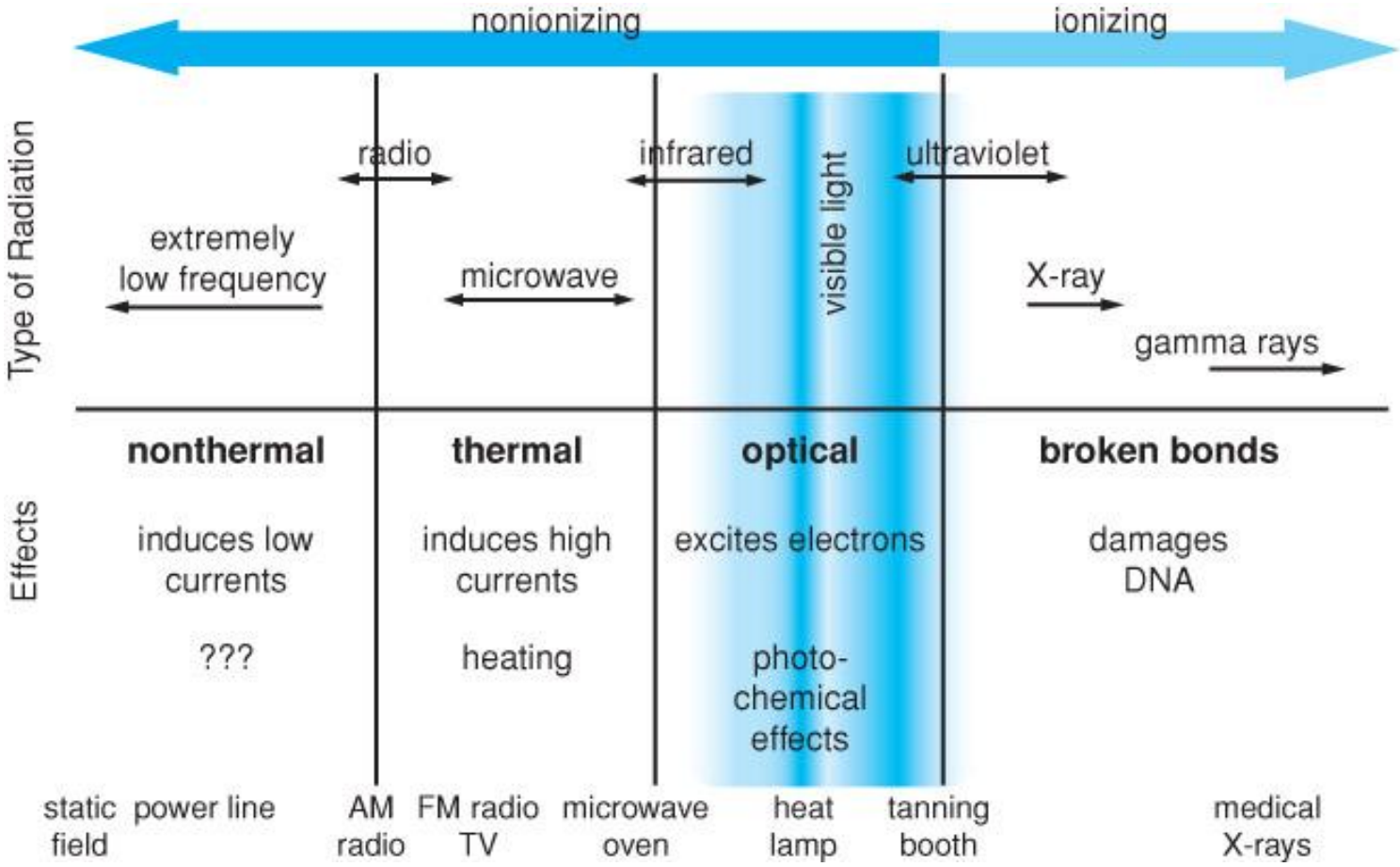
Chapter 8
Ionizing and Nonionizing Radiation



01: Types of radiation in the electromagnetic spectrum: Ionizing and nonionizing radiation.

Source: Reprinted from US Environmental Protection Agency. Radiation Protection: Understanding Radiation: Ionizing and Non-Ionizing Radiation. Available at: http://www.epa.gov/radiation/understand/ionize_nonionize.html. Accessed April 2, 2010.

02: Measuring radiation levels with a Geiger counter.

