole body	12.3 yr	12 d	12d
Iodine-131 (^{131}I)	Thyroid	8 d	138 d	7.6 d
Strontium-90 (^{90}Sr)	Bone	28 yr	50 yr	18 yr
Plutonium-239 (^{239}Pu)	Bone	24,400 yr	200 yr	198 yr
	Lung	24,400 yr	500 yr	500
Cobalt-60 (^{60}Co)	Whole body	5.3 yr	9.5 d	9.5 d
Iron-55 (^{55}Fe)	Spleen	2.7 yr	600 d	388 d
Iron-59 (^{59}Fe)	Spleen	45.1 d	600 d	41.9 d
Manganese-54 (^{54}Mn)	Liver	303 d	25 d	23 d
Cesium-137 (^{137}Cs)	Whole body	30 yr	70 d	≈70 d

[a] Mixed in body water as tritiated water
d = days; yr = years

Exposure and Risk

Where do the data come from?

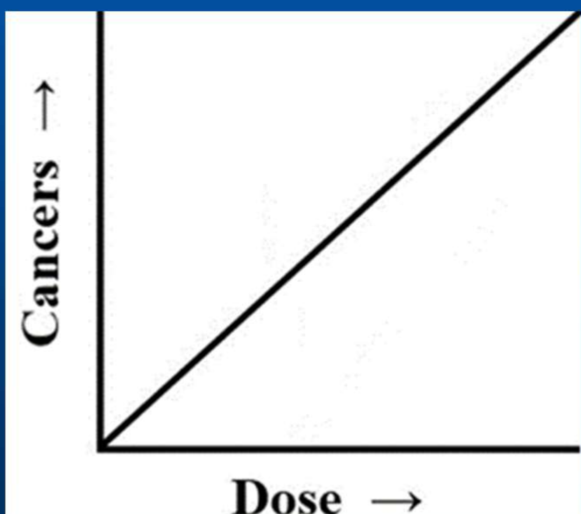
1. Survivors of Hiroshima and Nagasaki.

2. Patients exposed to medical radiation.

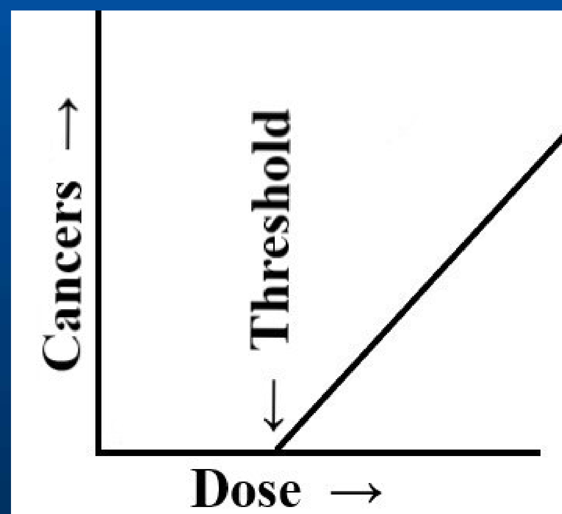
3. Occupational exposure in the nuclear industry.

Exposure and Risk

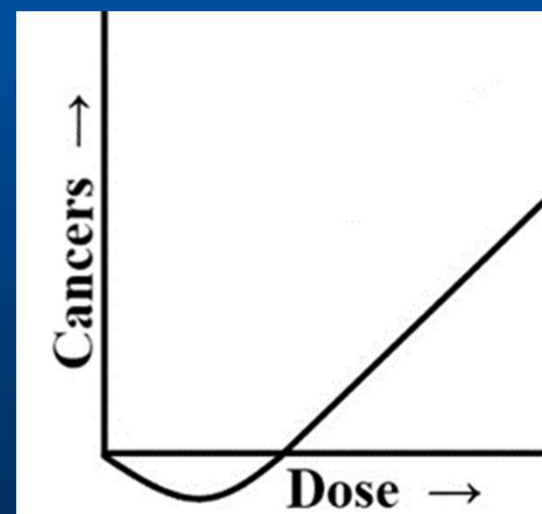
The Linear-No-Threshold Model (a), Threshold Model (b), and the Hormesis Model (c).



(a)



(b)



(c)

Exposure and Risk

The linear, no threshold model (LNT) is used by the U.S. EPA, FDA, and NRC. Has been called "a regulatory convenience."

The LNT model is most radiologically conservative.

The use of the LNT model implies that *any* exposure to radiation poses some health risk, i.e. there is *no* safe dose.

Limitations in using the LNT model

The relation between risk and dose at small levels of radiation is not well understood.

Most of the data based on large levels of exposure. “Hiroshima should not be the gold standard.”

If 1,000 aspirin kills one person (taken all at once), then does it follow that 1 aspirin should kill one person out of 1,000?

Limitations in using the LNT model

Background cancer rate is 0.20 (1 in 5).

At small levels of radiation, difficult to differentiate noise from signal. Smallest dose the epidemiologist can measure risk reliably is about 10 rem.

Cancer development is complicated.

Not all cancers are diseases. Cells become damaged everyday and repair themselves; a normal process of life.

Limitations in using the LNT model

People often have cancerous cells, but progression to full malignancy is rare.

Non-target cells (not hit by radiation) can "communicate" with impacted cells.

Cancers appear years after exposure (long latent period).

Limitations in using the LNT model

Linearity is in question: may depend on the organ.

Breast cancer is thought to be linear.

Bone cancer from radium exhibits a threshold dose response.

