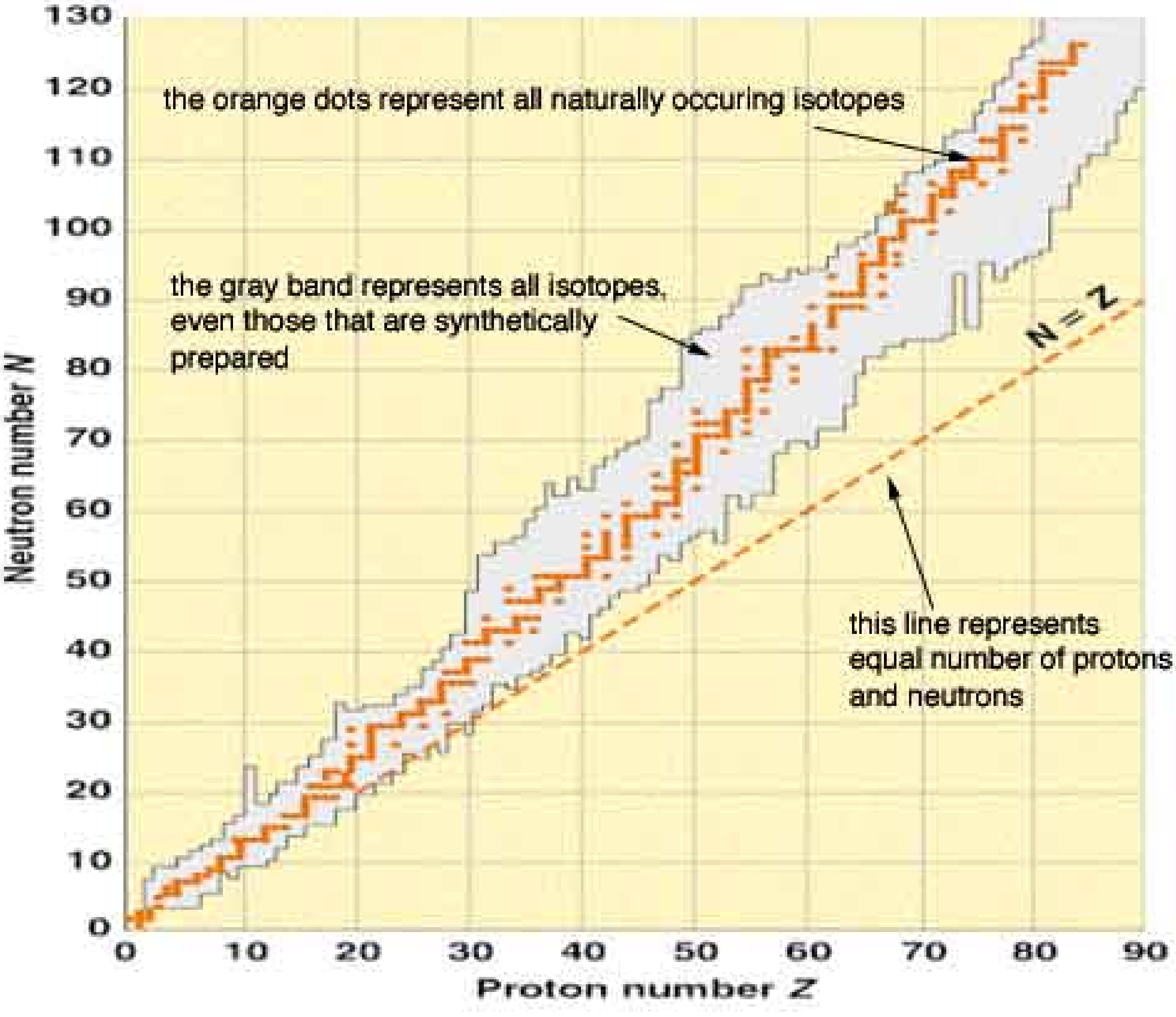
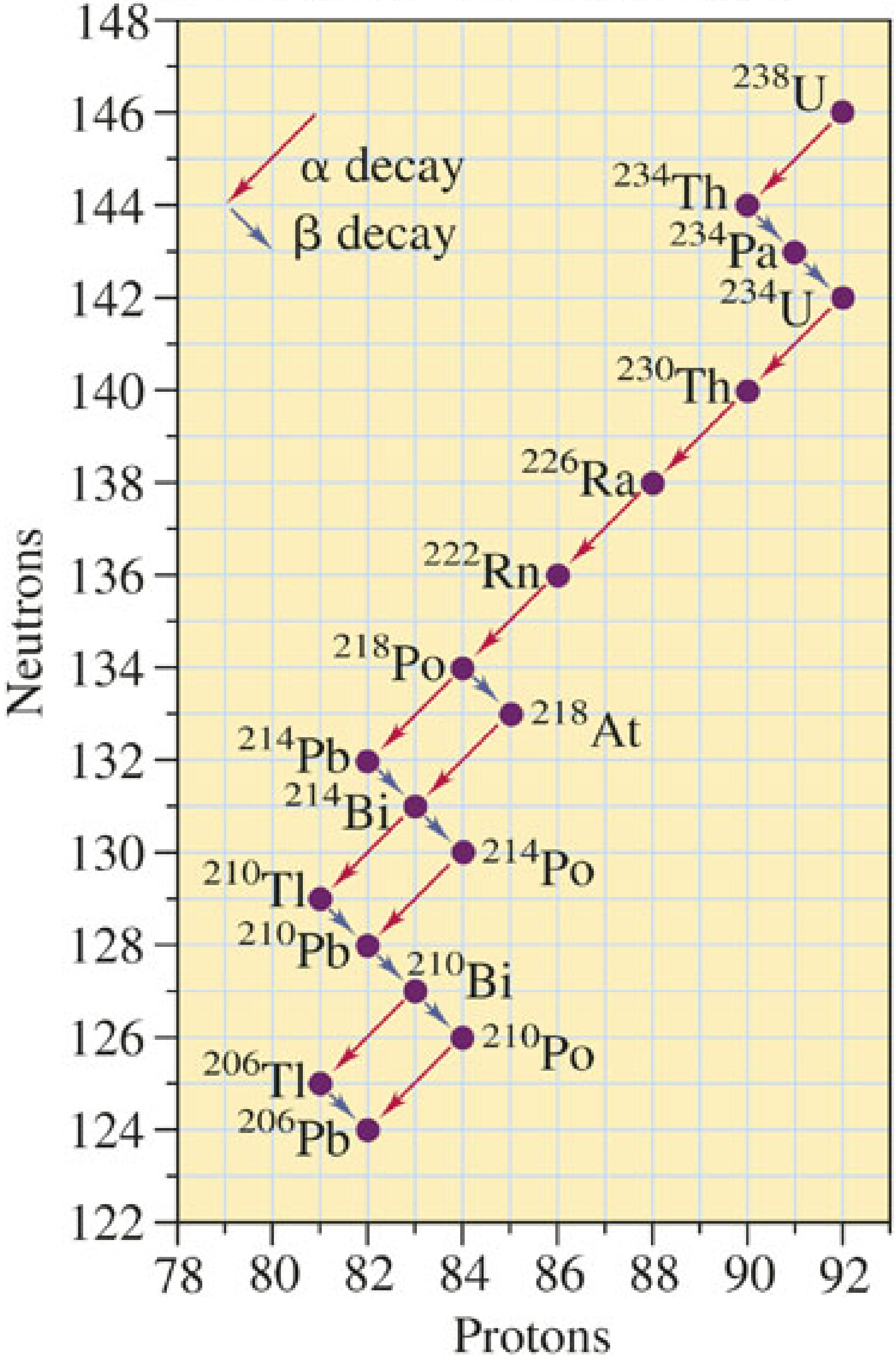
The Belt of Stability

