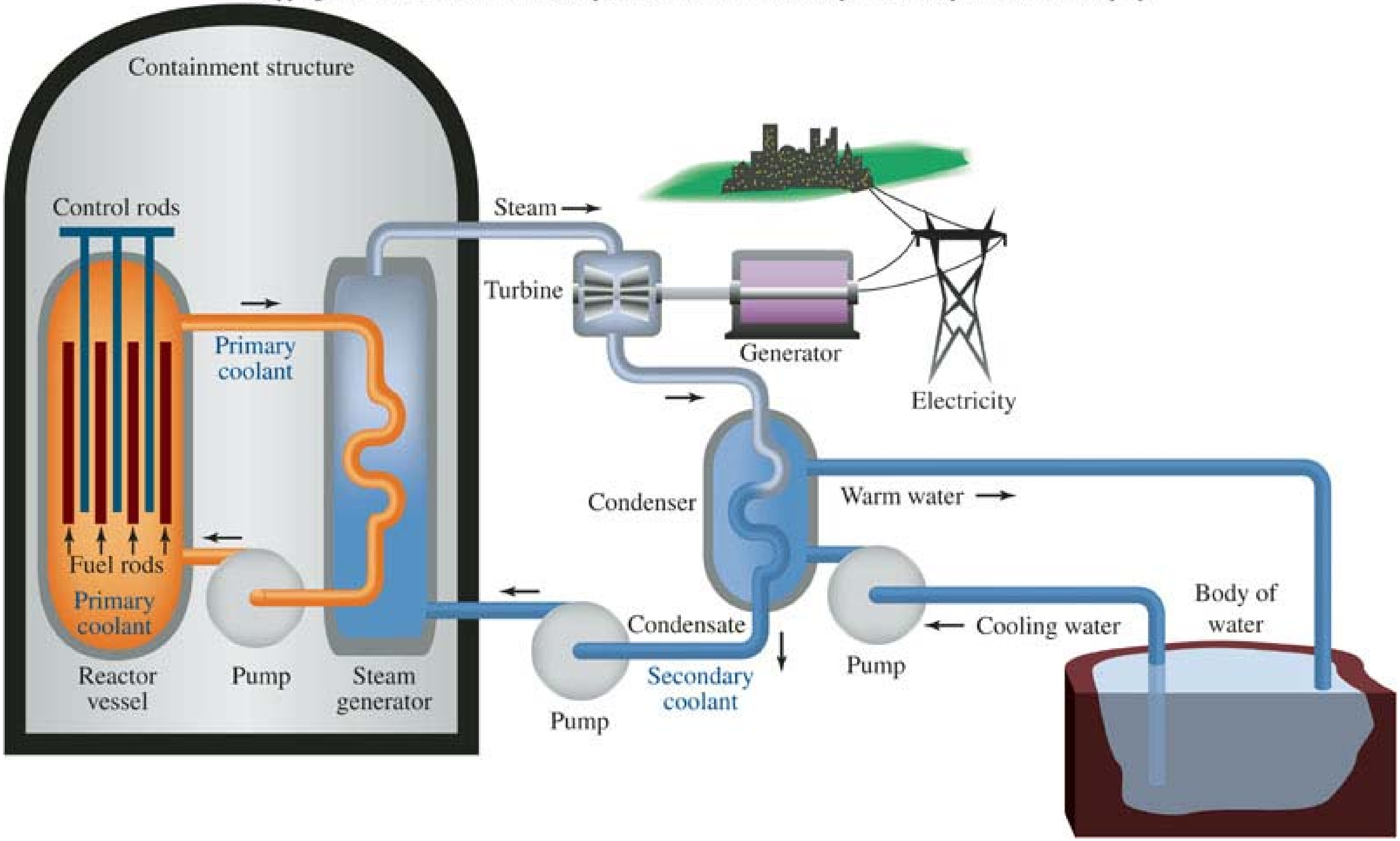
