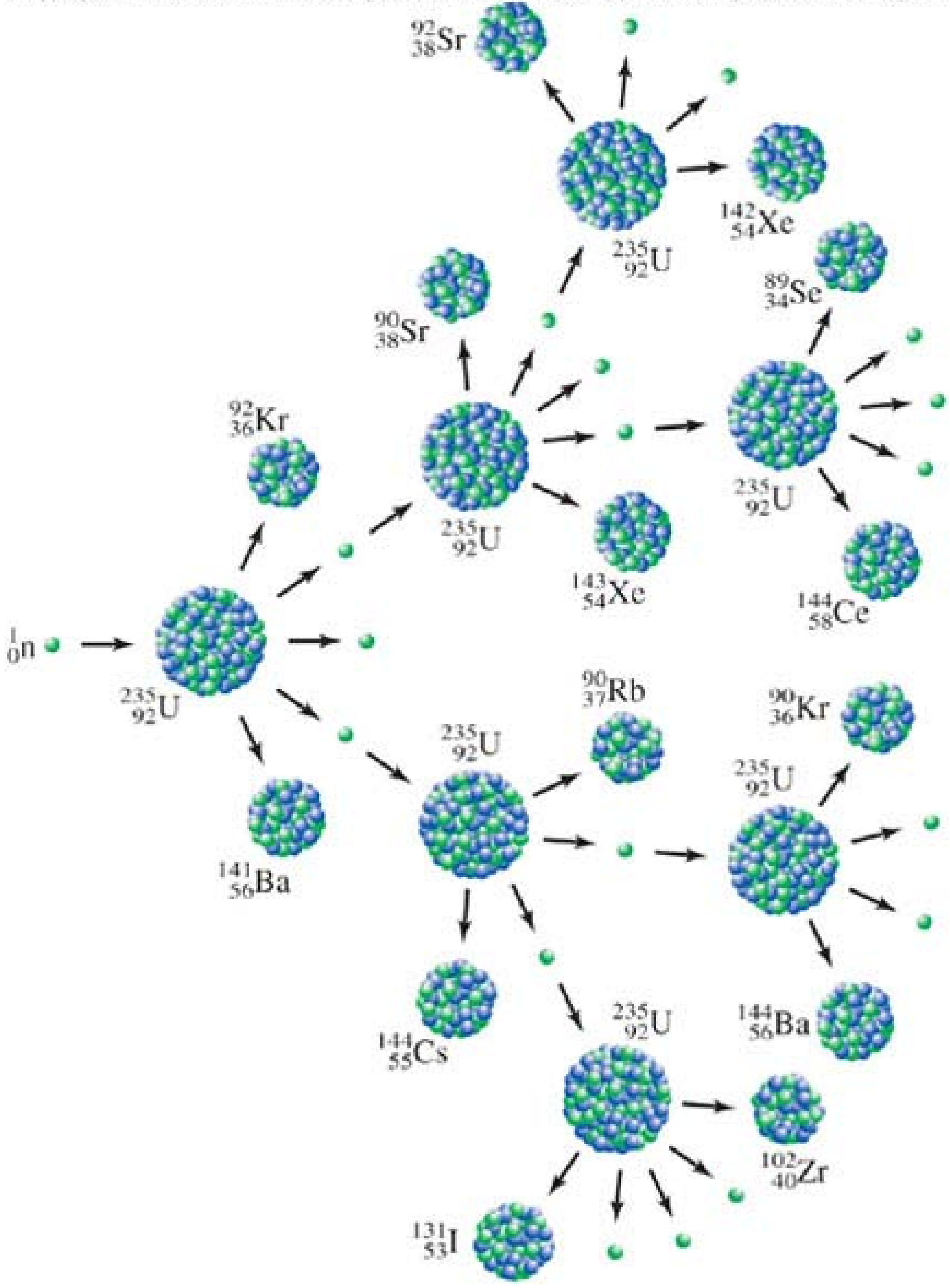
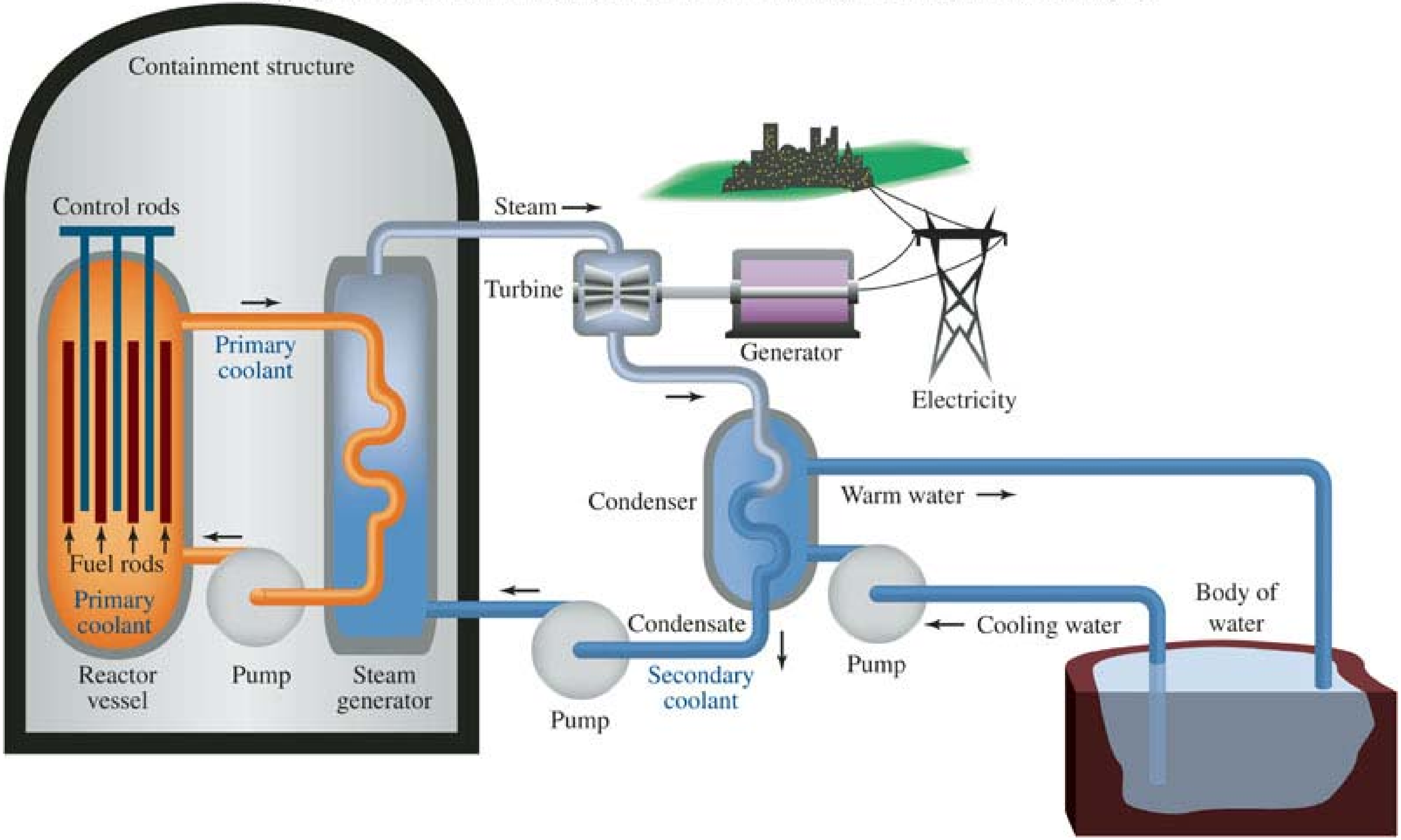
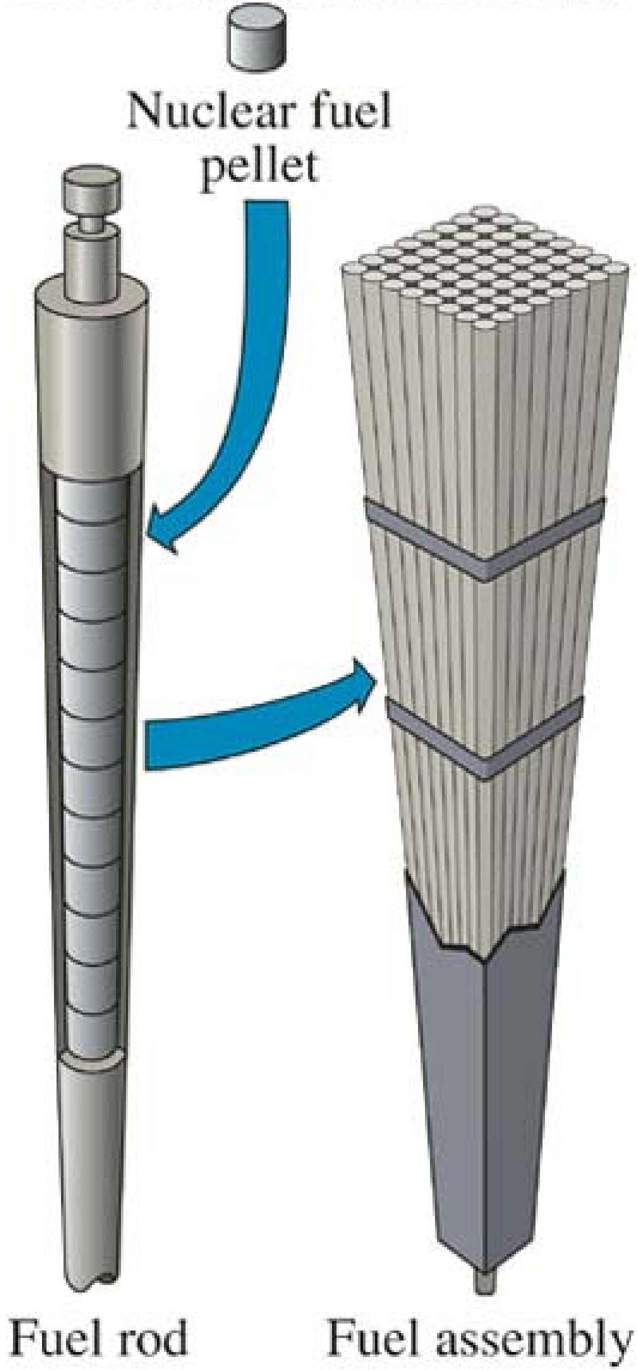