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Protons
α decay
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^{234}U
^{230}Th
^{226}Ra
^{222}Rn
^{218}Po
^{218}At
^{214}Pb
^{214}Bi
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^{210}Tl
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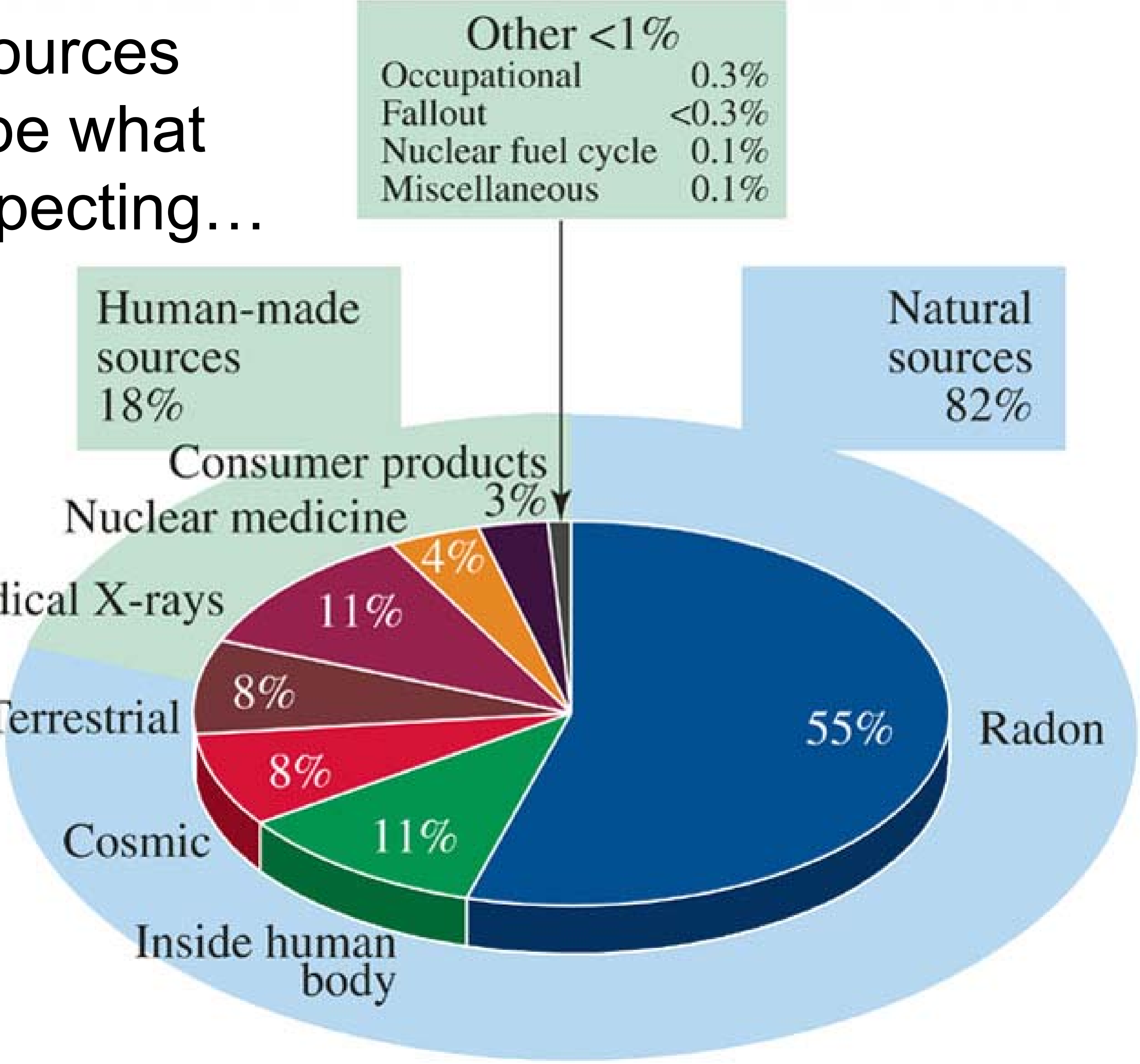
^{210}Bi
^{210}Po
^{206}Tl
^{206}Pb

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



Your Exposure to Radioactivity

How do we measure the amount of radioactivity?

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

$1 \text{ Ci} = 3.7\text{x}10^{10}$ disintegrations per second

Rad: How much does a body absorb?

1 rad = .01 Joules per kg of tissue

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

Rem: a composite of rad and Q

number of rems = Q x (number of rads)

Stievert (Sv):1 Stievert = 100 rem

How much is too much?