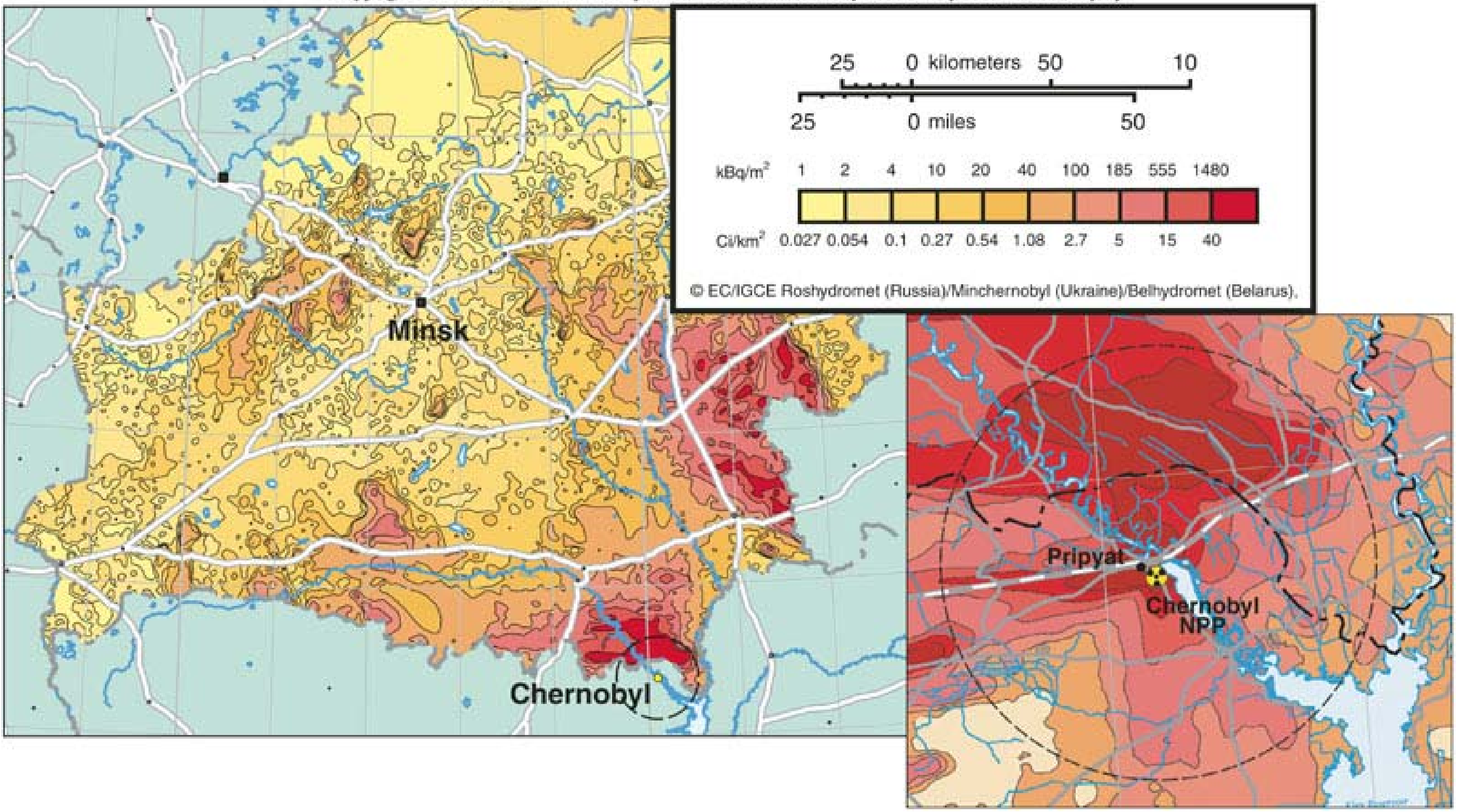
A Nuclear Power Plant