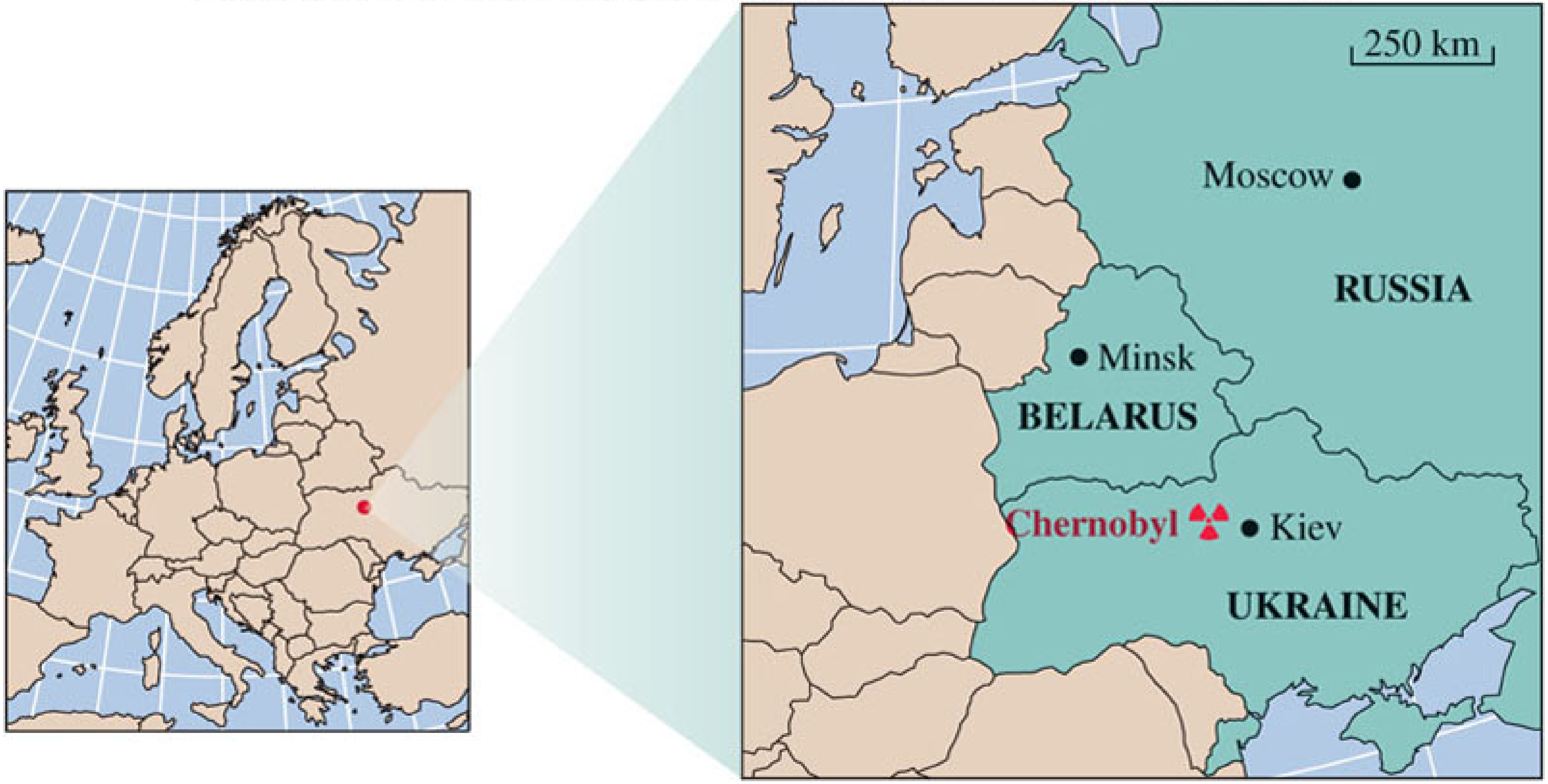
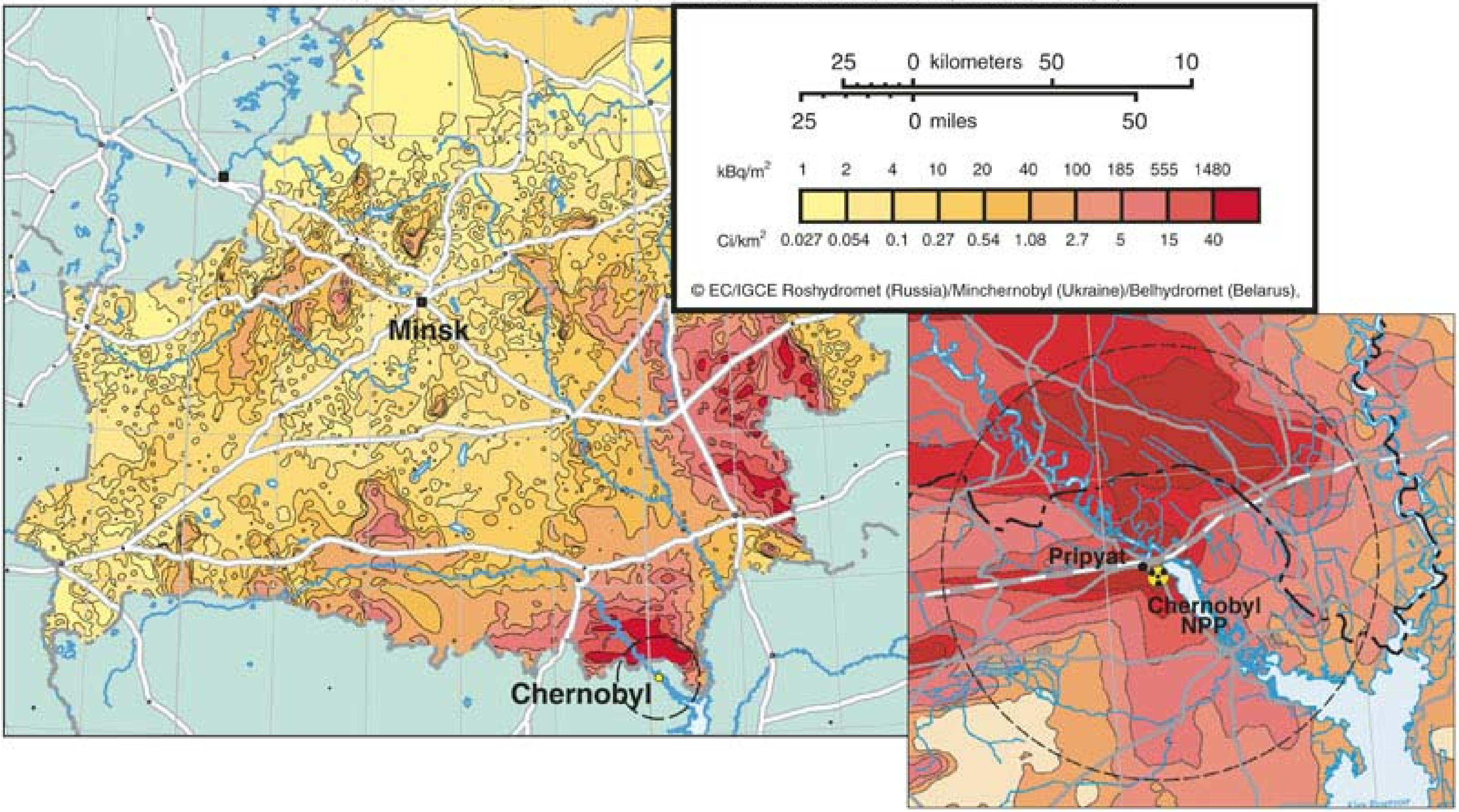