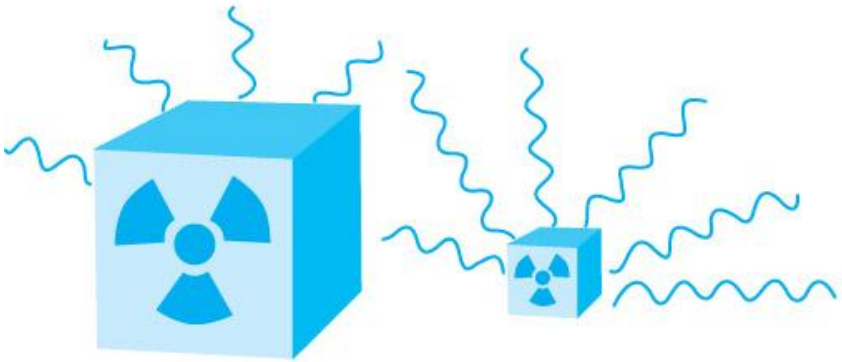
Source: Reprinted from National Library of Medicine. Images from the History of the Public Health Service, Disease Control and Prevention. Available at: http://www.nlm.nih.gov/exhibition/phs_history/41.html. Accessed April 2, 2010.

The size or weight of a container or shipment does not indicate how much radioactivity is in it.

The amount of radioactivity in a quantity of material can be determined by noting how many curies of the material are present. This information should be found on labels and/or shipping papers.

More curies = a greater amount of radioactivity

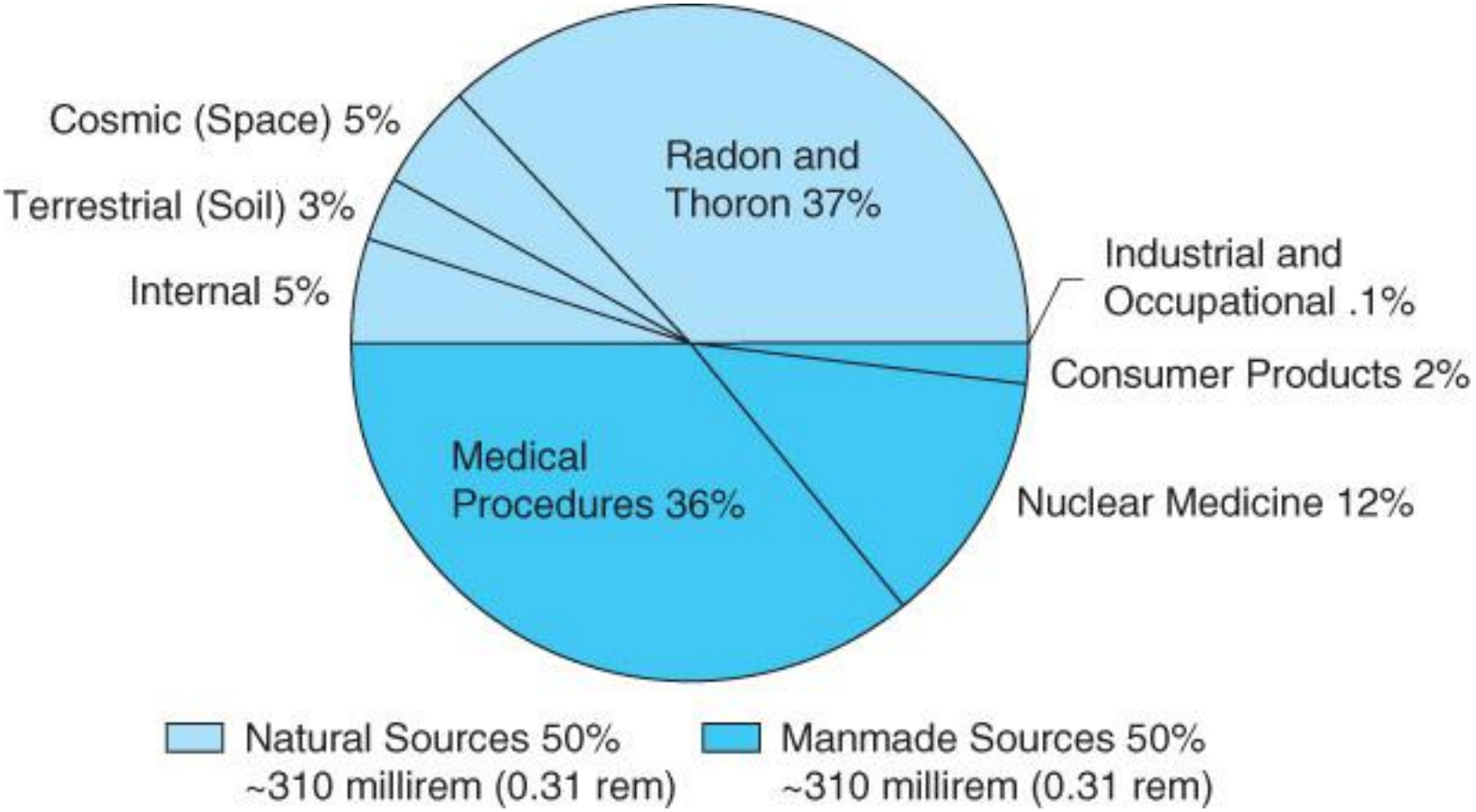
A large amount of material can have a very small amount of radioactivity; a very small amount of material can have a lot of radioactivity.



For example, uranium-238 has 0.00015 curies of radioactivity per pound (0.15 millicuries), while cobalt-60 has nearly 518,000 curies per pound.

