



NPRE 441: Principles of Radiation Protection

Instructor: Ling-Jian Meng,
Professor,
Department of Nuclear, Plasma and Radiological Engineering,
University of Illinois at Urbana-Champaign



Textbook Information

Textbook

Required textbook

[1] J. Turner, "Atoms, Radiation, and Radiation Protection", Third Edition, Wiley-VCH, 2007.

References:

- [1] H. Cember - "Introduction to Health Physics", 4th Edition, McGraw-Hill (2023).
- [2] J. K. Shultis and R. E. Faw, "Radiation Shielding," American Nuclear Society (2000).
- [3] R. E. Faw and J. K. Shultis, "Radiological Assessment: Sources and Doses, American Nuclear Society (1999).
- [4] E. L. Alpen, "Radiation Biophysics," Academic Press (1998).
- [5] Radiation Detection and Measurements, Third Edition, G. F. Knoll, John Wiley & Sons, 1999.



Table of Content

Chapter 1: The Nucleus and Nuclear Radiation

Chapter 2: Interaction of Radiation with Matter

Chapter 3: Methods for Radiation Detection

Chapter 4: Counting Statistics

Chapter 5: Radiation Dosimetry

Chapter 6: Biological Effects of Radiation

Chapter 7: External Radiation Protection

Chapter 8: Radiation Protection Criteria and Exposure Limits



General Information

Instructor: Dr. Ling-Jian Meng, <ljmeng@illinois.edu>

Co-instructor: Dr. Elena Zannoni, <zannoni2@illinois.edu>

TA: Galen Selligman, <galenas2@illinois.edu>

Course website: <<http://courses.engr.illinois.edu/npre441/>>

8 Homeworks: 20%,

Mid-term exam: 20%,

6 in-class quizzes: 30%,

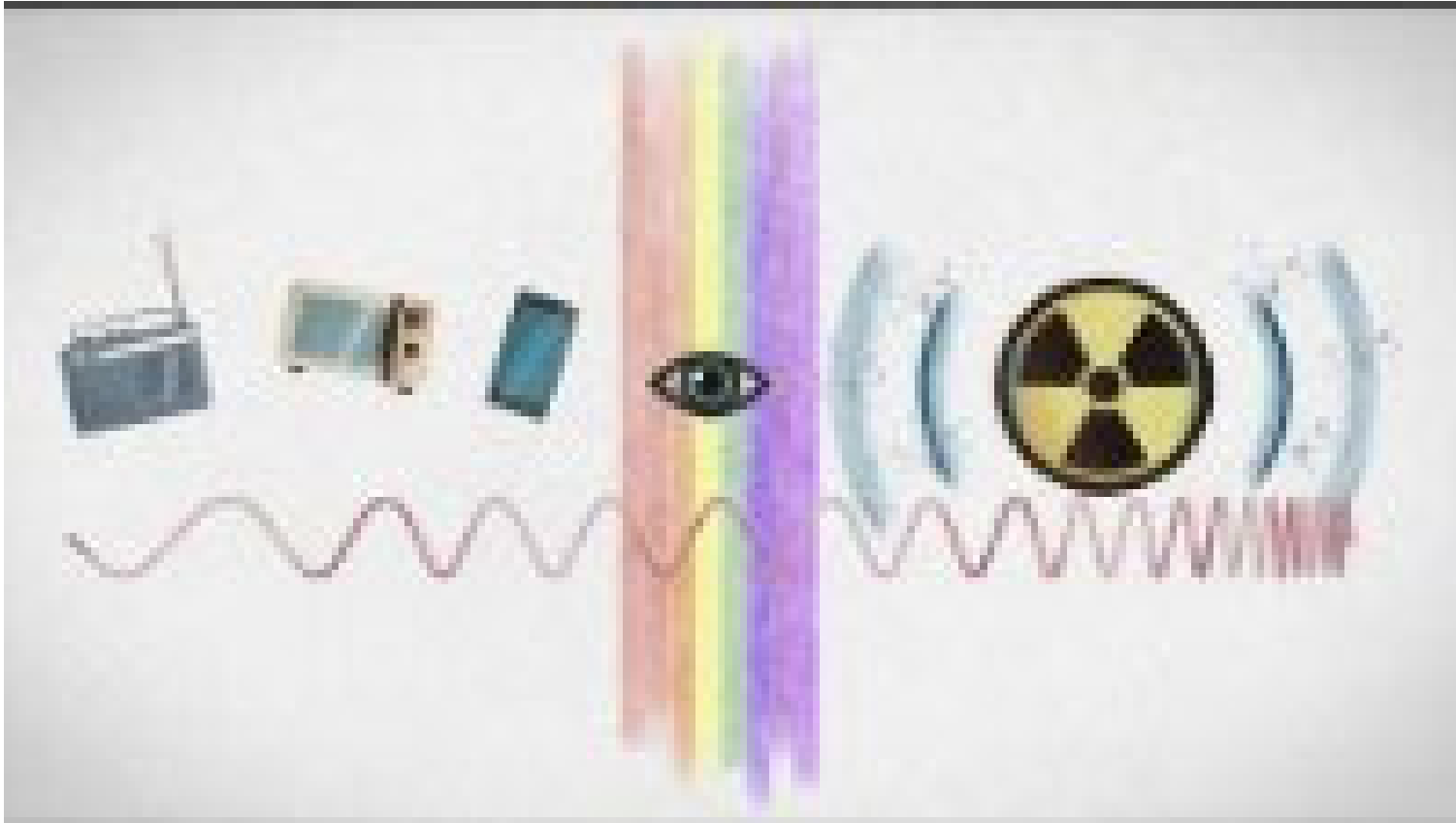
Final exam: 20%,

Term-project: 10%.



An Initial Overview of Ionizing Radiation

Radiation



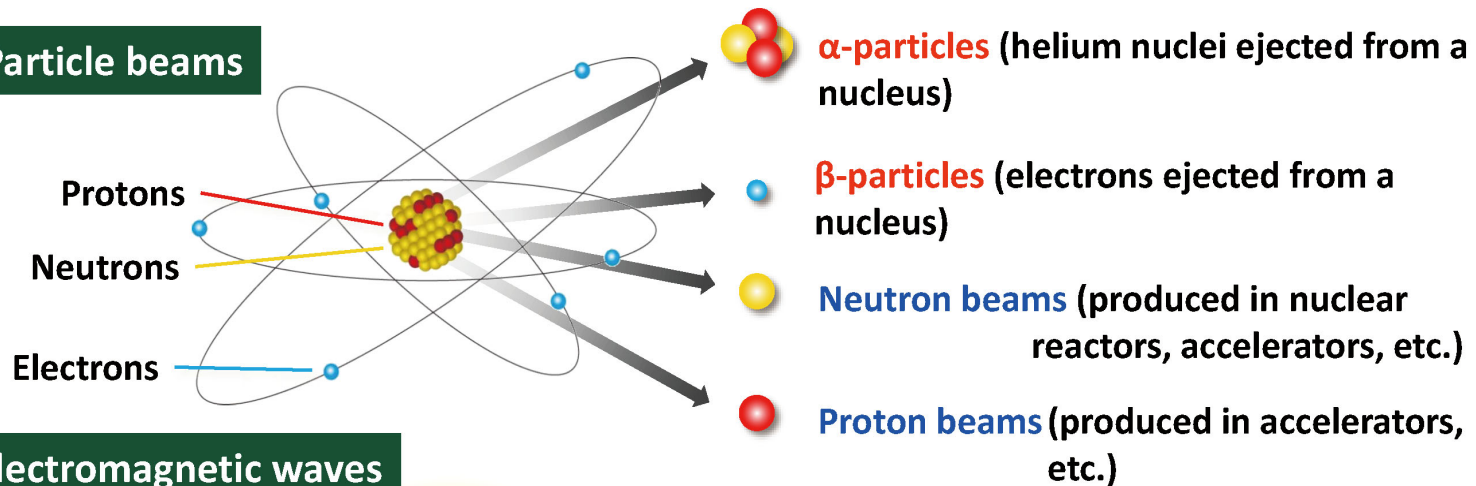
<https://www.iaea.org/newscenter/news/what-is-radiation>