$^{92}_{38}\text{Sr}$
$^{142}_{54}\text{Xe}$
$^{235}_{92}\text{U}$
$^{89}_{34}\text{Se}$
$^{90}_{38}\text{Sr}$
$^{92}_{36}\text{Kr}$
$^{235}_{92}\text{U}$
$^{235}_{92}\text{U}$
$^{143}_{54}\text{Xe}$
$^{144}_{58}\text{Ce}$
$^{1}_{0}\text{n}$
$^{235}_{92}\text{U}$
$^{90}_{37}\text{Rb}$
$^{90}_{36}\text{Kr}$
$^{235}_{92}\text{U}$
$^{235}_{92}\text{U}$
$^{141}_{56}\text{Ba}$
$^{144}_{56}\text{Ba}$
$^{144}_{55}\text{Cs}$
$^{235}_{92}\text{U}$
$^{102}_{40}\text{Zr}$
$^{131}_{53}\text{I}$

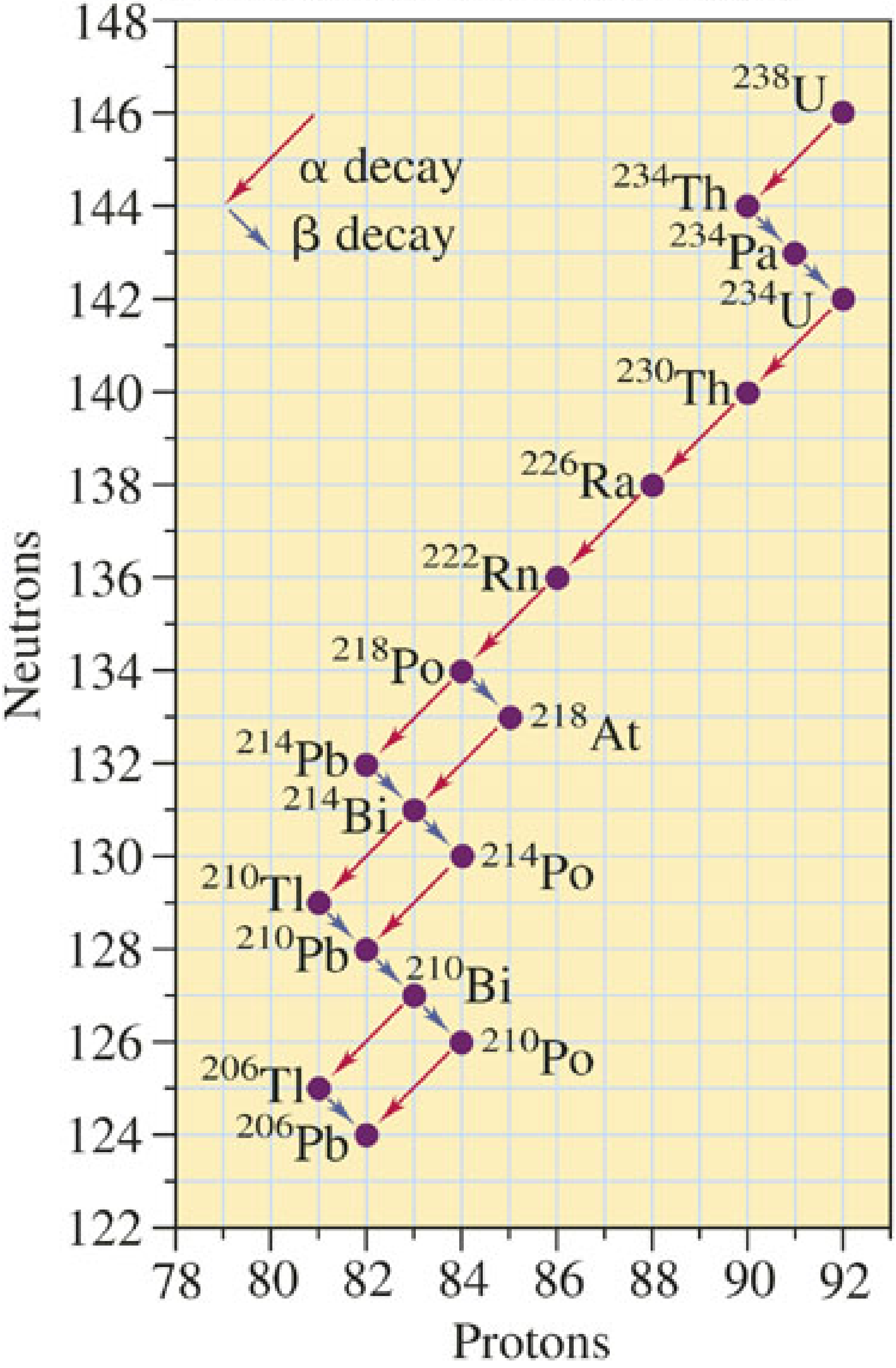

Containment structure
Control rods
Steam
Turbine
Generator
Electricity
Primary coolant
Condenser
Warm water
Fuel rods
Primary coolant
Reactor vessel
Pump
Steam generator
Condensate
Secondary coolant
Pump
Pump
Cooling water
Body of water