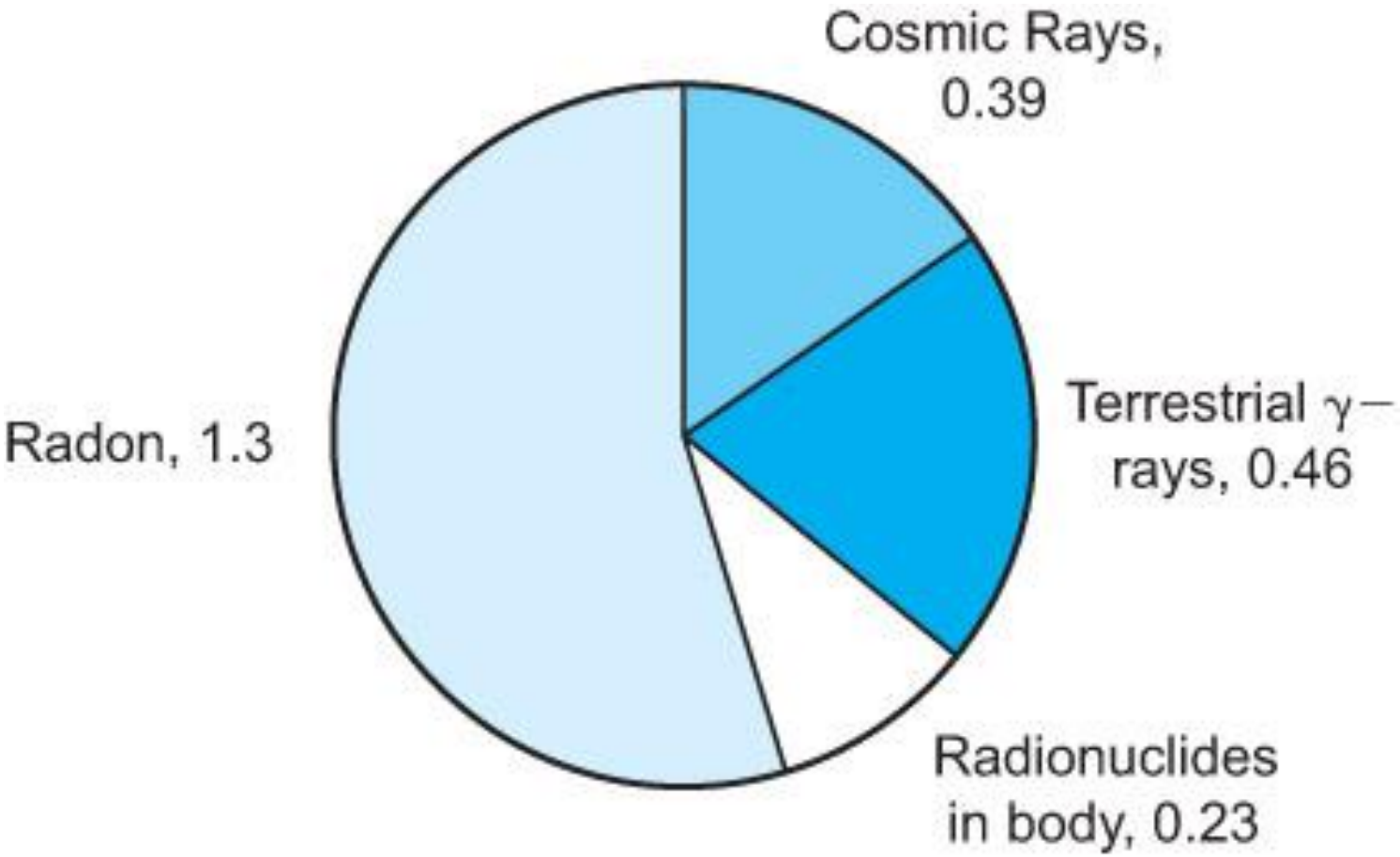
03: Measurement: How much radiation is present?

Source: Reprinted from Oak Ridge Institute for Science and Education. Guidance for Radiation Accident Management, Radiation Emergency Assistance Center/Training Site (REAC/TS). Measurement: Activity: How much is present? Available at: http://orise.orau.go



04: Sources of radiation exposure in the United States.

Source: Reprinted from United States Nuclear Regulatory Commission. Available at: http://www.nrc.gov/images/reading-rm/basic-ref/glossary/ionizing-radiation.jpg. Accessed April 3, 2010.