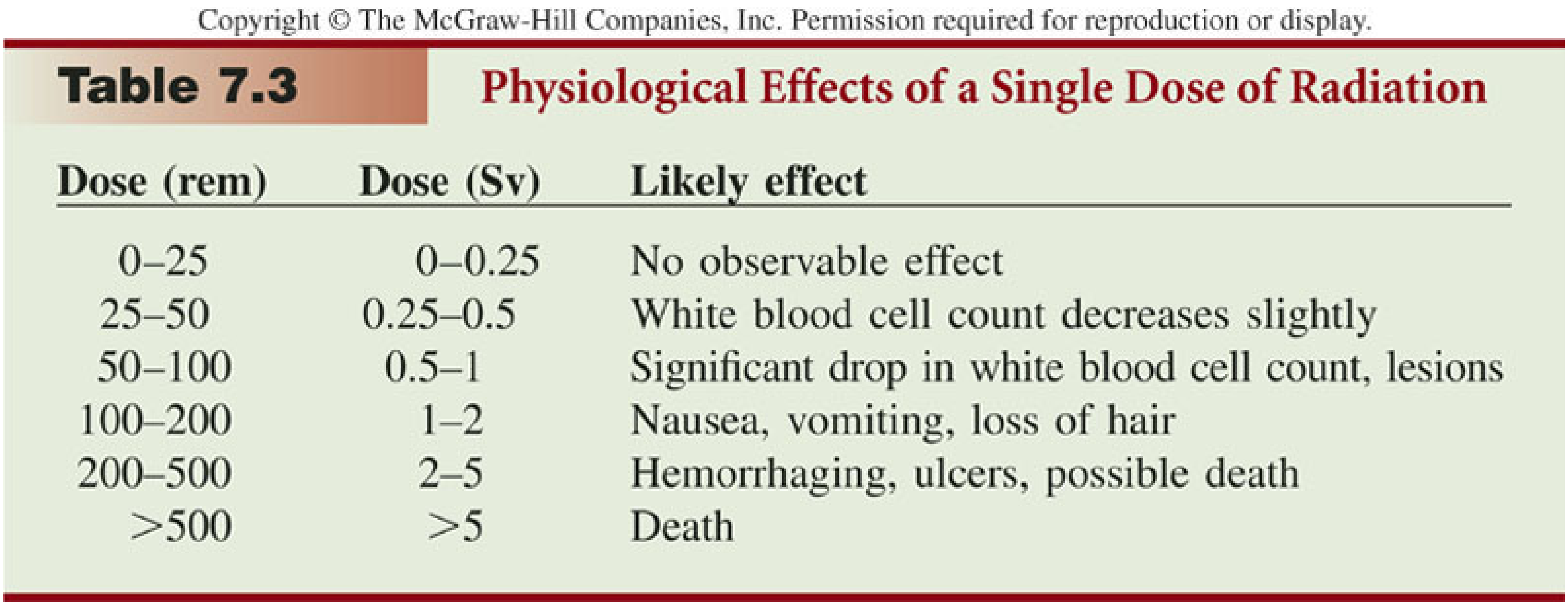
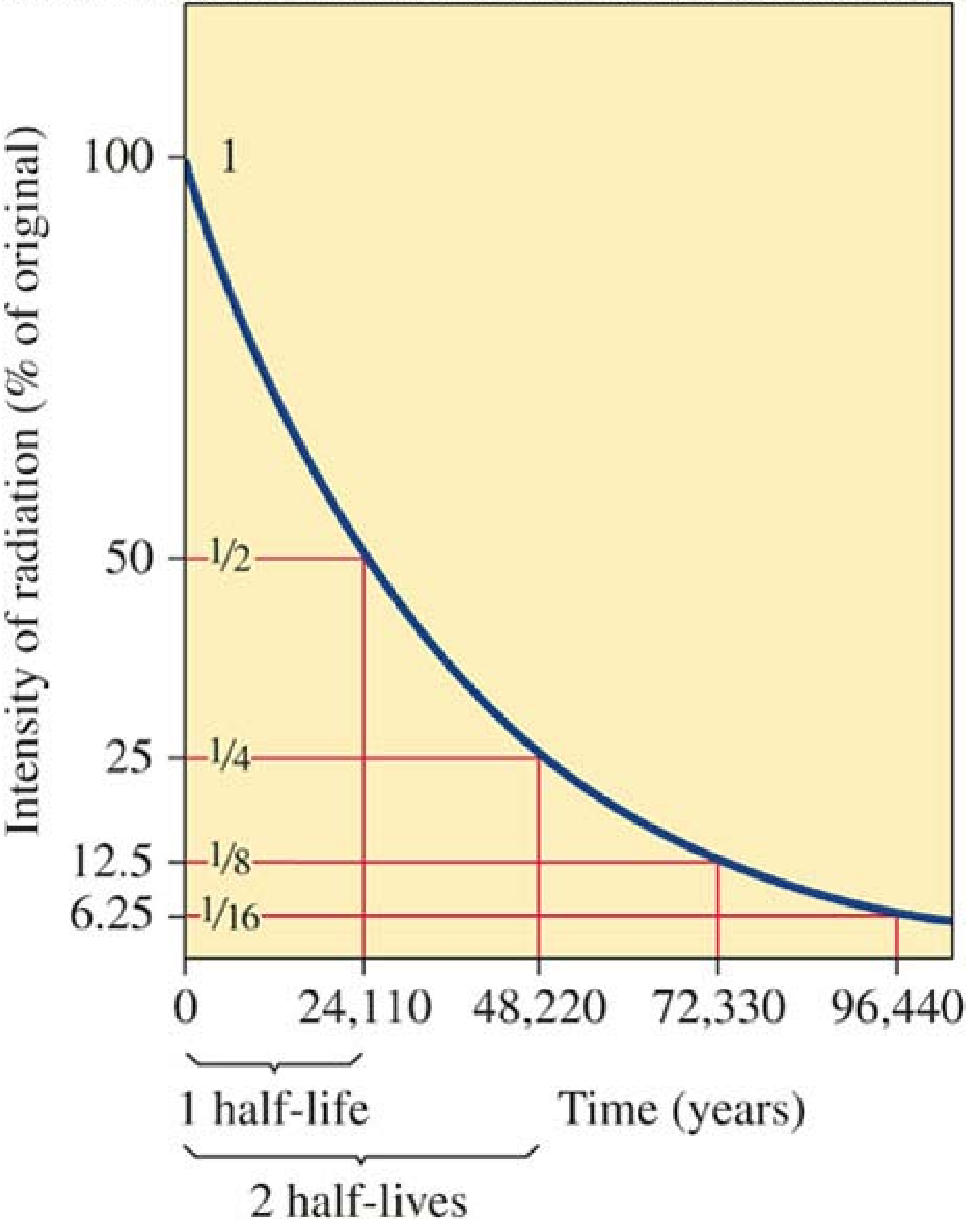


Table 7.3 Physiological Effects of a Single Dose of Radiation

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



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* 24,110 years, there will be 25 atoms remaining

Note: the amount remaining never actually goes to zero!