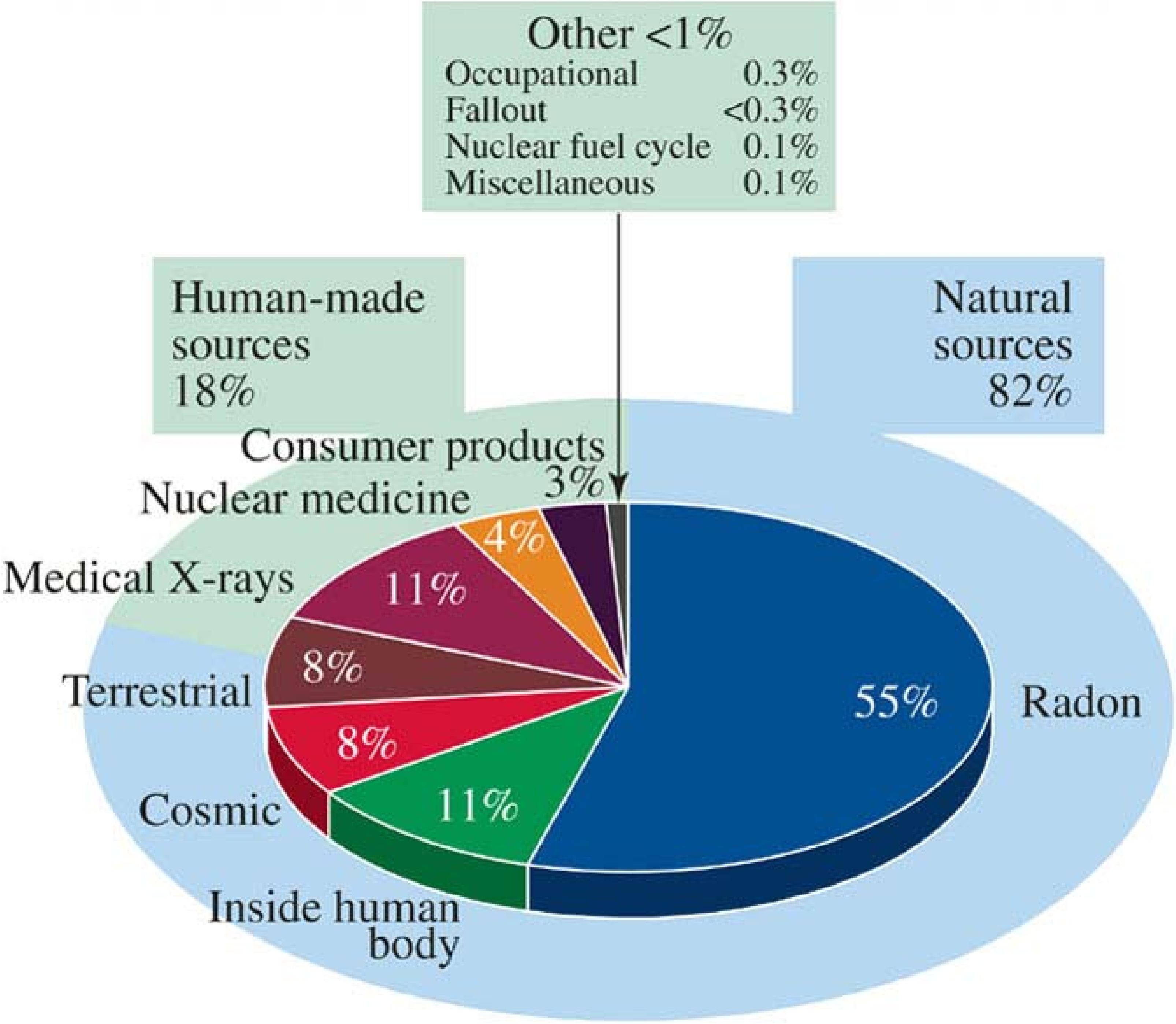

Nuclear fuel pellet
Fuel rod
Fuel assembly

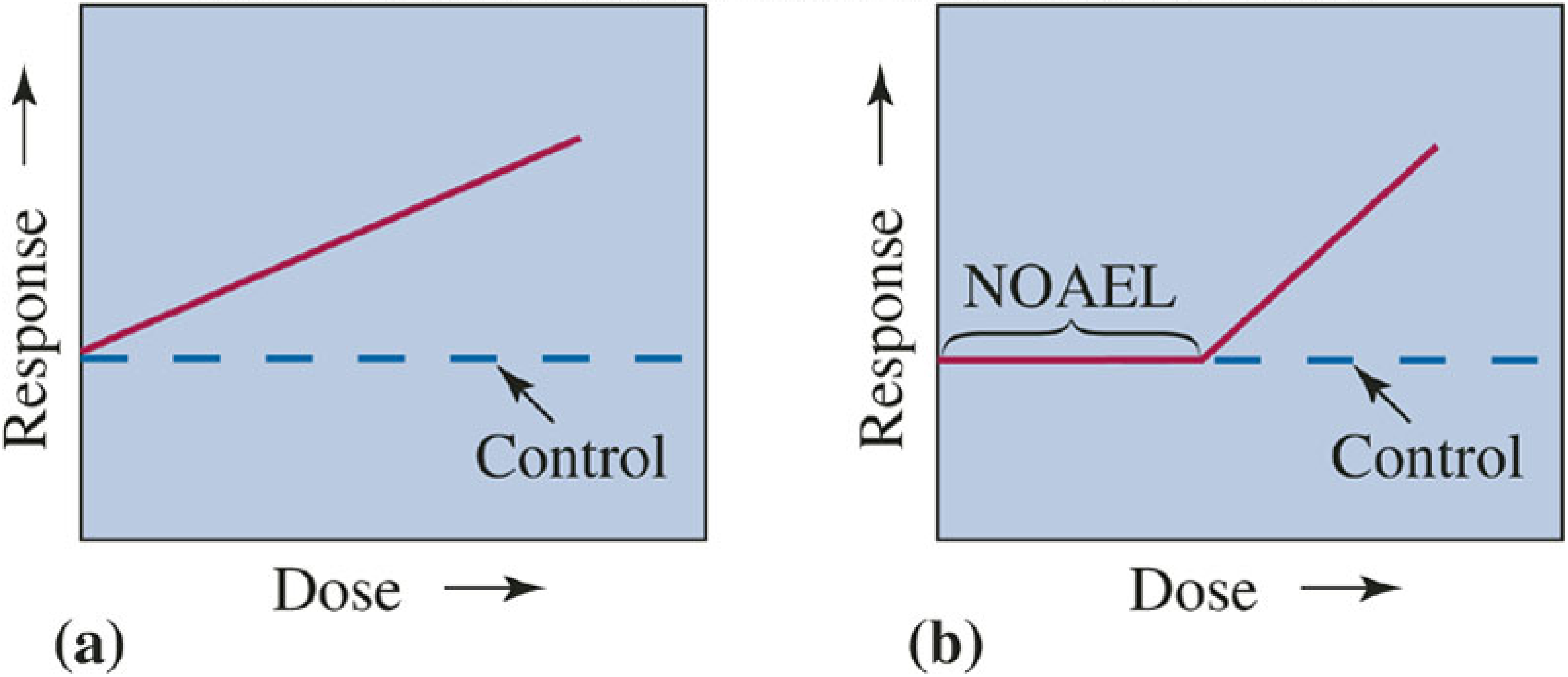

250 km
Moscow
RUSSIA
Minsk
BELARUS
Chernobyl
Kiev
UKRAINE

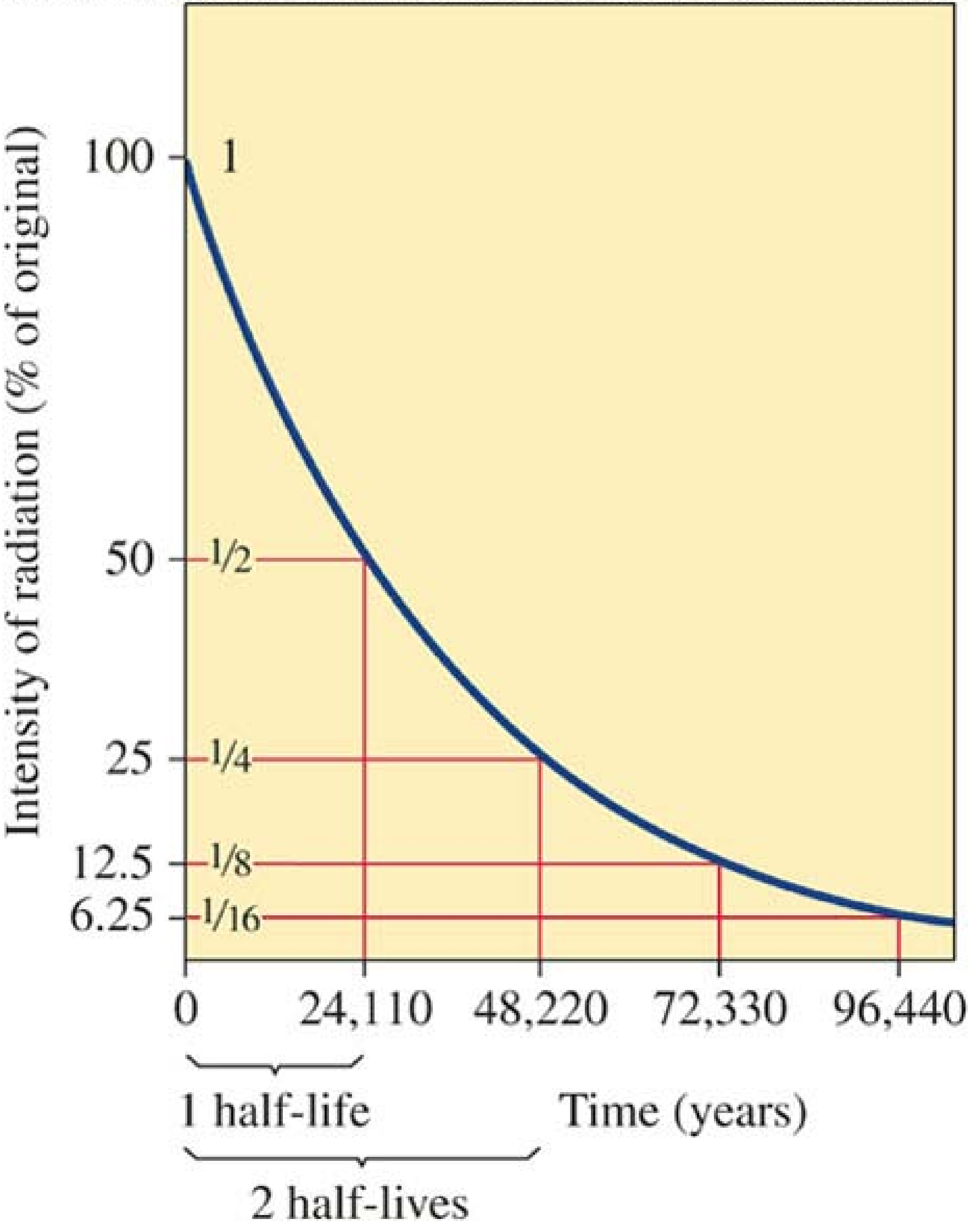


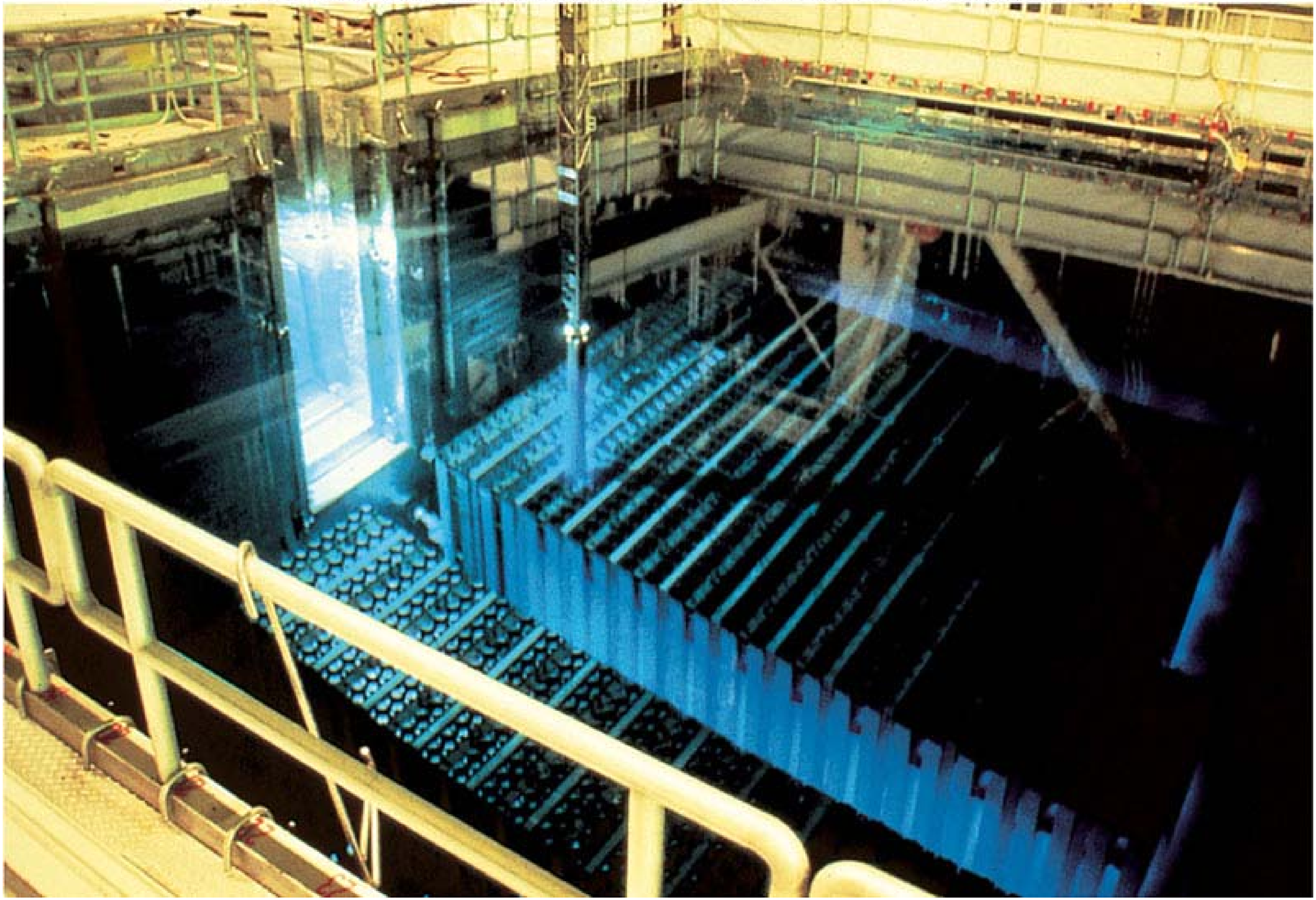
© EC/IGCE Roshydromet (Russia)/Minchernobyl (Ukraine)/Belhydromet (Belarus).