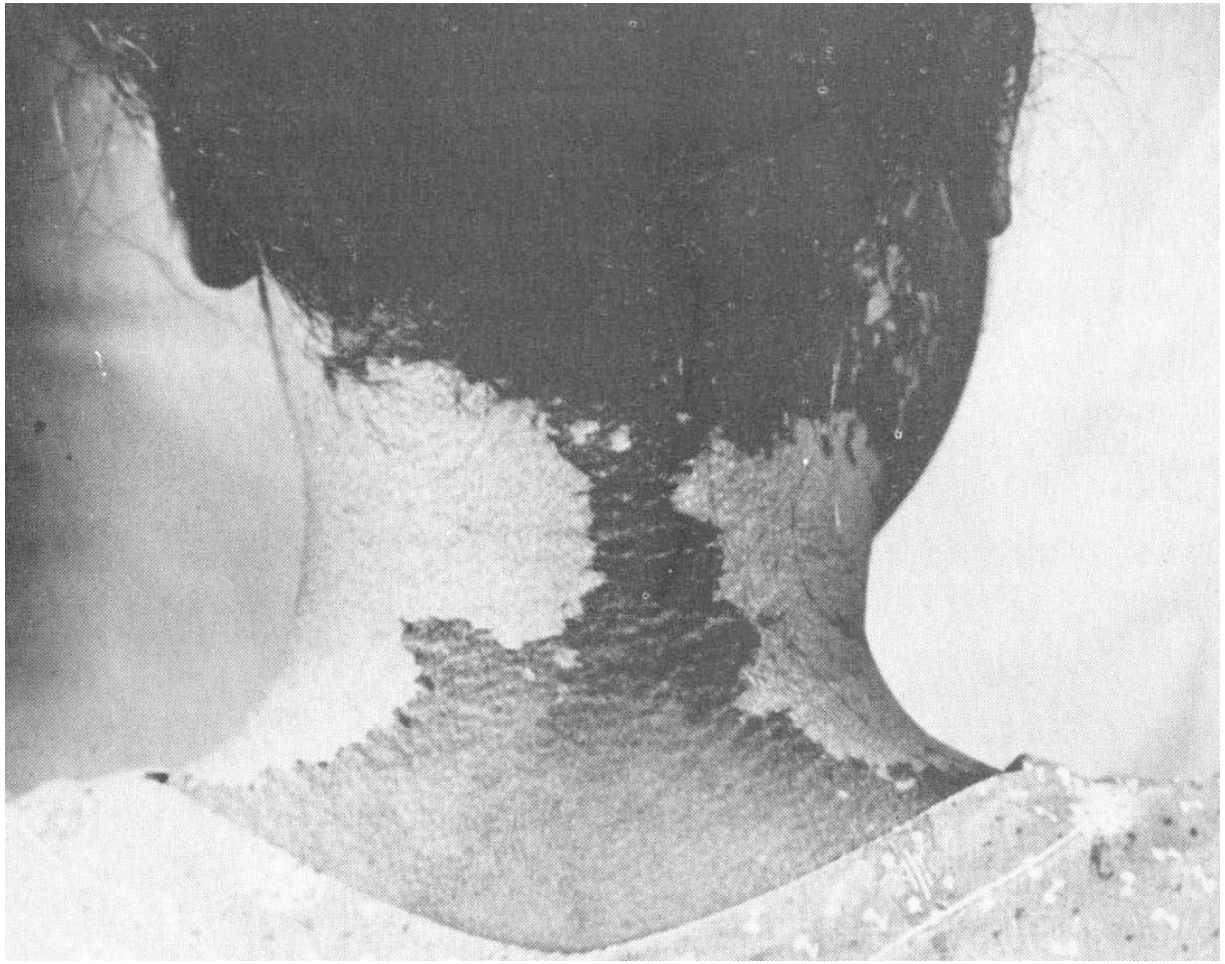


05: Annual effective doses to adults from natural sources of radiation (mSv).

Source: Data are from World Health Organization, International Agency for Research on Cancer, Ionizing Radiation, Part 1: X- and Gamma (γ)-Radiation, and Neutrons, IARC Monographs, 2000, vol. 75, p. 78.

06: Three Mile Island Nuclear Power Plant.

Source: Reprinted courtesy of Centers for Disease Control and Prevention. Public Health Image Library, ID# 1194. Available at: http://phil.cdc.gov/Phil/details.asp. Accessed March 24, 2010.



07A: Beta burn on the neck 1 month after exposure.

Source: Adapted and reprinted from S Glasstone and PJ Dolan, eds. The Effects of Nuclear Weapons. 3rd ed. Washington, DC: US Department of Defense and the Energy Research and Development Administration; 1977:568, 569, 595, 597.

07B: Beta burn one year after exposure.

Source: Adapted and reprinted from S Glasstone and PJ Dolan, eds. The Effects of Nuclear Weapons. 3rd ed. Washington, DC: US Department of Defense and the Energy Research and Development Administration; 1977:568, 569, 595, 597.

07C: Thermal (flash) burn—the patient's skin is burned in a pattern corresponding to the dark portions of a kimono worn at the time of the explosion.

Source: Adapted and reprinted from S Glasstone and PJ Dolan, eds. The Effects of Nuclear Weapons. 3rd ed. Washington, DC: US Department of Defense and the Energy Research and Development Administration; 1977:568, 569, 595, 597.