Different Types of Ionizing Radiation

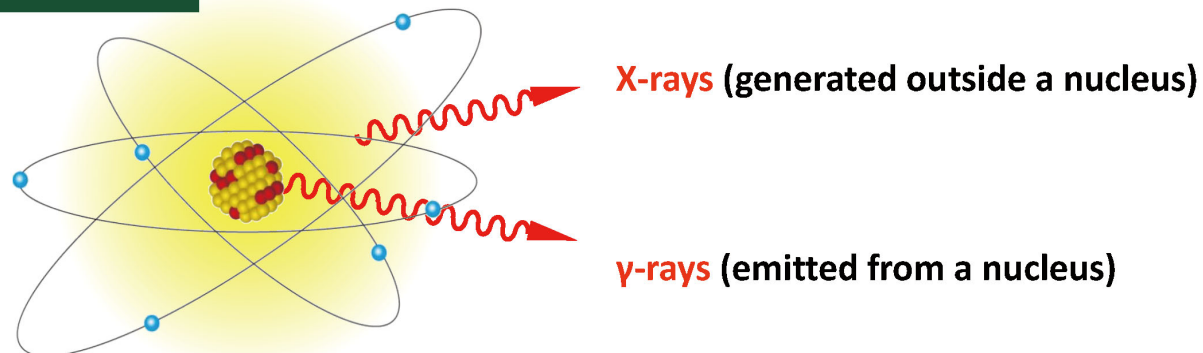
Ionizing radiation

Radiation that causes ionization

Particle beams

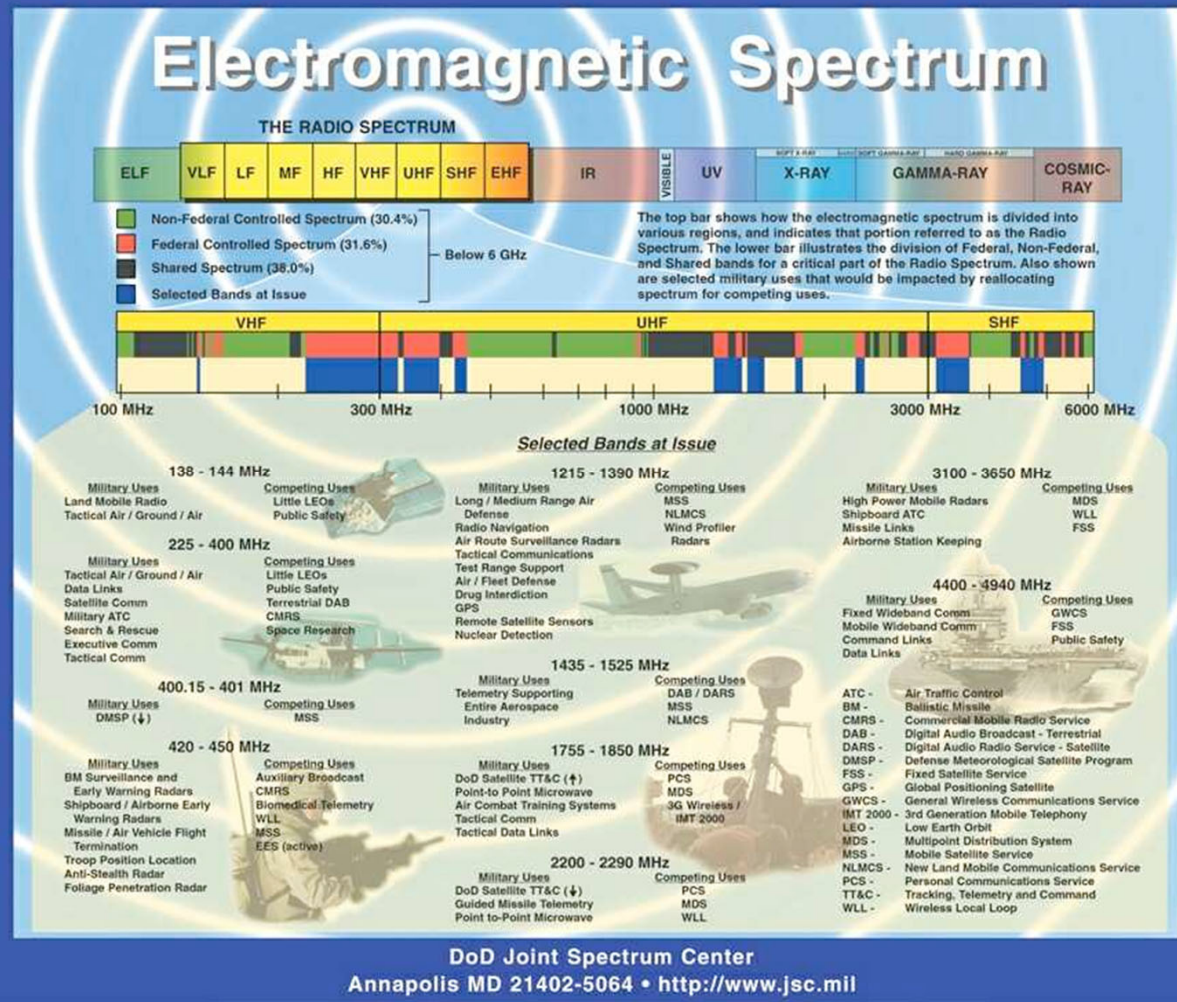


Electromagnetic waves



<https://www.env.go.jp/en/chemi/rhm/basic-info/1st/index.html>

Electromagnetic Radiation



Copyright © 2001 IIT Research Institute. Prepared for the Department of Defense, Joint Spectrum Center (JSC). Photographs used with permission from the U.S. Air Force, U.S. Army, U.S. Navy, Felicia Campbell (Land Warrior)

Copyright © 2001 IIT Research Institute. Prepared for the Department of Defense, Joint Spectrum Center (JSC). Photographs used with permission from the U.S. Air Force, U.S. Army, U.S. Navy, Felicia Campbell (Land Warrior)

Electromagnetic Radiation

1. γ -rays: Electromagnetic radiation emitted from a nucleus or in annihilation reactions between matter and antimatter. The quantum energy of any electromagnetic photon is given in keV by

$$\begin{aligned} E_{\gamma} &= h\nu = \frac{hc}{\lambda} = \frac{12.398 \text{ keV-}\text{\AA}}{\lambda} \\ &= \frac{1.2398 \text{ keV-nm}}{\lambda} \end{aligned} \quad (1.1)$$

where 1 \AA (Angstrom) = 10^{-10} m, Planck's constant is