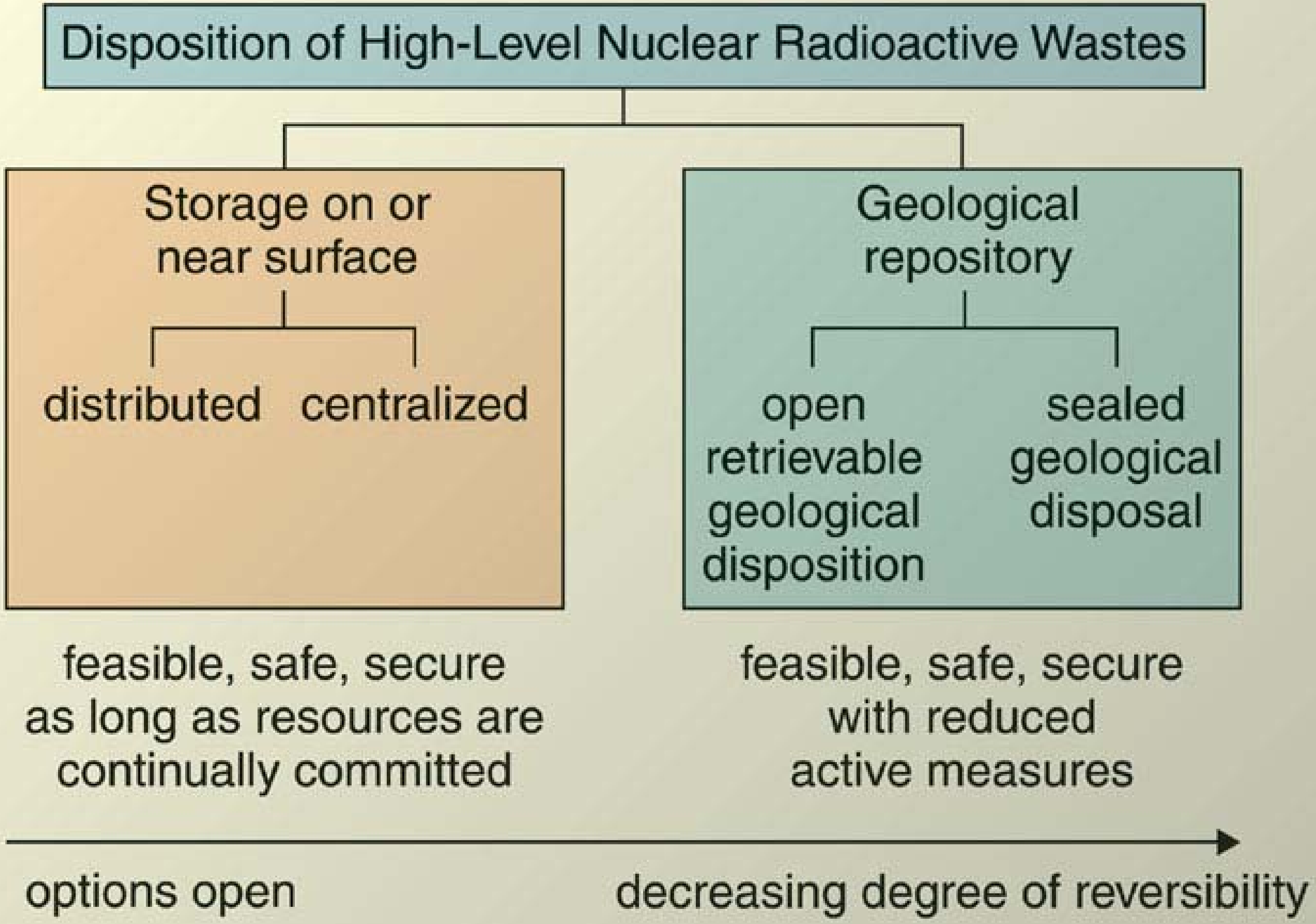

α decay
β decay
238U
234Th
234Pa
234U
230Th
226Ra
222Rn
218Po
218At
214Pb
214Bi
214Po
210Tl
210Pb
210Bi
210Po
206Tl
206Pb
Neutrons
148
146
144
142
140
138
136
134
132
130
128
126
124
122
Protons
78
80
82
84
86
88
90
92


Other <1%
Occupational 0.3%
Fallout <0.3%
Nuclear fuel cycle 0.1%
Miscellaneous 0.1%
Human-made sources 18%
Natural sources 82%
Consumer products 3%
Nuclear medicine 4%
Medical X-rays 11%
Terrestrial 8%
Cosmic 8%
Inside human body 11%
Radon 55%


Response
Dose
Control
(a)
Response
NOAEL
Dose
Control
(b)


Intensity of radiation (% of original)
100
1
50
1/2
25
1/4
12.5
1/8
6.25
1/16
0
24,110
48,220
72,330
96,440
1 half-life
2 half-lives
Time (years)





# Disposition of High-Level Nuclear Radioactive Wastes

**Storage on or near surface**

- distributed
- centralized

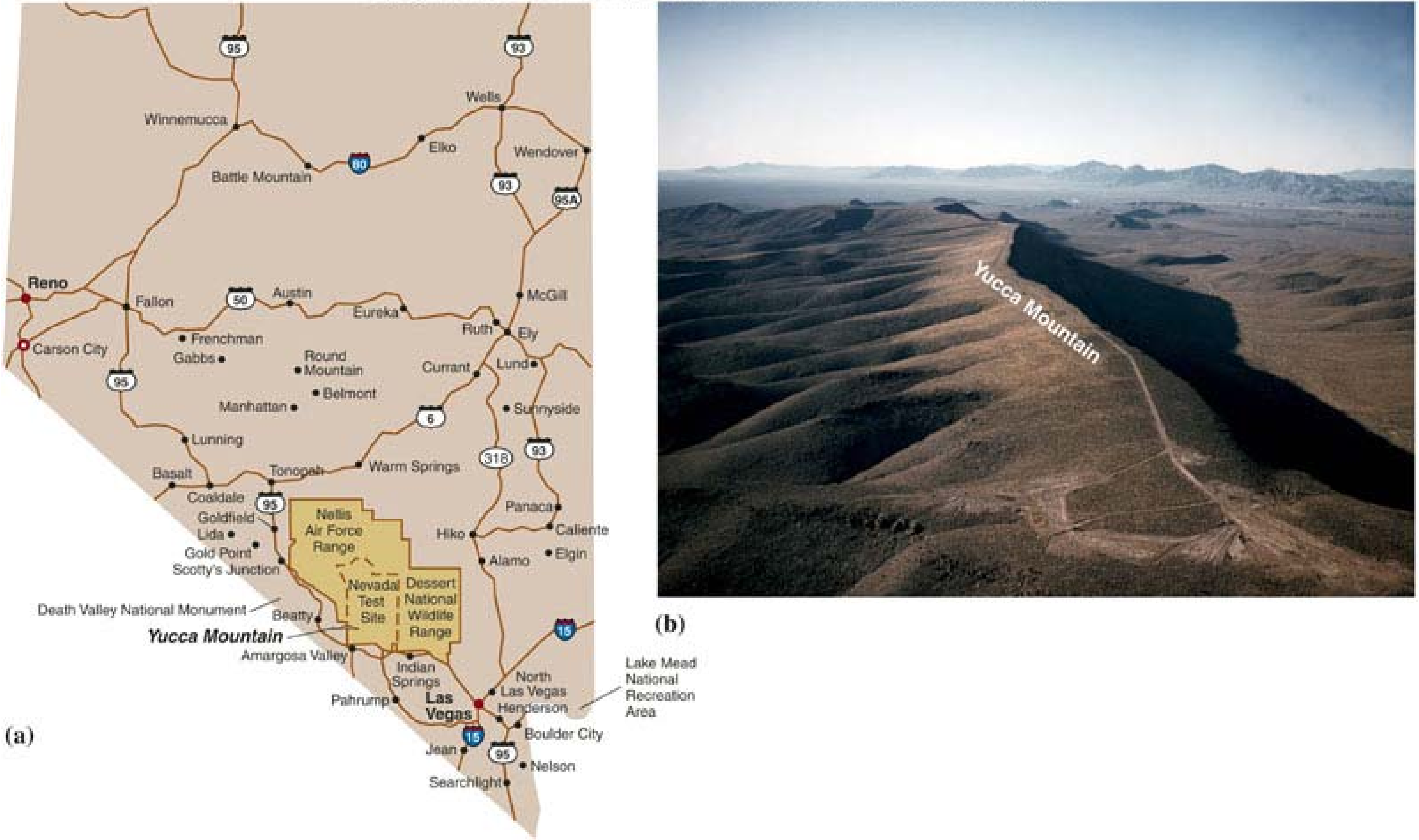
feasible, safe, secure as long as resources are continually committed