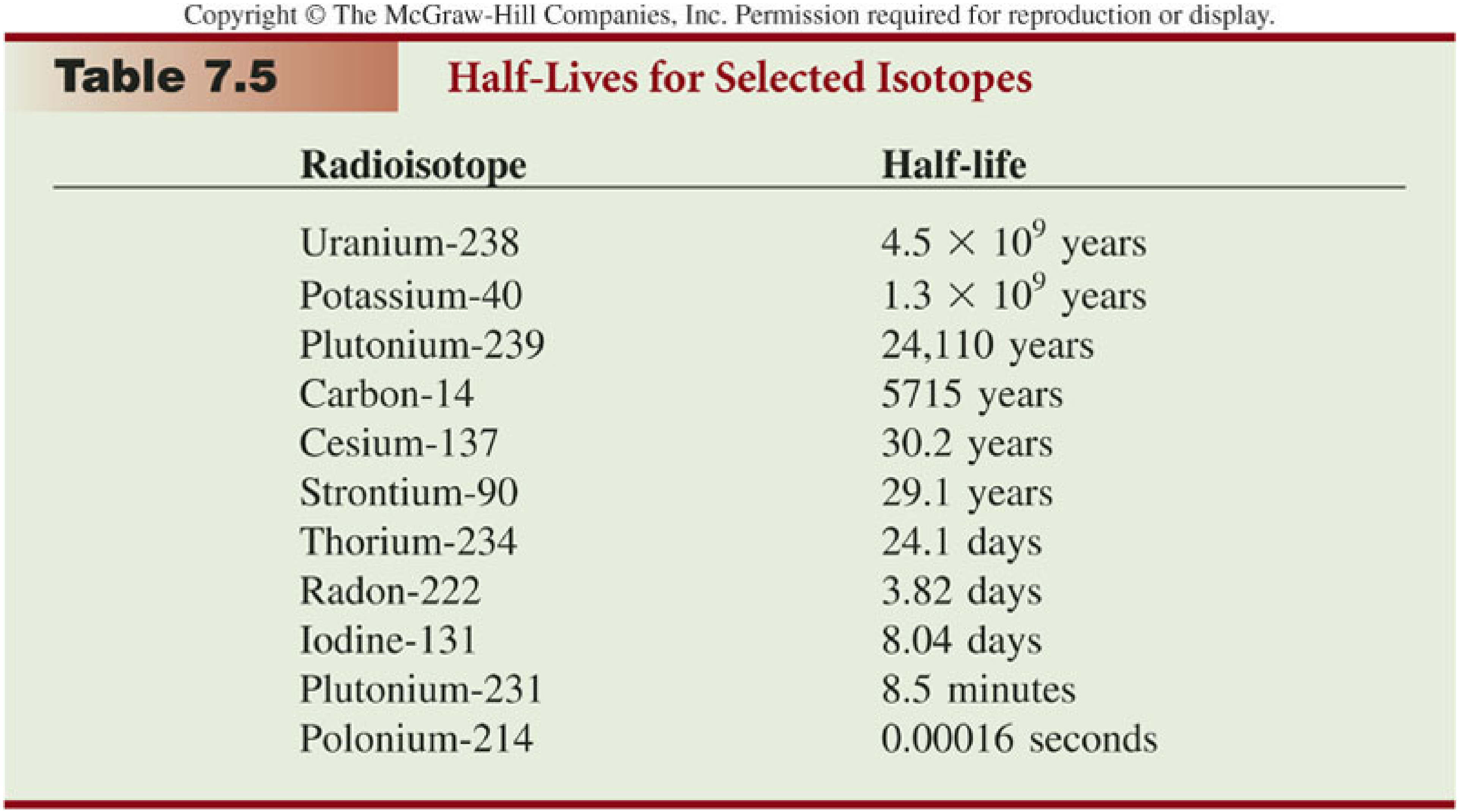


Table 7.5 Half-Lives for Selected Isotopes

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?

Disposing of Nuclear Waste

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?

High-level radioactive waste (HLW)

> Consists of the radioactive materials in spent nuclear fuel and their reprocessing, AND the waste from weapons development
>
> Because of toxicity and the long half-lives, they require **permanent** isolation from the environment
>
> Contains highly acidic/basic solutions, heavy metals – *toxic, caustic* as well as radioactive: “mixed waste”

Disposing of Nuclear Waste

In the U.S., military waste is **much** more prevalent

Approximately 99% of U.S. HLW is military

Military waste is approximately 350,000 cubic meters:

Nine football fields covered to a depth of 30 feet

Spent nuclear fuel (SNF) adds “only” 30 tons per year from each reactor

Disposing of Nuclear Waste

Fuel rods are initially 3-5% U-235

After 3 or 4 years of use, there is no longer enough U-235 in a rod for the fission to proceed