$$\begin{aligned} h &= 6.626 \times 10^{-34} \text{ J s} \\ &= 4.136 \times 10^{-18} \text{ keV s} \end{aligned}$$

(note that $1.6022 \times 10^{-16} \text{ J} = 1 \text{ keV}$), and the velocity of light *in vacuo* is

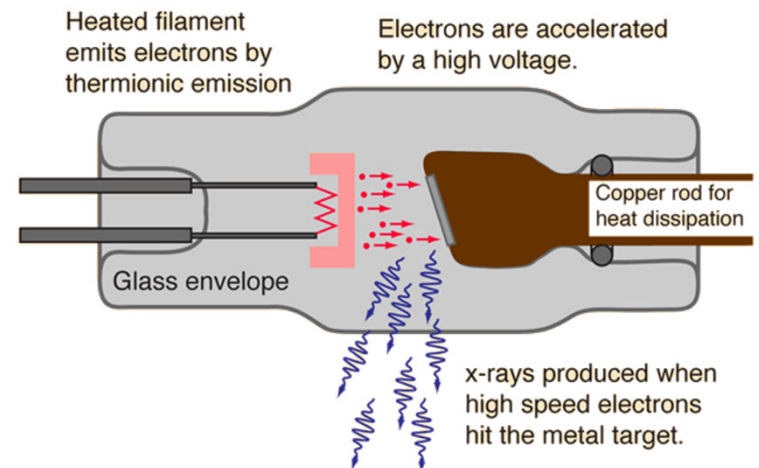
$$\begin{aligned} c &= 2.998 \times 10^8 \text{ m/s} \\ &= 2.998 \times 10^{18} \text{ \AA/s} \\ &= 2.998 \times 10^{17} \text{ nm/s} \end{aligned}$$

Evidently, by Eq. (1.1) the quantum energy of a photon of 0.1-nm wavelength is 12.4 keV, within one part in 6000.

Electromagnetic Radiation

2. *X-rays*: Electromagnetic radiation emitted by charged particles (usually electrons) in changing atomic energy levels (called *characteristic* or *fluorescence x-rays*) or in slowing down in a Coulomb force field (*continuous* or *bremsstrahlung x-rays*). Note that an x-ray and a γ -ray photon of a given quantum energy have identical properties, differing only in mode of origin. Older texts sometimes referred to all lower-energy photons as x-rays and higher energy photons as γ -rays, but this basis for the distinction is now obsolete. Most commonly, the energy ranges of x-rays are now referred to as follows, in terms of the generating voltage:

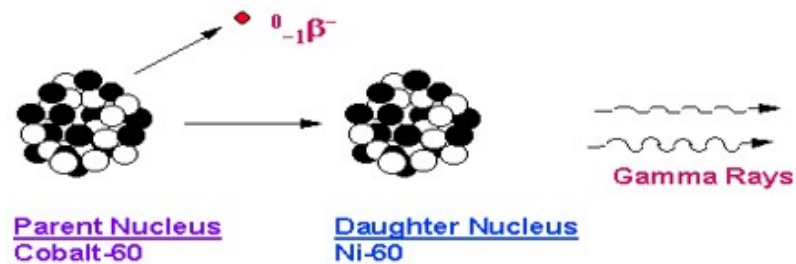
0.1–20 kV	Low-energy or “soft” x-rays, or “Grenz rays”
20–120 kV	Diagnostic-range x-rays
120–300 kV	Orthovoltage x-rays
300 kV–1 MV	Intermediate-energy x-rays
1 MV upward	Megavoltage x-rays



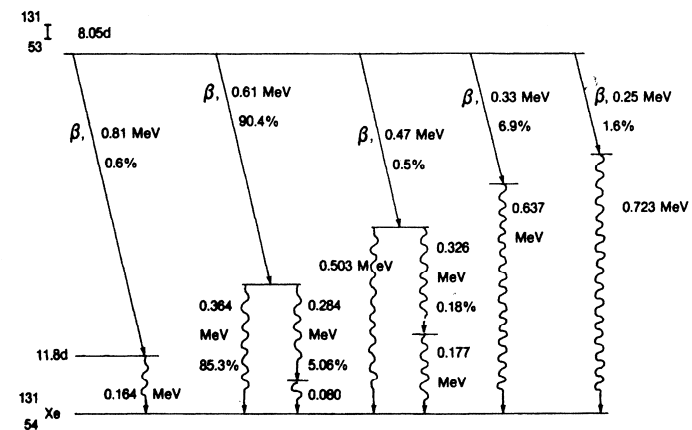
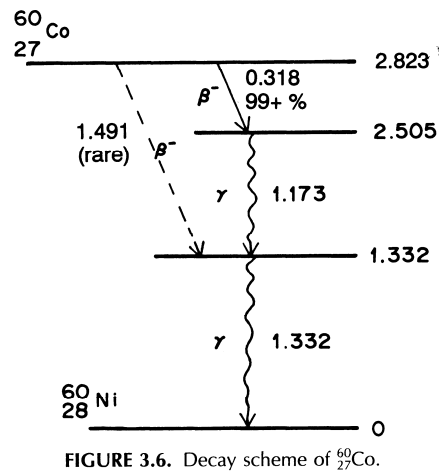
(Right) <http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/xtube.html>