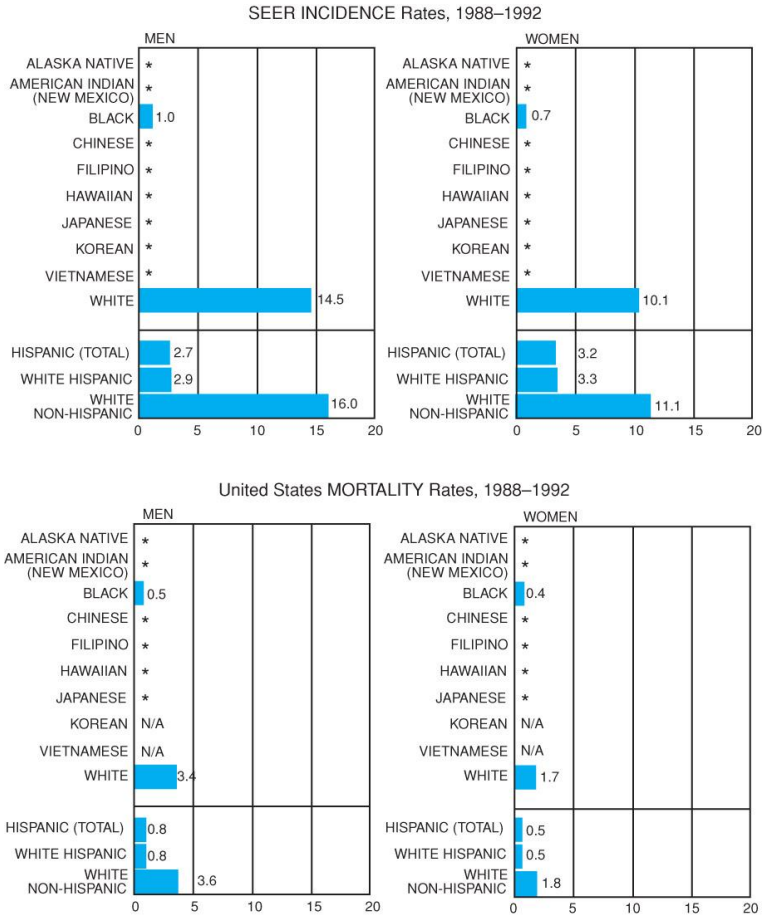
07D: Thermal (flash) burn—the skin under the areas of contact with clothing is burned and the protective effect of thicker layers of clothing can be seen on the shoulders and across the back.

Source: Adapted and reprinted from S Glasstone and PJ Dolan, eds. The Effects of Nuclear Weapons. 3rd ed. Washington, DC: US Department of Defense and the Energy Research and Development Administration; 1977:568, 569, 595, 597.

08: High-tension power lines. Environmental health studies have examined their potential health effects.

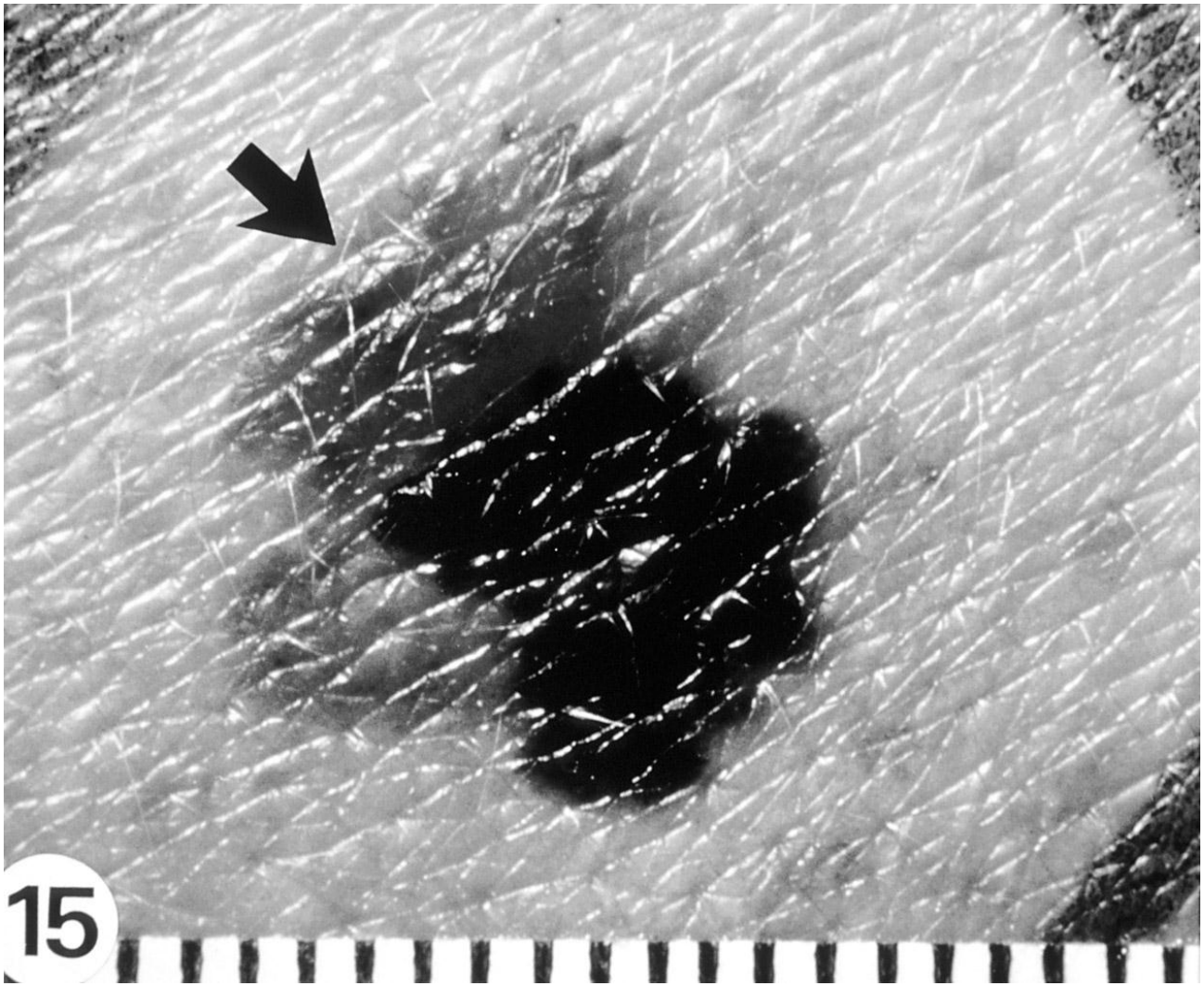
09: Cell phone antenna.