Fallout from Chernobyl



The question that all countries asked in 1986, and continue to ask to this day:
Could it happen here?

Radioactivity

$$^{239}_{93}Np \rightarrow ^{239}_{94}Pu + ^{0}_{-1}e$$

“Beta decay” – the unstable nucleus emits an electron, converting a neutron into a proton

This is “radioactivity” – defined by Marie Curie as the spontaneous emission of radiation

There are two major processes of emission – alpha emission and beta decay

Alpha emission involves the emission of 2 protons and 2 neutrons – the nucleus of a Helium atom!

$$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$$

In addition, many processes emit radiation without emitting particles

On such form of high energy radiation is termed gamma rays

Types of Radioactivity

Table 7.2 Types of Nuclear Radiation

Type	Symbol	Consists of	Charge	Change to nucleus that emits it
Alpha	${}^{4}_{2}He$	2 protons 2 neutrons	2+	The mass number decreases by 4, and the atomic number decreases by 2.
Beta	${}^{0}_{-1}e$	an electron	1−	The mass number does not change, and the atomic number increases by 1.
Gamma	${}^{0}_{0}\gamma$	photon of energy	0	No change in either the mass number or in the atomic number.

Radioactivity

How do you know if a particular isotope is radioactive?

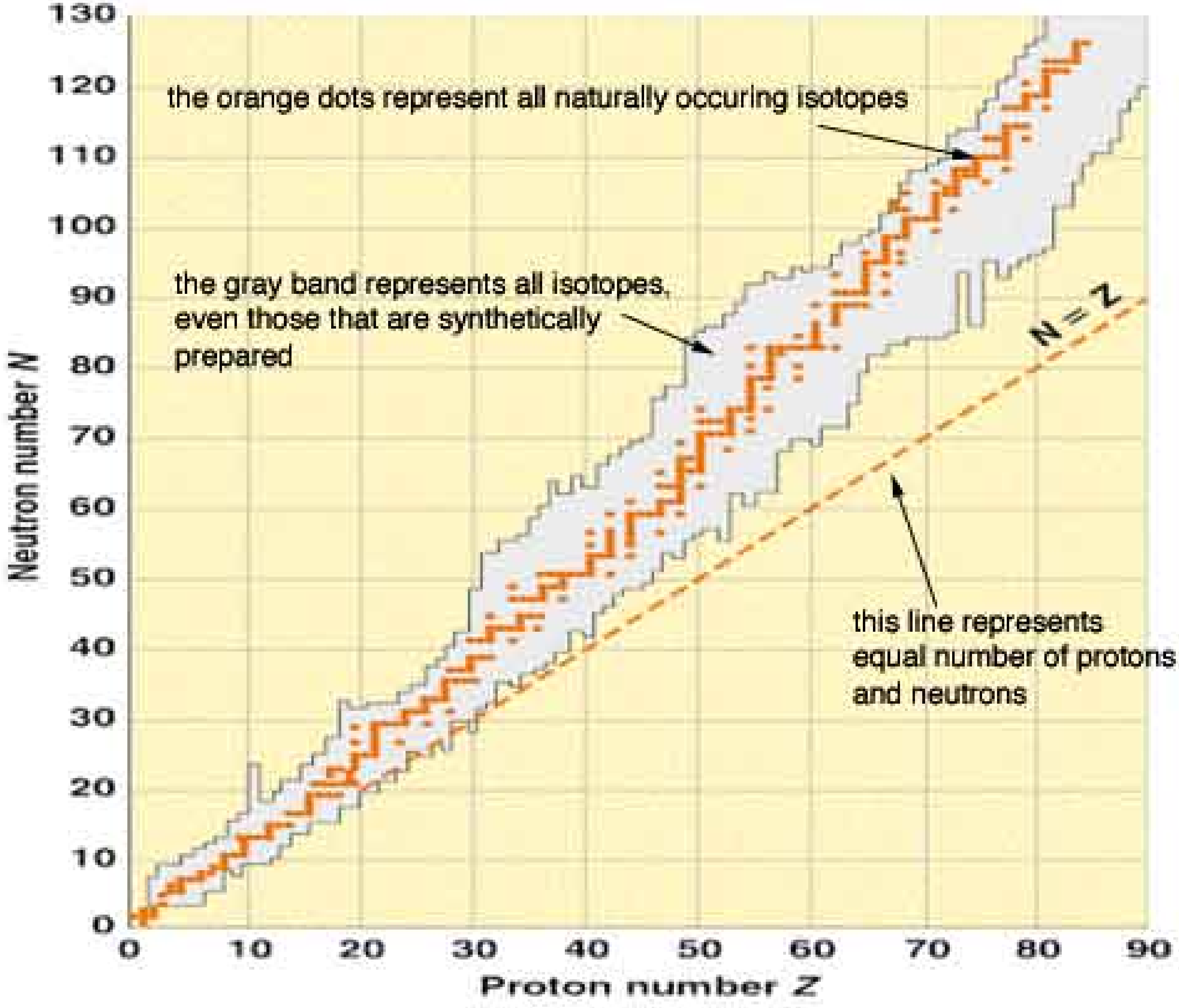
- ALL elements with atomic number ≥ 84 are radioactive
- Some lighter isotopes are also radioactive, but are much harder to predict (C-14, H-3, K-40)