Beta Decay and Gamma Ray Emission

Gamma-Ray Radiation



<https://assignmentpoint.com/about-gamma-radiation/>



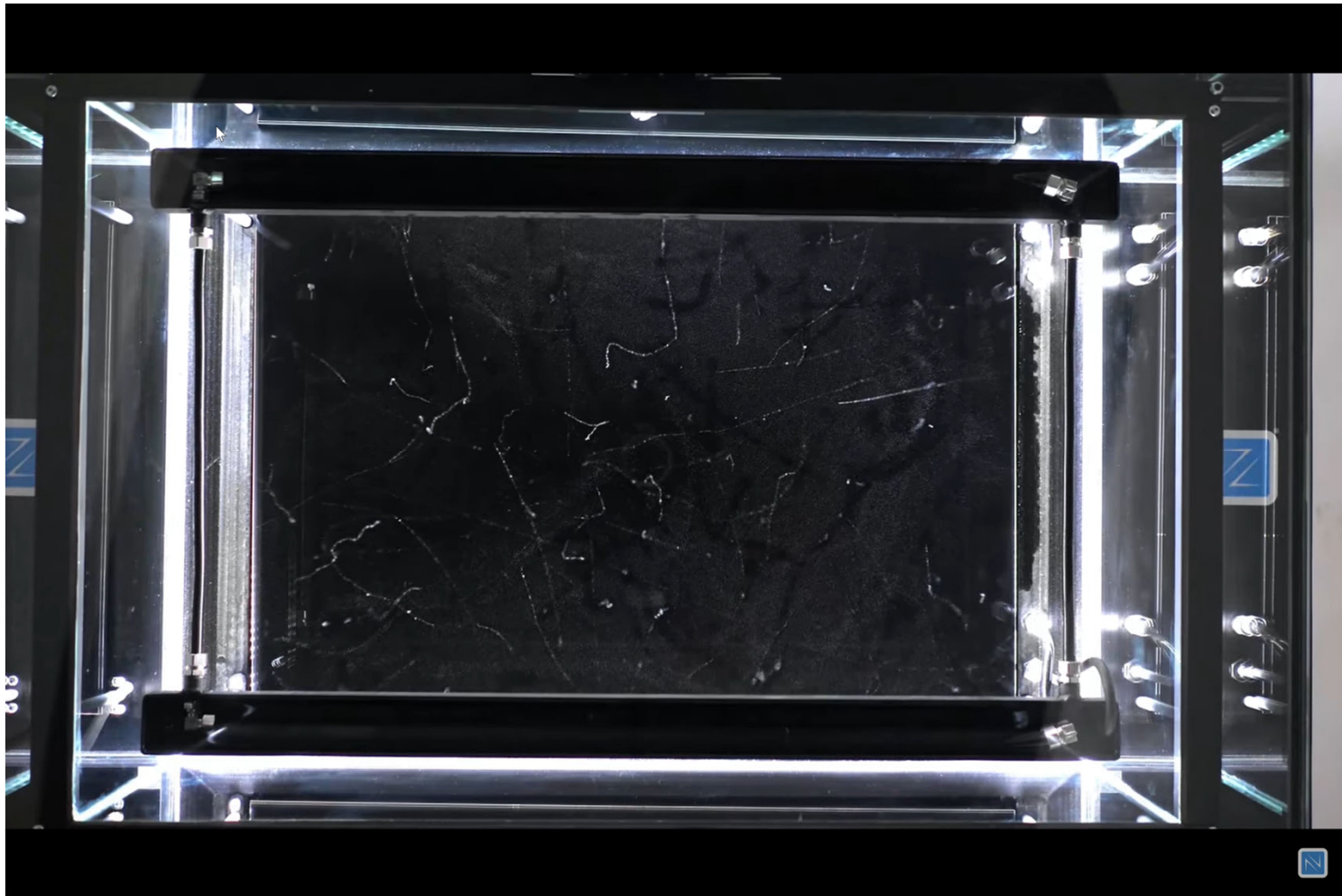
Charged Particles

3. Fast Electrons: If positive in charge, they are called positrons. If they are emitted from a nucleus they are usually referred to as β -rays (positive or negative). If they result from a charged-particle collision they are referred to as “ δ -rays”. Intense continuous beams of electrons up to 12 MeV are available from Van de Graaff generators, and pulsed electron beams of much higher energies are available from linear accelerators (“linacs”), betatrons, and microtrons. Descriptions of such accelerators, as encountered in medical applications, have been given by Johns and Cunningham (1974) and Hendee (1970).

4. Heavy Charged Particles: Usually obtained from acceleration by a Coulomb force field in a Van de Graaff, cyclotron, or heavy-particle linear accelerator. Alpha particles are also emitted by some radioactive nuclei. Types include:




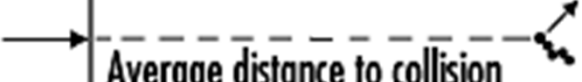
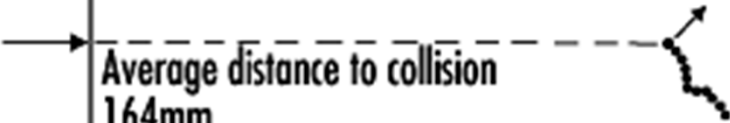
- Proton—the hydrogen nucleus.
- Deuteron—the deuterium nucleus, consisting of a proton and neutron bound together by nuclear force.
- Triton—a proton and two neutrons similarly bound.
- Alpha particle—the helium nucleus, i.e., two protons and two neutrons. ^3He particles have one less neutron.
- Other heavy charged particles consisting of the nuclei of heavier atoms, either fully stripped of electrons or in any case having a different number of electrons than necessary to produce a neutral atom.
- Pions—negative π -mesons produced by interaction of fast electrons or protons with target nuclei.