10: California sun worshiper.



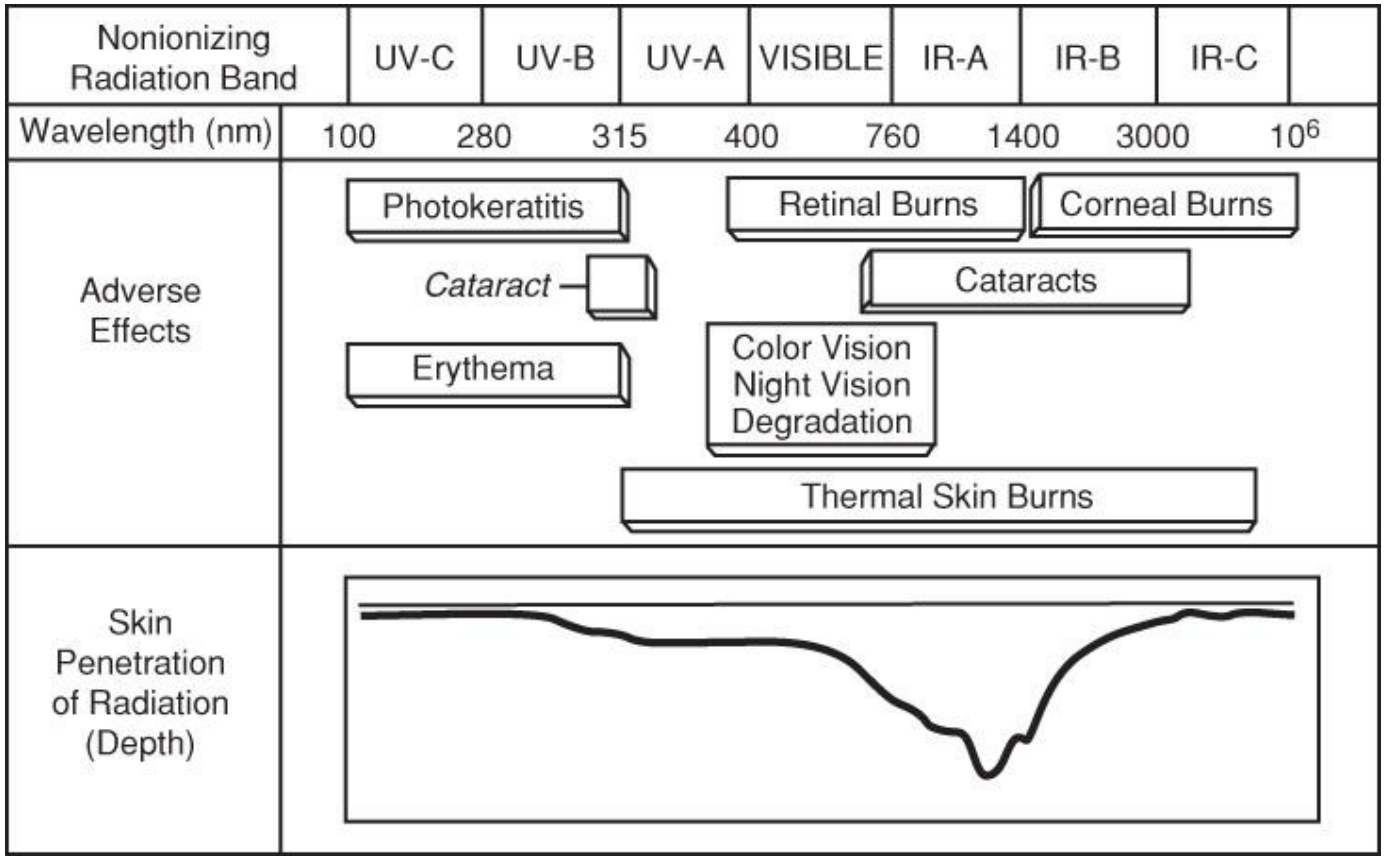
11: Incidence and mortality of melanoma of the skin, 1988–1992. Note: Rates are "average annual" per 100,000 population, age-adjusted to 1970 U.S. standard; N/A = information not available; * = rate not calculated when fewer than 25 cases.