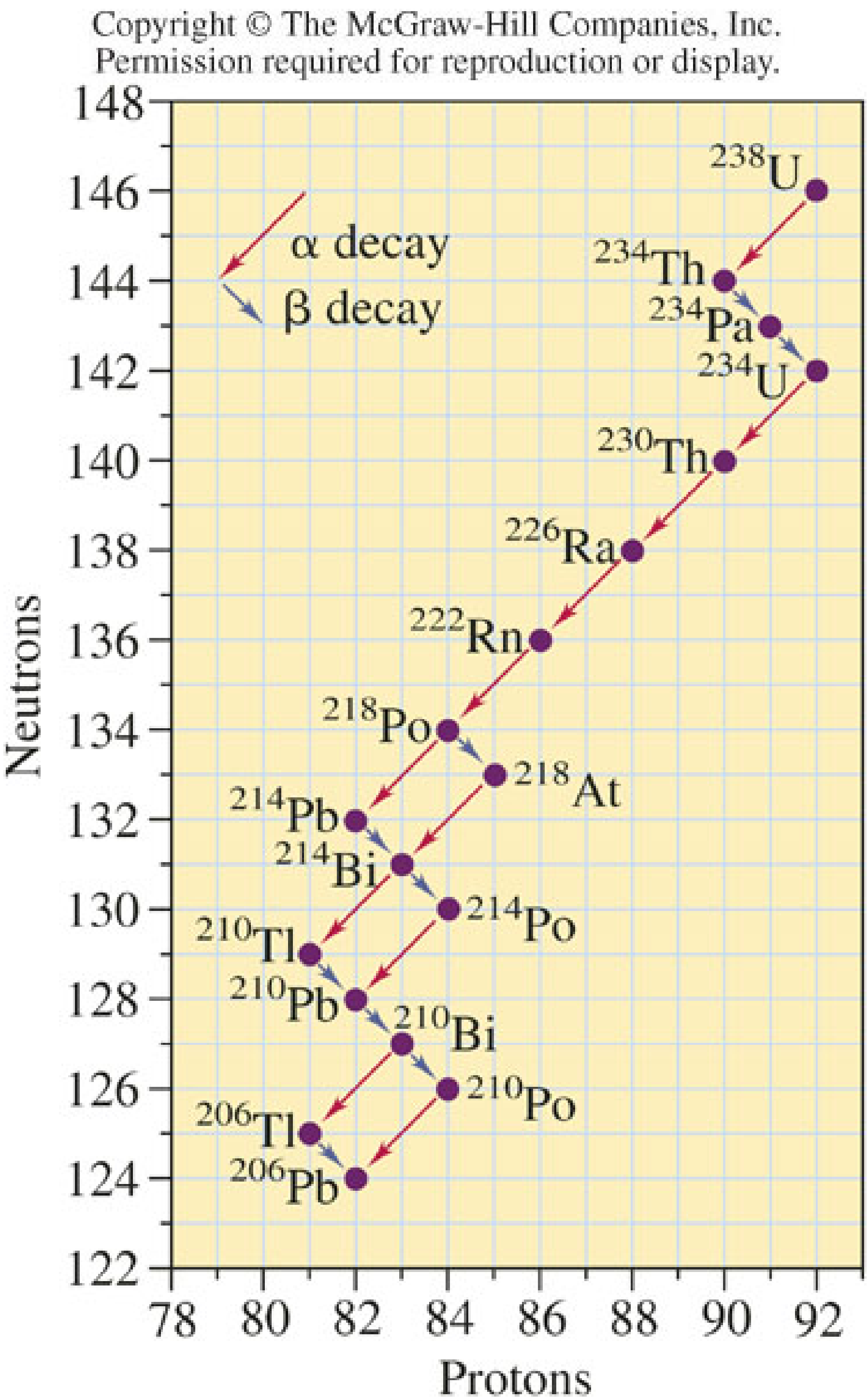
Even if you know an isotope is radioactive, how do you know *what kind* of emission an element will undergo?

Calculate the ratio of neutrons to protons, and compare to those isotopes which are known to be stable:

- The “Belt of Stability”

The Belt of Stability





Even then, it's not trivial to predict the sequence of steps a **radioisotope** will take on its path towards stability

An example:

The **Radioactive Decay Series** of U-238

Eventually, U-238 decays to Pb-206

But this takes several steps, and can take millions of years (or more)

Note: Radon-222

The Hazards of Radioactivity

Often, alpha and beta particles and gamma rays possess enough energy to damage living cells by altering their molecule structure

The damage is greatest in cells which are growing rapidly

This is why radiation treatment is often effective in limiting the growth of cancer

But *other* rapidly growing cells are also affected: bone marrow, skin, hair follicles, stomach, intestines

The Hazards of Radioactivity

Radiation sickness results from overexposure.