Deterministic Model

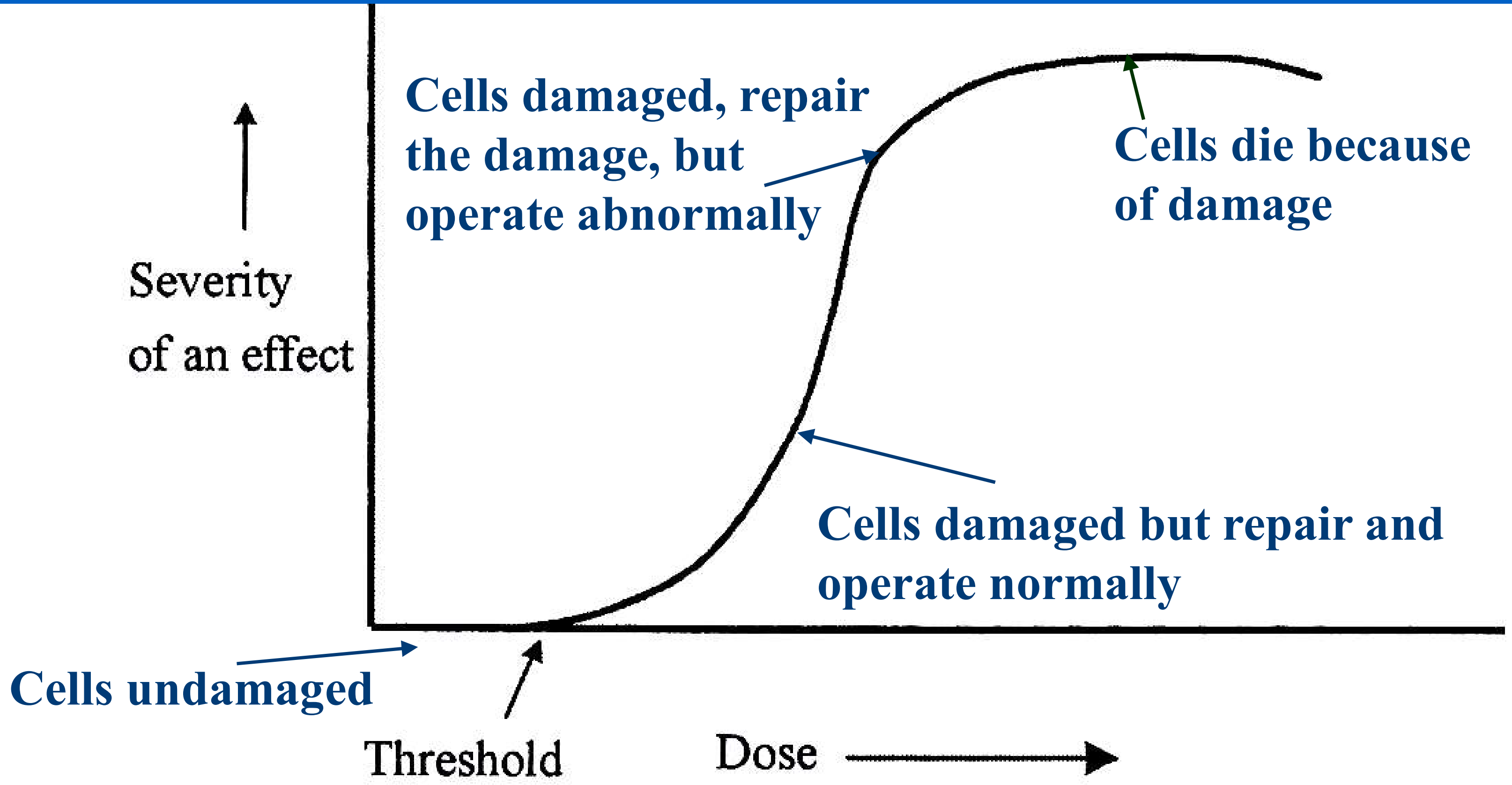
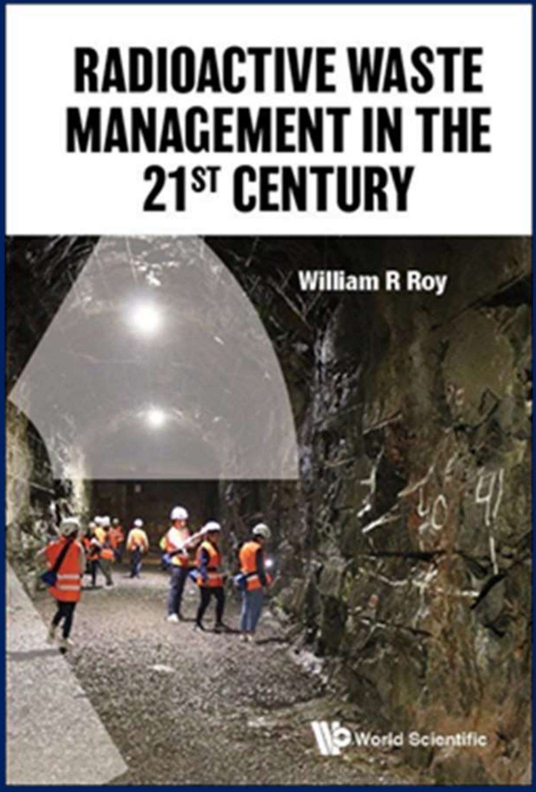


Fig. 2.2 *Deterministic effects of radiation*

Class Assignment 1

Read the Preface in the course textbook.



Questions?