Source: Reprinted from National Cancer Institute, SEER Program. Racial/Ethnic Patterns of Cancer in the United States, 1988–1992: Melanoma, 1996, p. 85. NIH Pub. No. 96-4104. Bethesda, MD.



12: Malignant melanoma.

Source: Courtesy of National Cancer Institute.



13: The optical spectrum and ocular effects. Photochemical mechanisms dominate in the UVR bands and in the short wavelength region of the visible spectrum. Thermal injury only occurs from brief, intense acute exposures and is more characteristic at longer

Source: Reprinted from Journal of Photochemistry and Photobiology B: Biology, vol. 64, DH Sliney, Photoprotection of the eye—UV radiation and sunglasses, p. 167. Copyright 2001, with permission from Elsevier.

TABLE 8-1 Ionizing Radiation Measurements

	Radioactivity	Absorbed Dose	Dose Equivalent	Exposure
Common Units	Curie (Ci)	Rad	Rem	Roentgen (R)
SI Units	Becquerel (Bq)	Gray (Gy)	Sievert (Sv)	Coulomb/kilogram (C/kg)

Source: Adapted and reprinted from Oak Ridge Institute for Science and Education. Guidance for Radiation Accident Management: Measurement. Available at: http://orise.orau.gov/reacts/guide/measure.htm. Accessed April 2, 2010.

T01: Ionizing Radiation Measurements

TABLE 8-2 Radioactivity, Dose, and Exposure

Absorbed dose	"[T]he primary physical quantity of radiation dosimetry. It is defined as the radiation energy absorbed per unit mass of an organ or tissue and is used in studies of the damage to a particular organ or tissue."[a(p39)]
Dose equivalent (equivalent dose)	Obtained by weighting the absorbed dose in an organ or tissue by a radiation weighting factor that reflects the biological effectiveness of the charged particles that produce ionization within the tissue. Related to the concept of dose is *effective dose*, which measures the overall biological impact associated with radiation, by taking into account weighting factors and equivalent dose factors. Another aspect of dose is the *dose rate*, which is defined as "The dose delivered per unit of time. It is usually expressed as rads per hour or in multiples or submultiples of this unit such as millirads per hour. The dose rate is commonly used to indicate the level of hazard from a radioactive source."[b]
Exposure	"A quantity used to indicate the amount of ionization in air produced by x- or gamma-ray radiation. The unit is the roentgen (R). For practical purposes, one roentgen is comparable to 1 rad or 1 rem for X and gamma radiation."[b] Exposure to ionizing radiation can come from an external source, which exposes (irradiates) the entire body or part of the body such as a targeted organ or tissue. Radiation of this type is called an *external radiation dose*. An *internal radiation dose* arises from a radioactive substance that has been deposited inside the body.[c]

Sources: Adapted from [a]World Health Organization, International Agency for Research on Cancer. Ionizing Radiation, Part 1: X- and Gamma (γ)-Radiation, and Neutrons. *IARC Monographs*. 2000;75:35–115; [b]Oak Ridge Institute for Science and Education. Guidance for Radiation Accident Management. Radiation Emergency Assistance Center/Training Site (REAC/TS). Basics of Radiation: Definitions. Available at: http://orise.orau.gov/reacts/guide/definitions.htm. Accessed April 2, 2010; [c]Health Physics Society. Radiation Dose Units. Available at: http://hps.org/publicinformation/ate/faqs/radiationdoses.html. Accessed March 11, 2010.