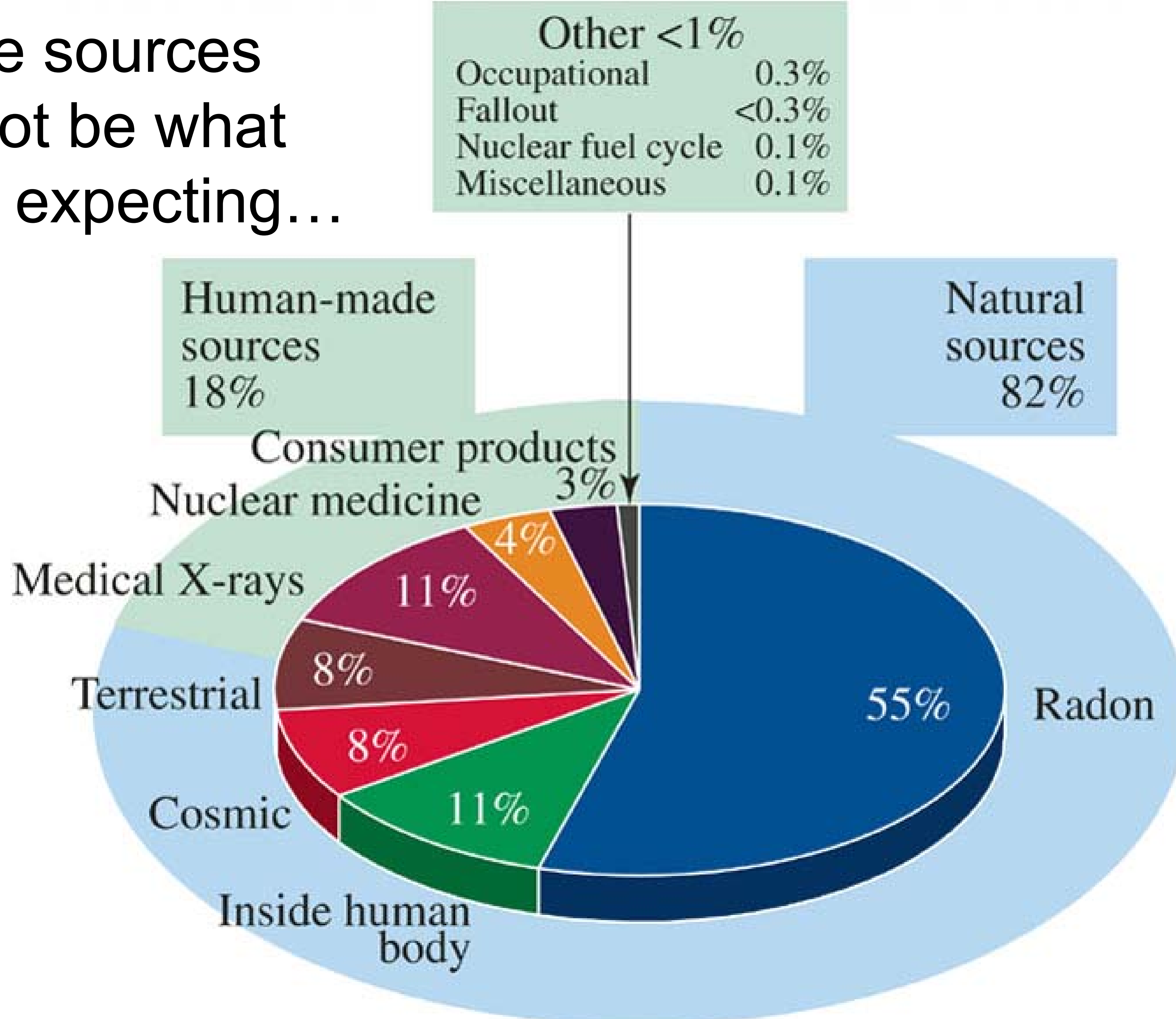
Early symptoms include anemia, malaise and susceptibility to infection

Victims exposed to even greater doses of radiation often sustain damage to their DNA

This leads to cancers and birth defects, and has been observed in the areas around Chernobyl, Hiroshima, Nagasaki

Despite our best precautions, everyone in the modern world is constantly exposed to low levels of radiation

But the sources may not be what you’re expecting…



Your Exposure to Radioactivity

Your exposure comes from cosmic rays, radon, soil and rock

But also from your own body

Carbon:

Your body contains ~ 10^{26} C atoms

Of these, 10^{14} are C-14, and radioactive

With every breath, you breathe in another 10^{6} C-14 atoms

Potassium:

.01% of all the K+ ions that drive your muscles are K-40, and radioactive

There are thousands of K-40 decays in your body every second

Your Exposure to Radioactivity

How do we measure the amount of radioactivity?