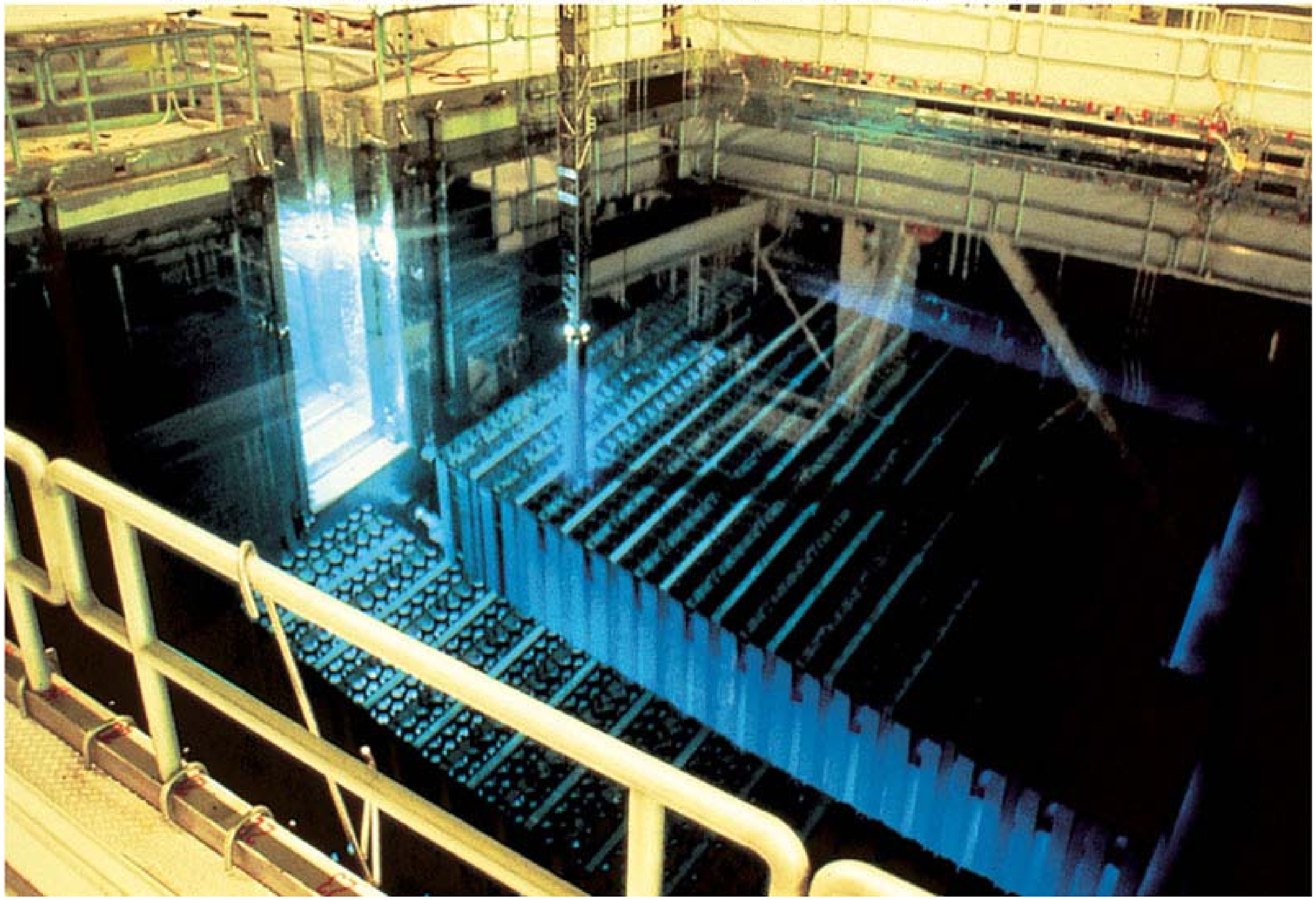
Rods are replaced on a rotating schedule

But even when removed from the reactor, the rods are extremely radioactive, and extremely hot

They contain various isotopes of uranium, Pu-239, and the fission products I-131, Cs-137, Sr-90

Spent fuel rods are transported by machinery to deep pools of water doped with a neutron absorber (usually boron)

Currently, all of the waste generated at nuclear power plants is still stored on-site in these pools



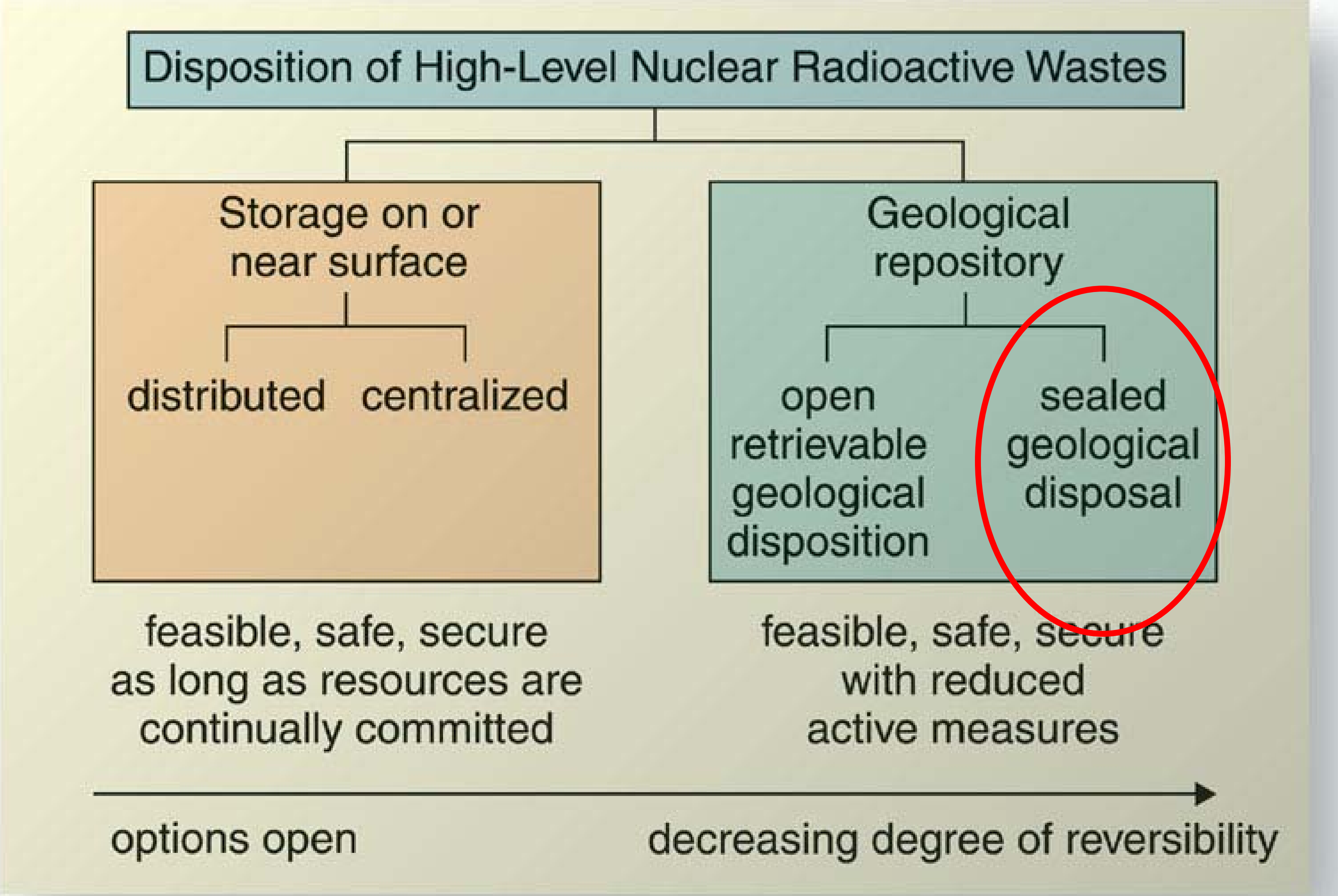
Disposing of Nuclear Waste

Currently, almost all of the waste generated at nuclear power plants is still stored on-site in these pools