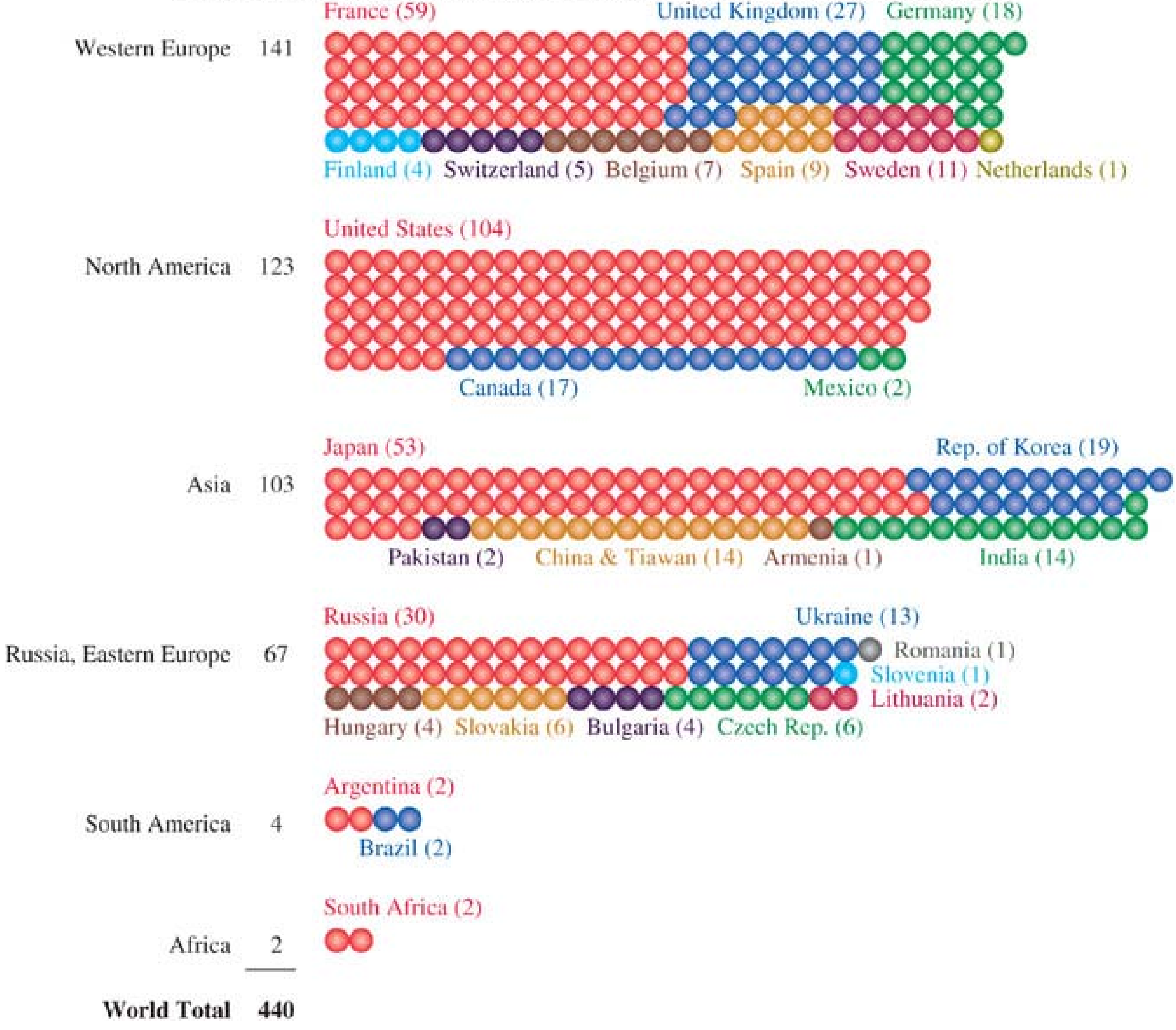
**Geological repository**

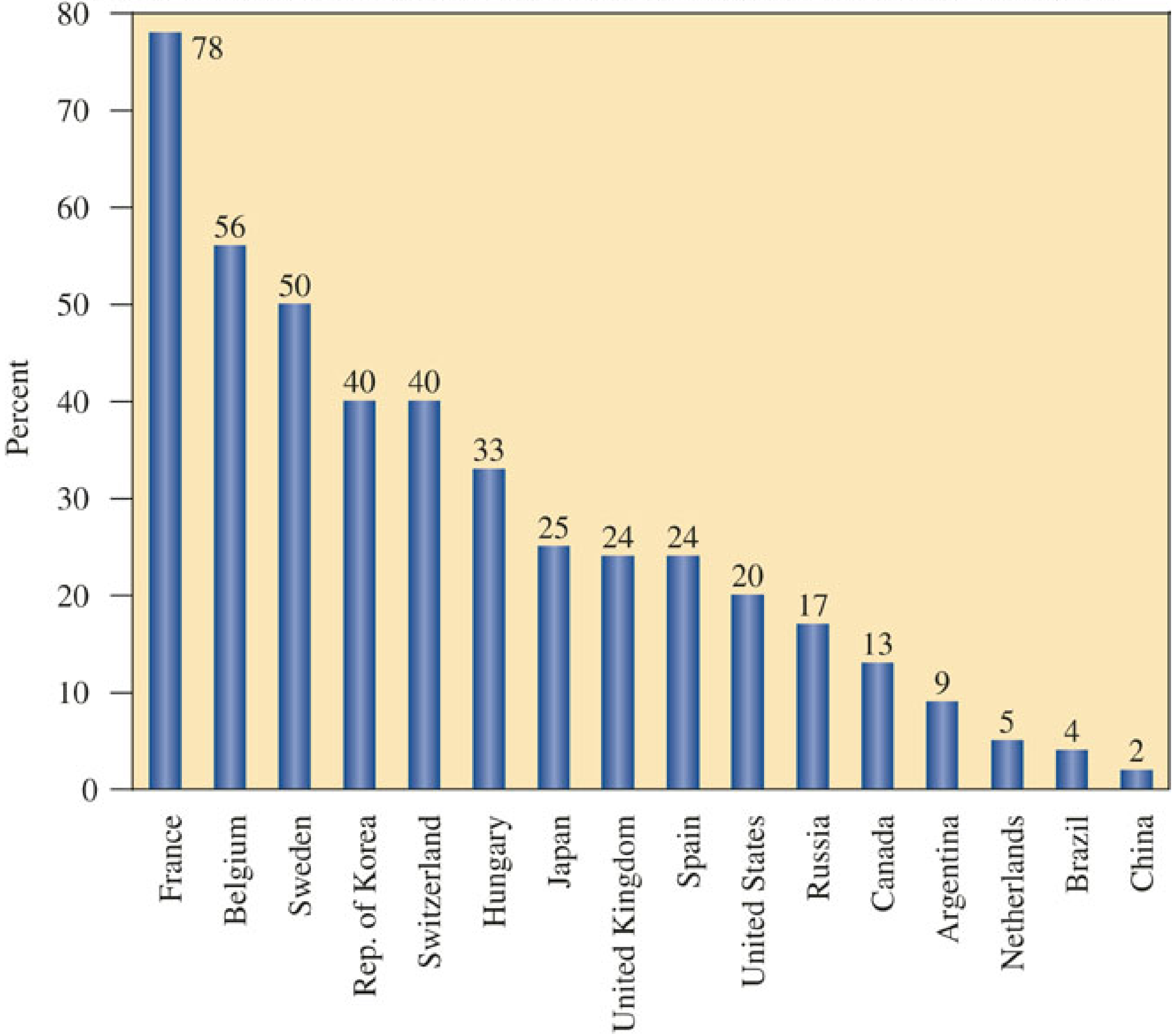
- open retrievable geological disposition
- sealed geological disposal

feasible, safe, secure with reduced active measures

options open → decreasing degree of reversibility


(a)
95
93
Wells
Winnemucca
Elko
Wendover
Battle Mountain
80
93
95A
Reno
McGill
Fallon
50
Austin
Eureka
Ruth
Ely
Carson City
Frenchman
Gabbs
Round Mountain
Currant
Lund
95
Belmont
Manhattan
Sunnyside
6
Lunning
318
93
Basalt
Tonopah
Warm Springs
Coaldale
95
Nellis Air Force Range
Panaca
Goldfield
Lida
Hiko
Caliente
Gold Point
Alamo
Elgin
Scotty's Junction
Nevada Test Site
Dessert National Wildlife Range
Death Valley National Monument
Beatty
Yucca Mountain
15
Amargosa Valley
Indian Springs
North Las Vegas
Lake Mead National Recreation Area
Pahrump
Las Vegas
Henderson
15
Boulder City
Jean
95
Nelson
Searchlight
(b)
Yucca Mountain


Western Europe 141
France (59)
United Kingdom (27)
Germany (18)
Finland (4)
Switzerland (5)
Belgium (7)
Spain (9)
Sweden (11)
Netherlands (1)
North America 123
United States (104)
Canada (17)
Mexico (2)
Asia 103
Japan (53)
Rep. of Korea (19)
Pakistan (2)
China & Tiawan (14)
Armenia (1)
India (14)
Russia, Eastern Europe 67
Russia (30)
Ukraine (13)
Romania (1)
Slovenia (1)
Lithuania (2)
Hungary (4)
Slovakia (6)
Bulgaria (4)
Czech Rep. (6)
South America 4
Argentina (2)
Brazil (2)
Africa 2
South Africa (2)
World Total 440


Percent
80
70
60
50
40
30
20
10
0
78
56
50
40
40
33
25
24
24
20
17
13
9
5
4
2
France
Belgium
Sweden
Rep. of Korea
Switzerland
Hungary
Japan
United Kingdom
Spain
United States
Russia
Canada
Argentina
Netherlands
Brazil
China

## Table 7.1 Nuclear Plant Closings Since 1990

| Nuclear Plant | State | License Issued | Date Shut Down |
|---|---|---|---|
| Millstone 1 | Connecticut | 1966 | 1998 |
| Zion 1, Zion 2 | Illinois | 1973 | 1998 |
| Big Rock Point | Missouri | 1962 | 1997 |
| Maine Yankee | Maine | 1972 | 1997 |
| Haddam Neck | Connecticut | 1967 | 1996 |
| San Onofre 1 | California | 1967 | 1992 |
| Trojan | Oregon | 1975 | 1992 |
| Yankee–Rowe | Maine | 1960 | 1991 |

Source: From Environmental Law & Policy Center, http://www.elpc.org/energy/nuclear_closings.html. Reprinted with permission.