Curies (Ci): How much does the sample decay?

1 Ci = 3.7×10^{10} disintegrations per second

The amount of radiation given off by one gram of Radium, the element which Marie Curie used to study radioactive decay

Radioactivity in chemical and biological labs can range as high as several mCi

Recall the dosages surrounding Chernobyl – up to 40 Ci

Your Exposure to Radioactivity

- How do we measure the amount of radioactivity?
- Rad: How much does a body absorb?
  - 1 rad = .01 Joules per kg of tissue
  - So, a 70 kg man who absorbs .7 Joules of radiation has received 1 rad
  - Less than 1 Joule of total energy!
- The effect of radiation depends on more factors than simply the total amount of energy absorbed

Your Exposure to Radioactivity

The effect of radiation depends on more factors than simply the total amount of energy absorbed

Some types of radiation are more dangerous than others

Q: a factor that describes how dangerous a particular kind of radiation is

$Q \equiv 1$ for β, γ, X-Rays

$Q = 20$ for α particles: they are heavier, and inflict more damage if they are absorbed by the body

Your Exposure to Radioactivity

The effect of radiation depends on more factors than simply the total amount of energy absorbed

Rem: a composite of rad and Q

number of rems = Q x (number of rads)

A 10 rad dose of β particles is a

1 x 10 = 10 rem dose

A 10 rad dose of α particles is a

20 x 10 = 200 rem dose

The rem is defunct, and has been replaced by the Stievert (Sv):

1 Stievert = 100 rem

How much is too much?

Table 7.3 Physiological Effects of a Single Dose of Radiation

Dose (rem)	Dose (Sv)	Likely effect
0–25	0–0.25	No observable effect
25–50	0.25–0.5	White blood cell count decreases slightly
50–100	0.5–1	Significant drop in white blood cell count, lesions
100–200	1–2	Nausea, vomiting, loss of hair
200–500	2–5	Hemorrhaging, ulcers, possible death
>500	>5	Death

Table 7.4 Your Annual Radiation Dose

Source of Radiation	(µSv/yr)
1. Location of your town or city	
a. Cosmic radiation at sea level (U.S. average 260 µSv*)	260
b. Additional dose if you are above sea level	____
1000 m (3300 ft) add 100 µSv	
2000 m (6600 ft) add 300 µSv	
3000 m (9900 ft) add 900 µSv	
2. House construction	
Building materials contain tiny amounts of radioisotopes.	
Brick (700 µSv); wood (300 µSv); concrete (70 µSv)	____
3. Ground	
Radiation from rocks and soil (U.S. average)	260
4. Food, water, and air (U.S. average)	400
5. Fallout from nuclear weapons testing (U.S. average)	40
6. Medical and dental X-rays	
a. Chest X-ray (100 µS)	____
b. Gastrointestinal tract X-ray (5000 µSv)	____
c. Dental X-rays (100 µSv each visit)	____
d. Other X-rays (estimate)	____
7. Jet travel (exposure to cosmic radiation)	
A 5-hour flight at 30,000 ft is 30 µSv	____
8. Other	
Live within 50 miles of a nuclear plant site, add 0.09 µSv	____
Live within 50 miles of a coal-fired power plant, add 0.3 µSv	____
Use a computer terminal, add 1 µS	____
Go through X-ray check stations at airports, add 0.02 µSv	____
Smoke 1.5 packs of cigarettes a day, add 13,000 µSv	____
Your Total Annual Dose of Radiation	____
U.S. annual average = 3600 µSv	

*Based on the "BEIR Report III," National Academy of Sciences, Committee on Biological Effects of Ionizing Radiation 1987. *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation.* Washington, DC: National Academy of Sciences.

How much is too much?

The physiological effects of radiation exposure are not usually noticeable for doses under 0.25 Sv