The national stockpile is estimated to be 52,000 metric tons

Not only is the storage capacity limited at the power plants, but these facilities were never designed for long term storage of waste

The U.S. banned fuel reprocessing in 1977, but no alternative use for the fuel was put into place



Disposition of High-Level Nuclear Radioactive Wastes

Storage on or near surface

- distributed
- centralized

Geological repository

- open retrievable geological disposition
- sealed geological disposal

feasible, safe, secure as long as resources are continually committed

feasible, safe, secure with reduced active measures

options open

decreasing degree of reversibility

Disposing of Nuclear Waste

The National Academy of Sciences has long supported the sealed geological disposal option, believing that it is unreasonable to expect active management over the lifetime of the radioactivity

The site must be isolated from groundwater for tens of thousands of years

Most proposals involve carving huge chambers 1000 feet below ground, and 1000 feet above the water table

There, HLW would be isolated for at least 10,000 years

Table 7.6 Sample Time-Line for HLW Underground Repository

Year	Event
2010	Construction on underground storage site begins.
2015	Waste storage begins.
2040	Loading ends.
2065	Waste packages retrievable until this time.
2320	Repository sealed by this year.
3000	Most dangerous radioactive substances have decayed to stable products. First waste package is assumed to fail because of manufacturing defects.
12010	End of regulatory period of 10,000 years. Radioactive exposure of farmers in nearby valley is predicted to be 0.007 μSv/year, an insignificant amount.
312010	Radioactive exposure for nearby farmers predicted to reach 250 μSv/yr, a dose that concerns regulators.
622010	Peak radioactive exposure for farmers predicted at 850 μSv/year.

Source: From *The New York Times, Science Times,* August 10, 1999. Reprinted with permission of The New York Times.

Yucca Mountain

(a)

(b)

Disposing of Nuclear Waste

The Yucca Mountain repository is the most likely… but it is by no means a sure thing

Nevada politicians have never agreed to allow the site to be used to store HLW

It is the *only* site which has been designated as appropriate for study

Disposing of Nuclear Waste

1982’s Nuclear Waste Policy Act required the DOE to name a storage location to accept spent fuel by 1998

In 2002, Congress finally approved Yucca Mountain, thereby overriding the local Nevada government

In 2006, DOE declared a March 31 2017 opening date

BUT the Nuclear Regulatory Commission must also approve the designs

As of April 2004, the NRC did not think that the Yucca Mountain designs were sufficient (too *short* a timeframe?!?)

In addition, the election of Harry Reid (D-**NV**) as Senate Majority Leader introduces new obstacles

Disposing of Nuclear Waste

Even if these many obstacles are cleared, the site is still not complete

$54 billion has already been spent

The current design calls for storage of 70,000 metric tons of spent fuel and 8000 tons of military waste

But the current stockpile is 52000 tons, and is expected to be 100,000 by 2010

Disposing of Nuclear Waste

If Yucca Mountain **is** approved, built and opened…

… how will waste from nuclear power plant storage be moved to the repository?

It has been estimated that it would take 25 years simply to move the existing waste

If it moves by train, it would pass through 43 states and pass within half a mile of 50 million people

On the other hand, security is much harder to maintain at hundreds of sites than at one site, and the fear of terrorist attack has reinvigorated the push to open Yucca Mountain

Low-Level Waste

90% of U.S. nuclear waste is “low-level”

Lab clothing, gloves, cleaning tools, etc. from labs and medical radiology, smoke detectors (Am-241)– very low levels of radioactivity

But also higher radiation sources from the materials used to make fuel rods

Estimated to be 4.5 million cubic meters by 2030

Sealed in steel canisters and buried 10 m deep in lined trenches

Military waste is disposed of at federal sites

Low-Level Waste

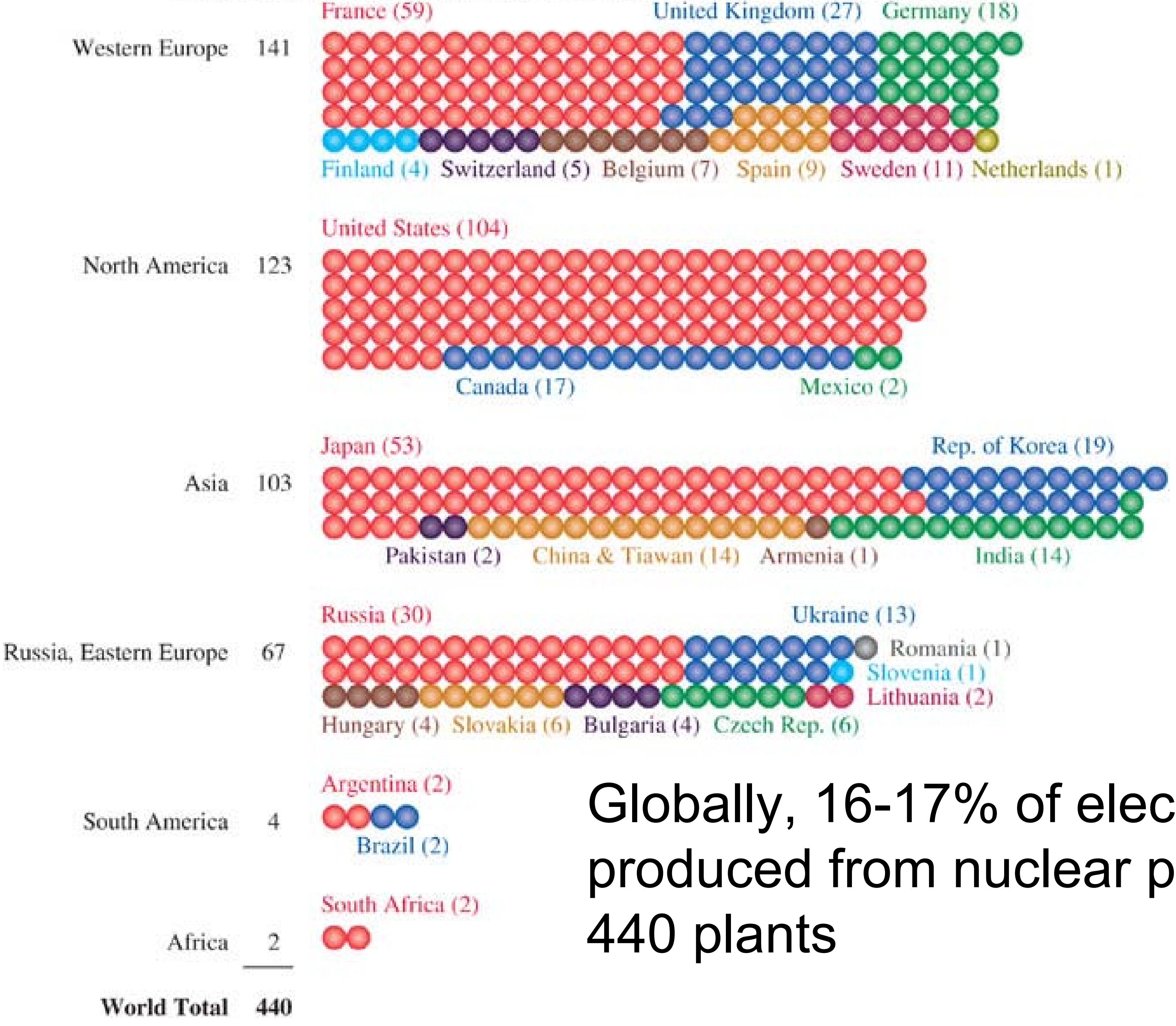
Military waste is disposed of at federal sites