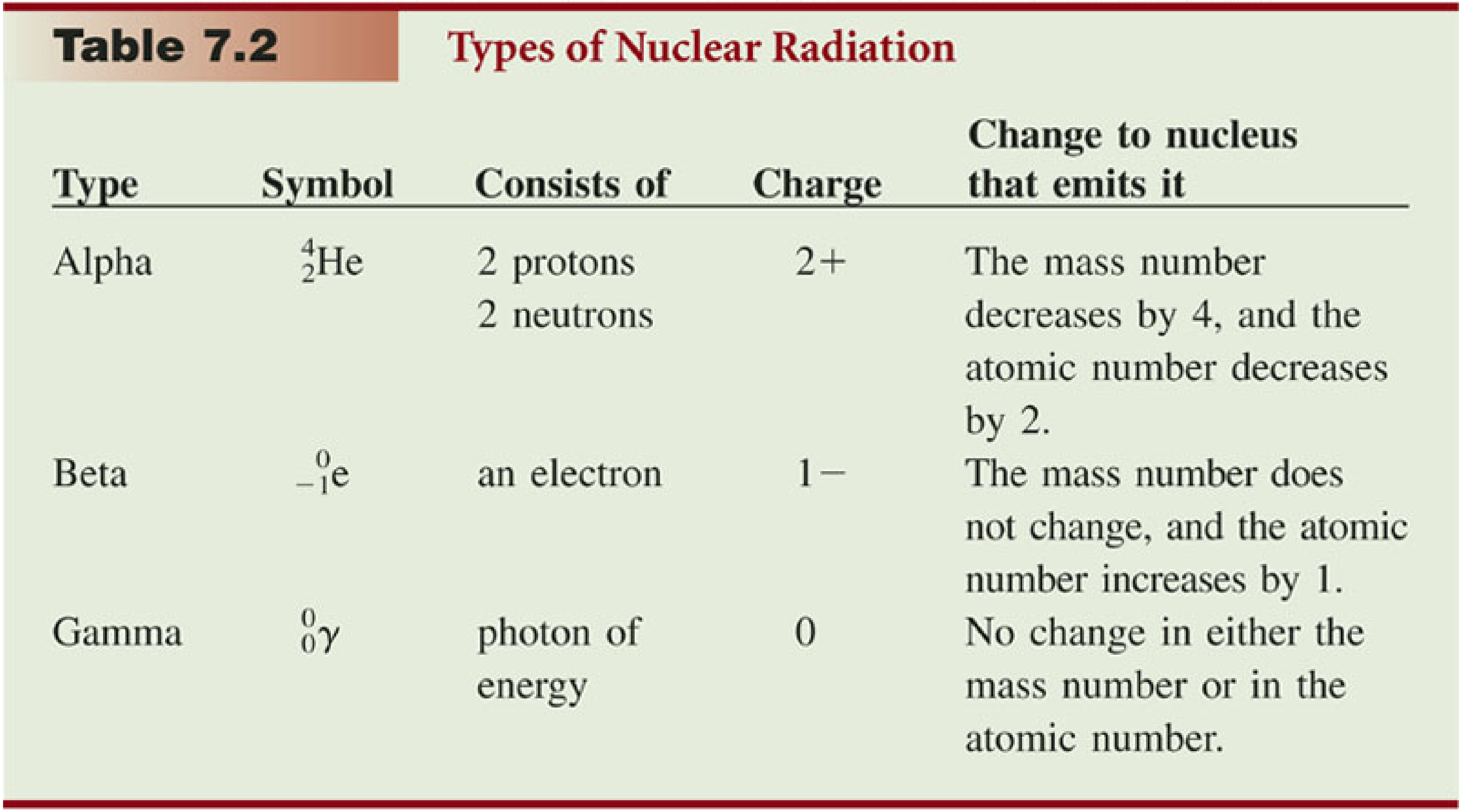


**Table 7.2** Types of Nuclear Radiation

| Type | Symbol | Consists of | Charge | Change to nucleus that emits it |
|---|---|---|---|---|
| Alpha | ${}^{4}_{2}\mathrm{He}$ | 2 protons<br>2 neutrons | 2+ | The mass number decreases by 4, and the atomic number decreases by 2. |
| Beta | ${}^{0}_{-1}\mathrm{e}$ | 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. |