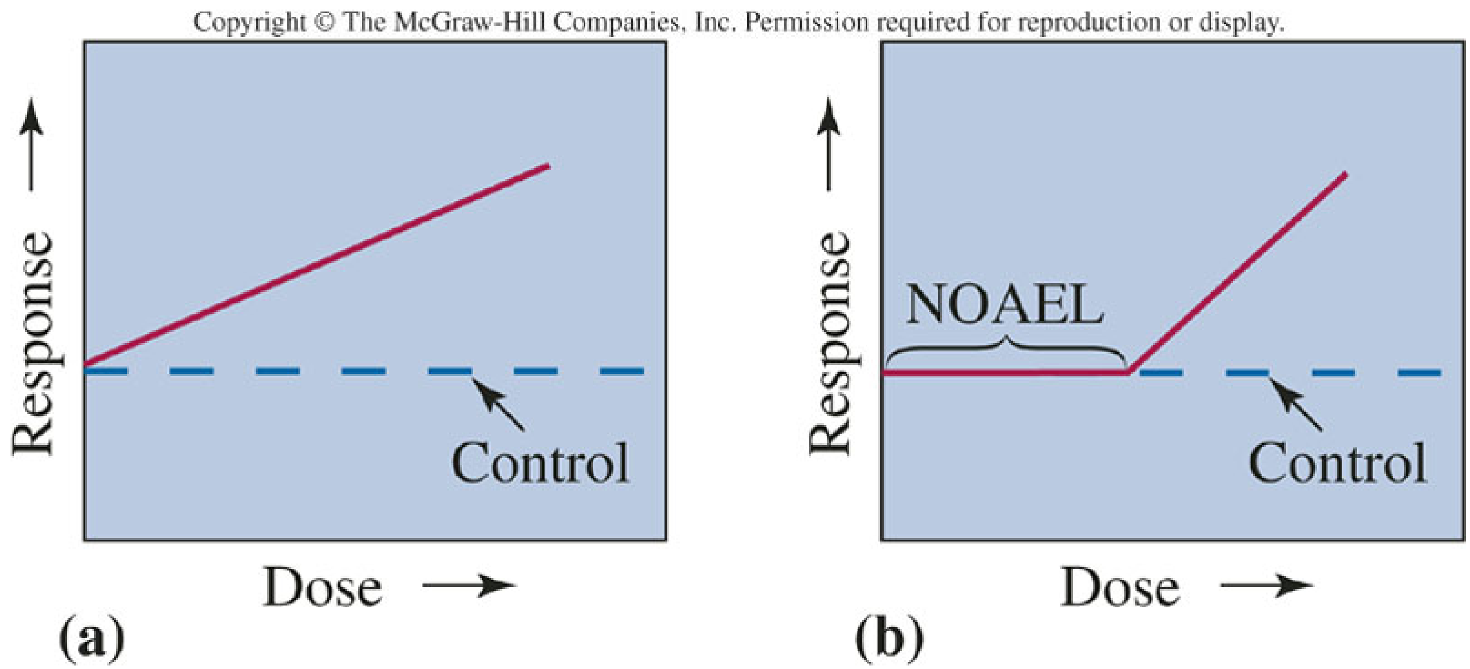
This is nearly 70 times the *average* annual exposure for someone in the U.S.

But this doesn’t *necessarily* mean that such doses are safe

Scientists are still unsure about the effects of long-term exposure to small doses

If you double your exposure, do you double your risk for leukemia?

Does that relationship hold *no matter how low your original dosage was?*



Two different models emerge:

Linear non-threshold model:

There is no dose of radiation which is safe

If you double your exposure, you double your risk

Threshold model:

There is an amount of radiation which the cells can absorb without damage

Only when this level is exceeded does damage occur

How long does spent fuel remain radioactive?

Recall that many radioisotopes undergo several steps in their decay chain before arriving at a stable species – a species which is no longer radioactive