T02: Radioactivity, Dose, and Exposure

TABLE 8-3 Definitions of Common Units of Radiation

Curie (Ci)	A unit of measure used to describe the amount of radioactivity in a sample of material[a]; 1 Ci equals 3.7×10^{10} disintegrations per second.[b]
Rad	Radiation absorbed dose. The former unit of absorbed dose of ionizing radiation.[c]
Rem	Roentgen equivalent in man. A measure of radiation dose related to biological effect (i.e., the equivalent dose or effective dose).[a] A rem is a measure of dose deposited in body tissue, averaged over the mass of the tissue of interest. One rem is approximately the dose from any radiation corresponding to one roentgen of gamma radiation.[c]
Roentgen (R)	The unit of exposure from X- or gamma rays.[a]

Sources: Adapted and reprinted from [a]Oak Ridge Institute for Science and Education. Guidance for Radiation Accident Management. Radiation Emergency Assistance Center/Training Site (REAC/TS). Basics of Radiation: Definitions. Available at: http://orise.orau.gov/reacts/guide/definitions.htm. Accessed March 24, 2010; [b]Oak Ridge Institute for Science and Education. Guidance for Radiation Accident Management: Measurement. Available at: http://orise.orau.gov/reacts/guide/measure.htm. Accessed April 2, 2010; [c]Lawrence Berkeley National Laboratory. Nuclear Science Glossary, Appendix A Glossary of Nuclear Terms. Available at: http://www.lbl.gov/abc/wallchart/glossary/glossary.html. Accessed April 2, 2010.

T03: Definitions of Common Units of Radiation

TABLE 8-4 International System of Units (SI Units) and Their Equivalency in Common Units

Becquerel (Bq)	(Corresponds to radioactivity) The SI unit of activity, which is defined as one disintegration per second; 37 billion Bq = 1 curie; 1 Bq = 2.7×10^{-11} i.
Exposure	The SI unit of exposure is the coulomb per kilogram (C/kg). One R = 2.58×10^{-4} C/kg.
Gray (Gy)	(Corresponds to absorbed dose) The SI unit of absorbed dose; 1 gray = 100 rad; 1 rad = 0.01 Gy.
Sievert (Sv)	(Corresponds to dose equivalent) The SI unit of dose equivalent; 1 Sv = 100 rem; 1 rem = 0.01 Sv.

Source: Adapted and reprinted from Oak Ridge Institute for Science and Education, Radiation Emergency Assistance Center/Training Site (REAC/TS). Guidance for Radiation Accident Management, Basics of Radiation: Definitions. Available at: http://orise.orau.gov/reacts/guide/definitions.htm. Accessed March 24, 2010; and Oak Ridge Institute for Science and Education. Guidance for Radiation Accident Management, Radiation Emergency Assistance Center/Training Site (REAC/TS). Measurement. Available at: http://orise.orau.gov/reacts/guide/measure.htm. Accessed March 24, 2010.

T04: International System of Units (SI Units) and Their Equivalency in Common Units

TABLE 8-5 Nonstochastic Health Effects of Whole-Body Exposure for an Average Person and Time to Onset Following Acute Exposure

Exposure (rem)	Health Effect	Time to Onset
5–10	Changes in blood chemistry	
50	Nausea	Hours
55	Fatigue	
70	Vomiting	
75	Hair loss	2–3 weeks
90	Diarrhea	
100	Hemorrhage	
400	Possible death	Within 2 months
1,000	Destruction of intestinal lining	
	Internal bleeding	
	Death	1–2 weeks
2,000	Damage to central nervous system	
	Loss of consciousness	Minutes
	Death	Hours to days

Source: Reprinted from US Environmental Protection Agency. Radiation Protection: Understanding Radiation: Health Effects. Available at: http://www.epa.gov/radiation/understand/health_effects.html. Accessed March 11, 2010.

T05: Nonstochastic Health Effects of Whole-Body Exposure for an Average Person and Time to Onset Following Acute Exposure

TABLE 8-6 Examples of Frequencies in the Radio Range

Radiofrequency Radiation	Frequencies
AM radio	0.5 to 1.5 MHz
Amateur radio	3 to 30 MHz
FM, VHF-TV	50 to 150 MHz
UHF-TV	300 to 3,000 MHz
Microwave ovens	2,450 MHz
Radar, microwave communication	3,000 to 300,000 MHz or 3 to 300 GHz

Source: Data are from PA Valberg. Radio frequency radiation (RFR): the nature of exposure and carcinogenic potential. *Cancer Causes Control.* 1997;8:324.

T06: Examples of Frequencies in the Radio Range

The UV Index

The UV index provides a daily forecast of the expected risk of overexposure to the sun [see Table 8-7]. The index predicts UV intensity levels on a scale of 1 to 11+, where low indicates a minimal risk of overexposure and 11+ means an extreme risk. Calculated on a next-day basis for every ZIP code across the United States, the UV index takes into account clouds and other local conditions that affect the amount of UV radiation reaching the ground in different parts of the country.

TABLE 8-7 UV Index Value and Exposure Level

UV Index Number	Exposure Level
0 to 2	Low
3 to 5	Moderate
6 to 7	High
8 to 10	Very High
11+	Extreme

Source: Data from US Environmental Protection Agency. SunWise Program. UV Index. Available at: http://www.epa.gov/sunwise/uvindex.html. Accessed April 4, 2010; and US Environmental Protection Agency. SunWise Program. UV Index scale. Available at: http://www.epa.gov/sunwise/uviscale.html. Accessed April 4, 2010.

T07: UV Index Value and Exposure Level