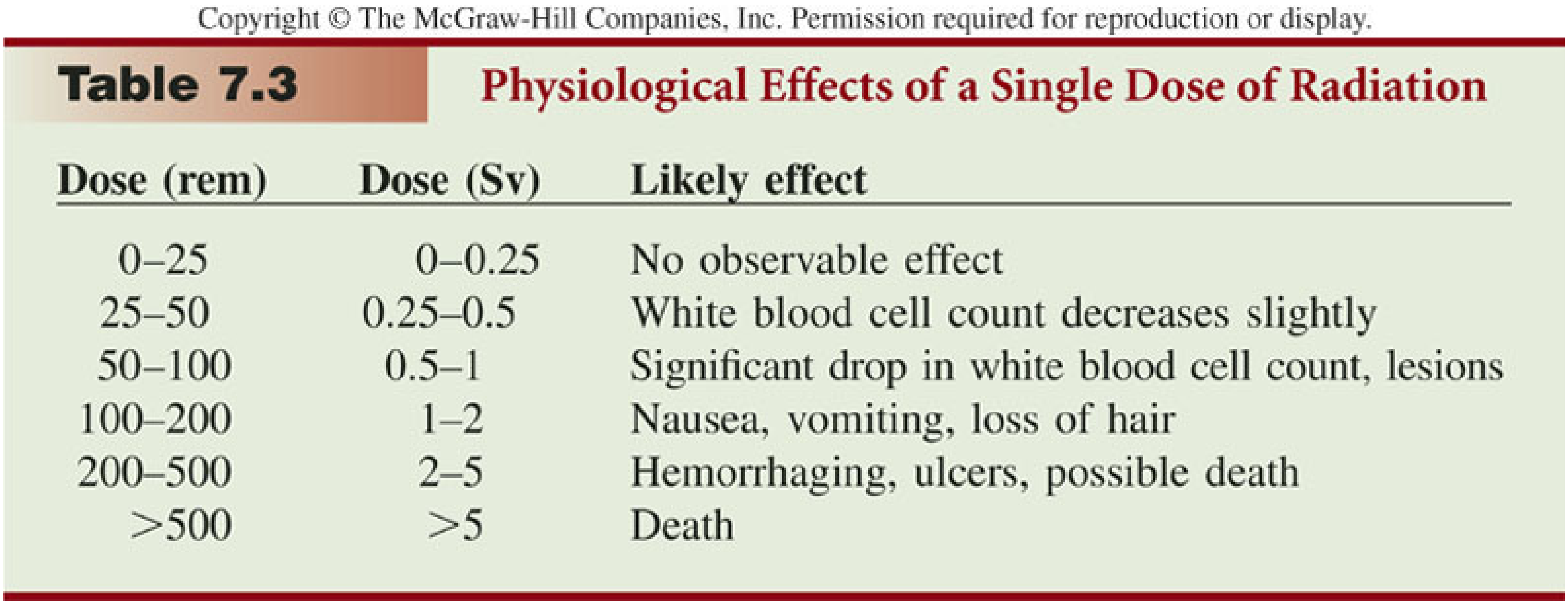


**Table 7.3** Physiological Effects of a Single Dose of Radiation

| 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 |

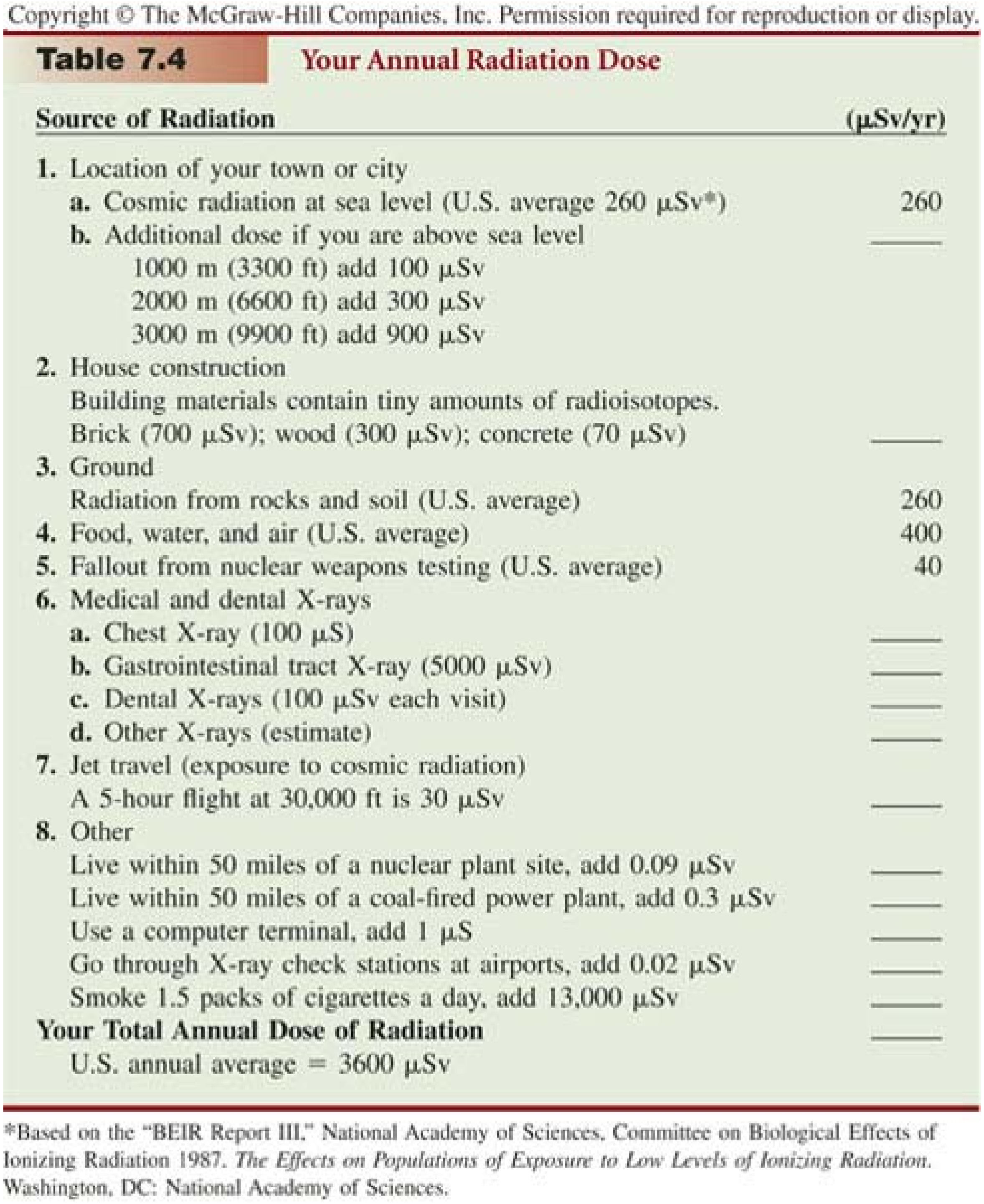
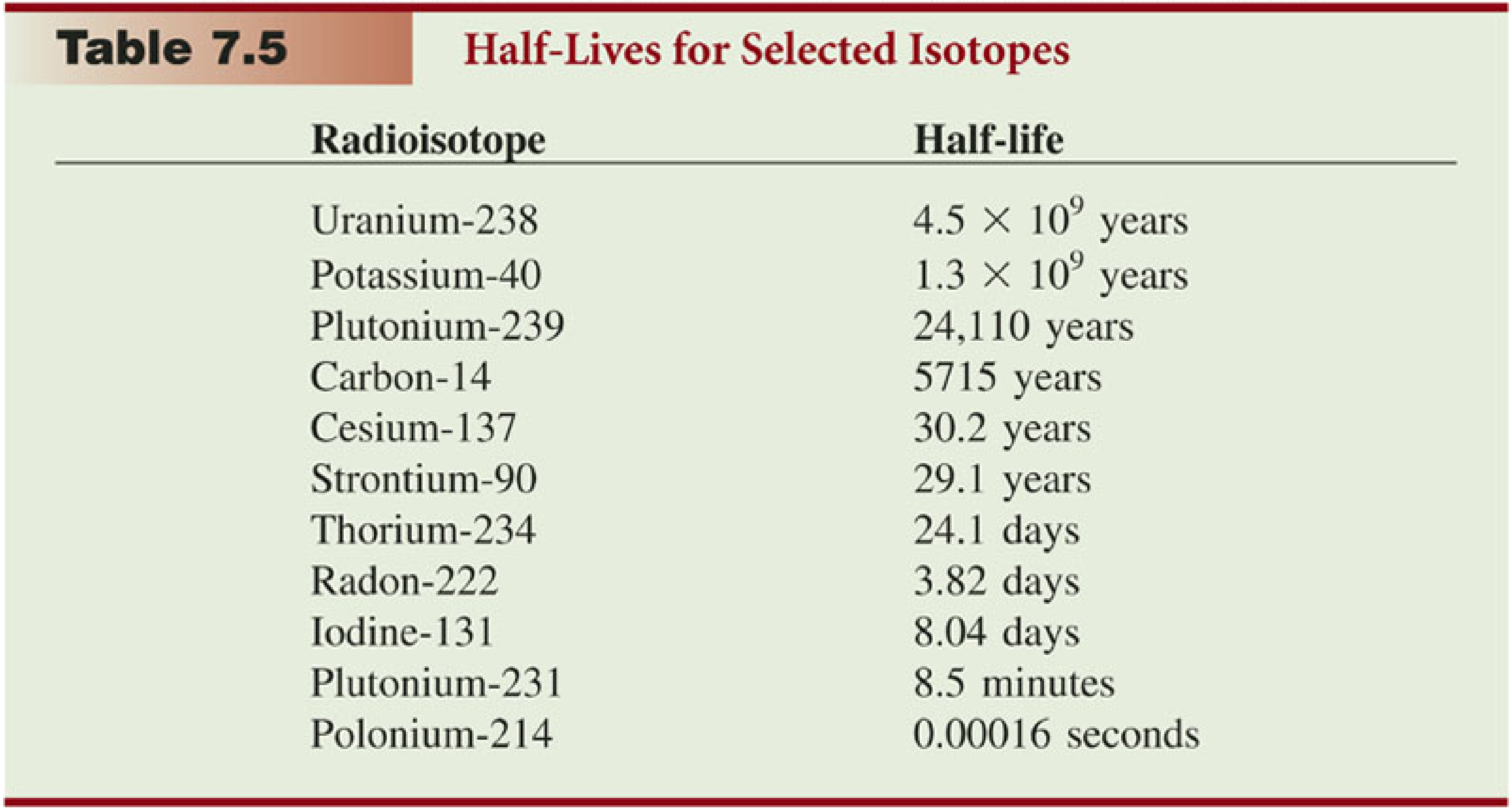


**Table 7.4** Your Annual Radiation Dose

| 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<br>1000 m (3300 ft) add 100 μSv<br>2000 m (6600 ft) add 300 μSv<br>3000 m (9900 ft) add 900 μSv | ____ |
| **2.** House construction<br>Building materials contain tiny amounts of radioisotopes.<br>Brick (700 μSv); wood (300 μSv); concrete (70 μSv) | ____ |
| **3.** Ground<br>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)<br>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.



## Table 7.5 Half-Lives for Selected Isotopes

| Radioisotope | Half-life |
|---|---|
| Uranium-238 | $4.5 \times 10^9$ years |
| Potassium-40 | $1.3 \times 10^9$ 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 |

## 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.

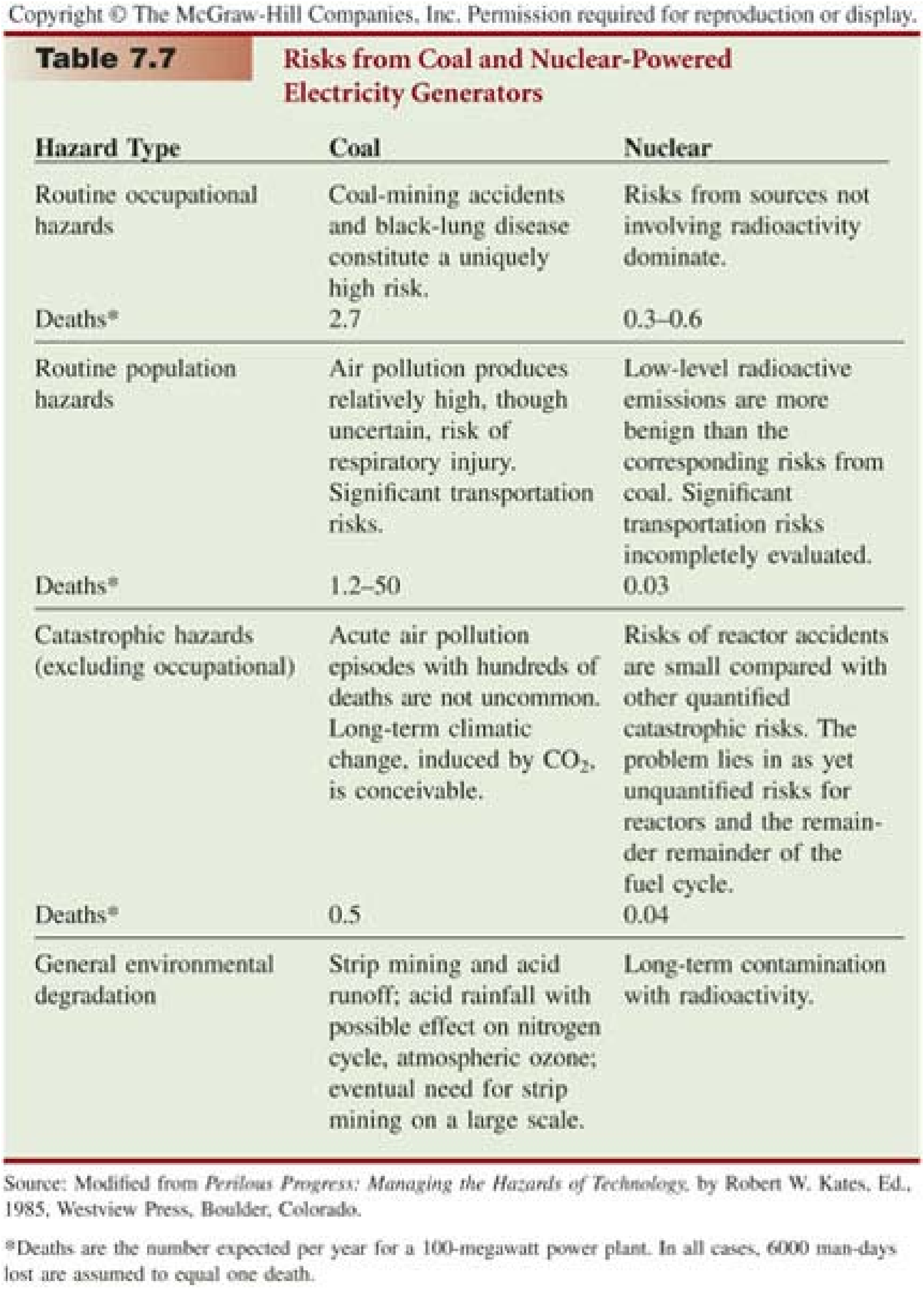


**Table 7.7** **Risks from Coal and Nuclear-Powered Electricity Generators**

| 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.