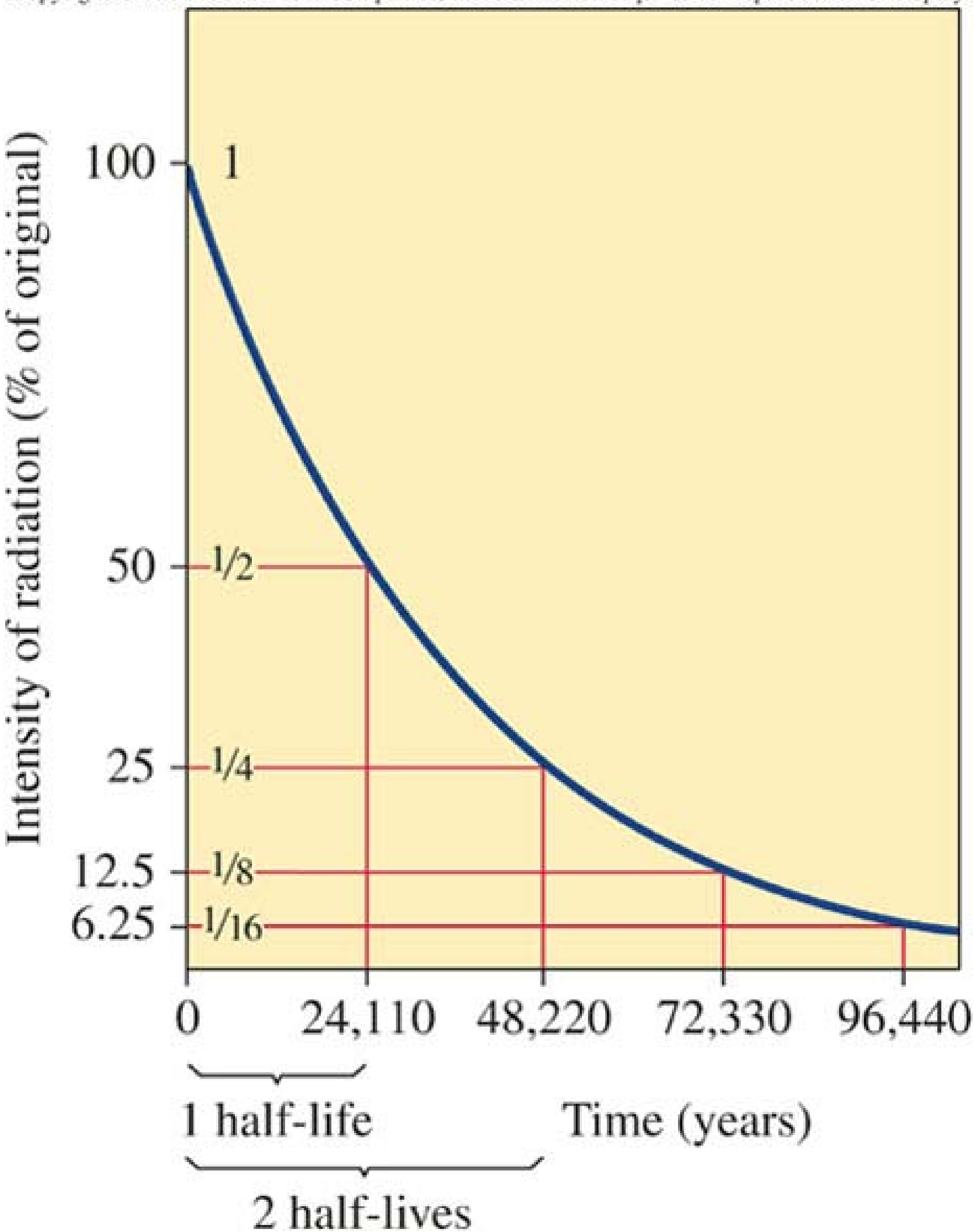
Each step in that chain can vary in its rate, from milliseconds to billions of years

We describe the rate of such processes by their **half-life**:

The length of time it takes for the original amount of the substance to be cut in half

Does not depend on temperature, pressure, environment

Does not depend on how much of the substance is present!



Pu-239 has a half-life of 24,110 years

If we start with 100 atoms of Pu-239:

In 24,110 years there will be 50 atoms remaining

After *another* 24,100 years, there will be 25 atoms remaining

Note: the amount remaining never actually goes to zero!

Table 7.5 Half-Lives for Selected Isotopes

Radioisotope	Half-life
Uranium-238	4.5×10^9 years
Potassium-40	1.3×10^9 years
Plutonium-239	24,110 years
Carbon-14	5715 years
Cesium-137	30.2 years
Strontium-90	29.1 years
Thorium-234	24.1 days
Radon-222	3.82 days
Iodine-131	8.04 days
Plutonium-231	8.5 minutes
Polonium-214	0.00016 seconds

Recall: the spent fuel from a nuclear power plant ends up as Pu-239 – with a half-life of 24,110 years.

What will we do with waste that is toxic for such a length of time?

C-14 dating

Carbon-14 has a half-life of 5715 years
Its decay process is a beta decay yielding Nitrogen-14:

$$^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}e$$

C-14 is formed naturally in the upper atmosphere by cosmic rays, and incorporated into carbon dioxide
This then mixes throughout the atmosphere, and 1 in every 10^{12} CO_2 molecules contains C-14
Thus, the 1 in 10^{12} ratio is maintained by any organic matter which relies on CO_2 for its respiration
When the organism dies, it stops respiring, and the C-14 begins to decay
By measuring the ratio of C-14 to C-12, and comparing to the 1 in 10^{12} “starting” ratio, we can tell how much times has passed since the organism died

LETTERS DUE ONE WEEK FROM TODAY

Yes, it’s only 2 pages, but it’s also 20% of your final grade