Civilian waste is disposed of at commercial sites

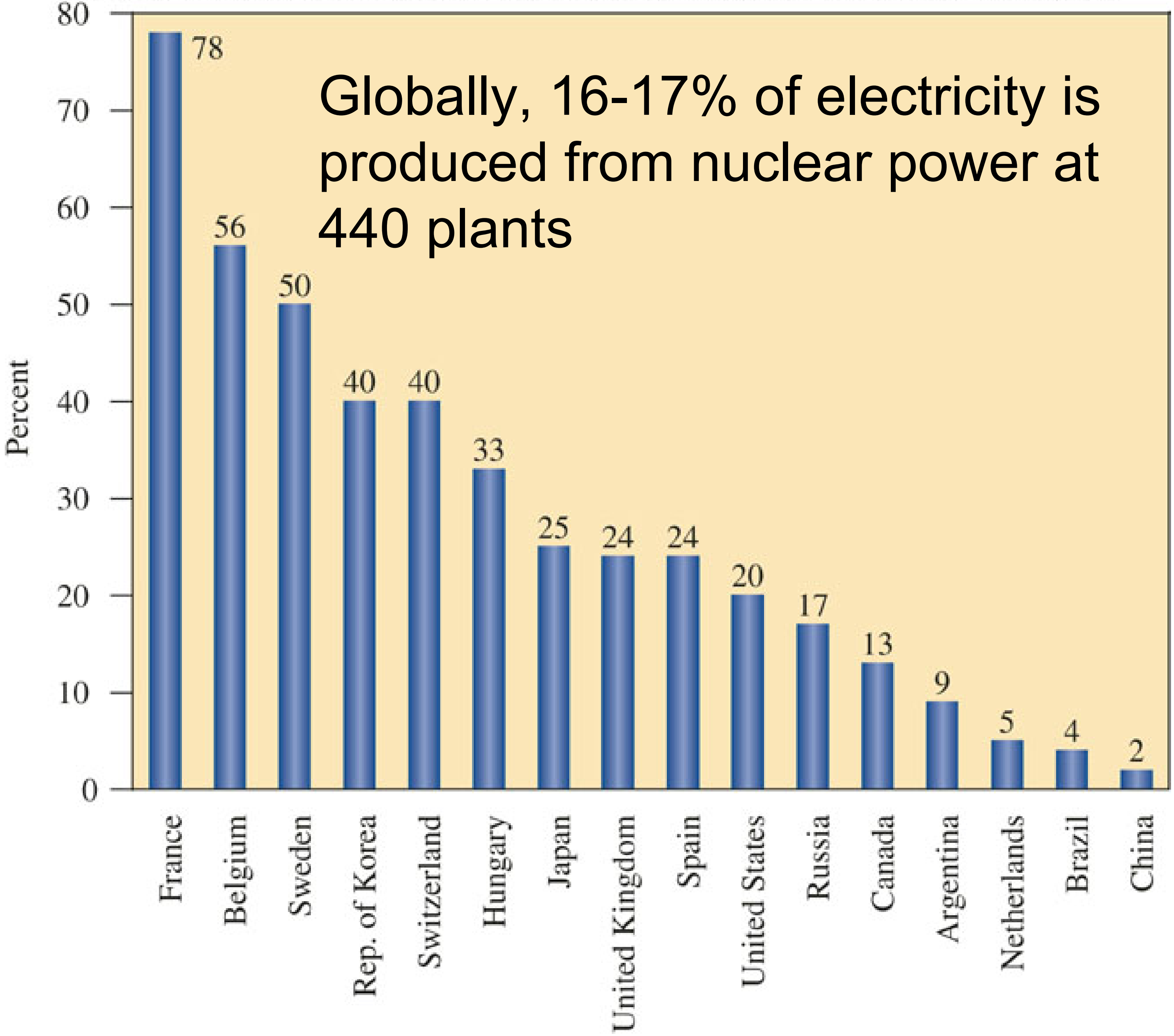
Two currently in operation – in Barnswell, SC and Richland, WA

Four other commercial LLW sites have closed in the last 35 years

Local political pressure (“not in my backyard”) has prevented the construction of any new plants



Globally, 16-17% of electricity is produced from nuclear power at 440 plants



Globally, 16-17% of electricity is produced from nuclear power at 440 plants

Nuclear Power: Costs and Benefits

Why don’t ALL countries rely more heavily on nuclear power?

The initial costs of constructing a plant are very high

Some have access to cheap electrical sources – water, wind, geothermal

But there’s also the careful balancing of *risk*

There is no such thing as zero risk – everyday life provides plenty of opportunity for harm

Nuclear Power: Costs and Benefits

When considering the relative risks of nuclear power, we have to consider more than just the danger of nuclear explosion (almost zero)

But we must also consider the risks associated with the *other* fuel options, which are not necessarily any less

An example: more radioactivity is emitted into the local environment by a coal-burning plant than by a nuclear plant

Coal contains traces of radioisotopes

If we burn 2.5 billion tons of coal by 2040, we'll be emitting 1000 tons of U-235… along with CO_2

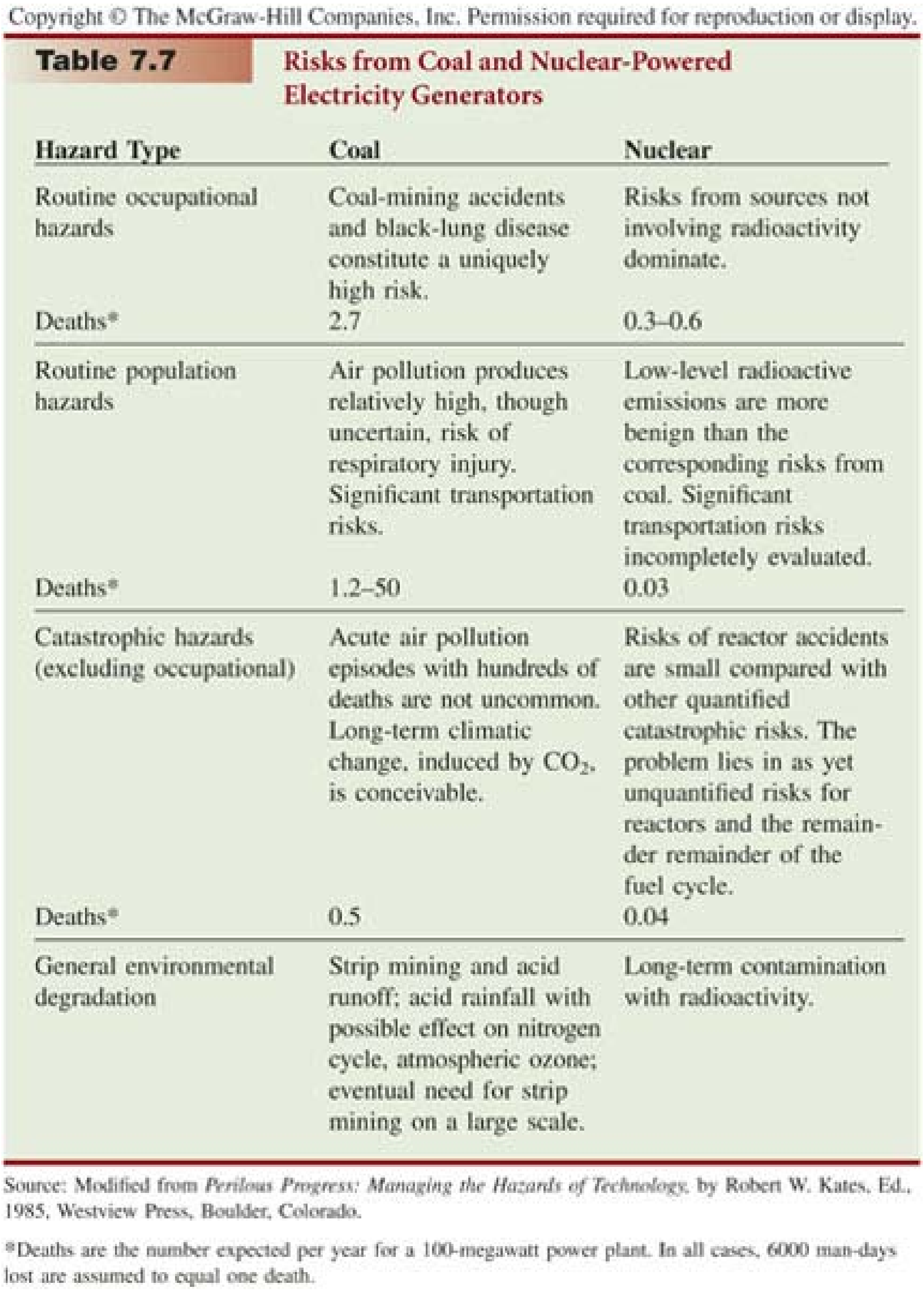


Table 7.7 Risks from Coal and Nuclear-Powered Electricity Generators

Hazard Type	Coal	Nuclear
Routine occupational hazards	Coal-mining accidents and black-lung disease constitute a uniquely high risk.	Risks from sources not involving radioactivity dominate.
Deaths*	2.7	0.3–0.6
Routine population hazards	Air pollution produces relatively high, though uncertain, risk of respiratory injury. Significant transportation risks.	Low-level radioactive emissions are more benign than the corresponding risks from coal. Significant transportation risks incompletely evaluated.
Deaths*	1.2–50	0.03
Catastrophic hazards (excluding occupational)	Acute air pollution episodes with hundreds of deaths are not uncommon. Long-term climatic change, induced by CO_2, is conceivable.	Risks of reactor accidents are small compared with other quantified catastrophic risks. The problem lies in as yet unquantified risks for reactors and the remainder remainder of the fuel cycle.
Deaths*	0.5	0.04
General environmental degradation	Strip mining and acid runoff; acid rainfall with possible effect on nitrogen cycle, atmospheric ozone; eventual need for strip mining on a large scale.	Long-term contamination with radioactivity.

Source: Modified from *Perilous Progress: Managing the Hazards of Technology*, by Robert W. Kates, Ed., 1985, Westview Press, Boulder, Colorado.

*Deaths are the number expected per year for a 100-megawatt power plant. In all cases, 6000 man-days lost are assumed to equal one death.

From a purely statistical analysis, the number of deaths expected is **much** higher in a coal-burning plant than in a nuclear plant

But human psychology plays a very important role in making these decisions…

… and people don't think statistically

People don't trust people

The Future of Nuclear Power?

It is inevitable that nuclear power will become *more* important in the coming years as fossil fuel reserves dwindle

But it is not a given that it will become the *most* important energy source

Smaller, cheaper, safer reactors with cookie-cutter designs have been approved, greatly decreasing the cost in time and money to start a new plant

But until the problem of nuclear waste is dealt with, it is unclear how much more nuclear power the U.S. can support

Letters due Thursday!

Chapter 8