Tracks of Charged Particles (such as Beta and Alpha) in Air



<https://www.thenakedscientists.com/forum/index.php?topic=47630.0>

Range of Ionizing Radiation in Tissue

Type of radiation	Source	Range in tissue
Alpha	^{210}Po 5.3 MeV	 Range 0.037mm
Beta	^{14}C 0.154 MeV maximum energy	 Maximum range 0.29mm (typically less)
Beta	^{32}P 1.71 MeV maximum energy	 Maximum range 8mm (typically less)
Gamma	^{125}I 0.035 MeV	 Average distance to collision 33mm
Gamma	^{60}Co 1.33 MeV	 Average distance to collision 164mm

Source: Shapiro 1972.



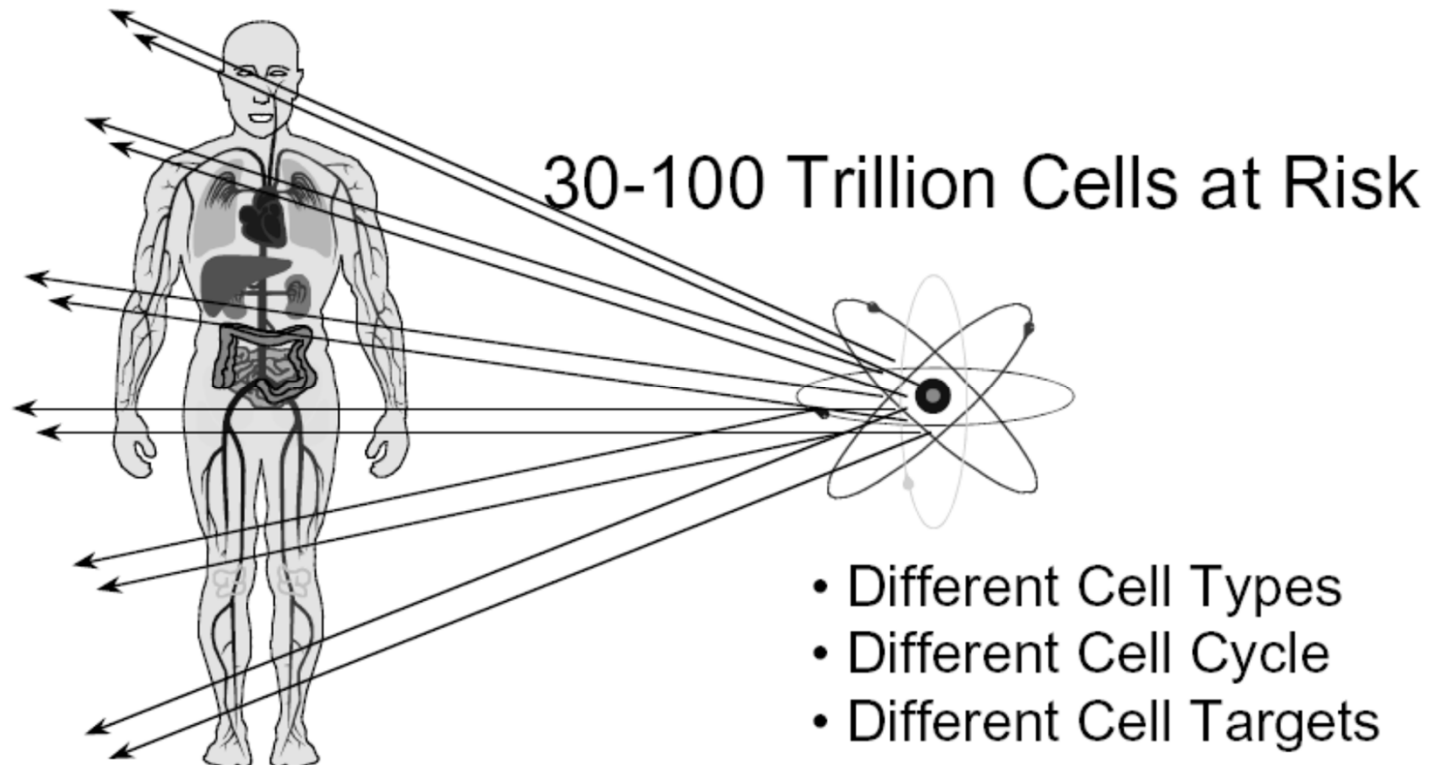
Directly and Indirectly Ionizing Radiation

The ICRU (International Commission on Radiation Units and Measurements, 1971) has recommended certain terminology in referring to ionizing radiations which emphasizes the gross differences between the interactions of charged and uncharged radiations with matter:

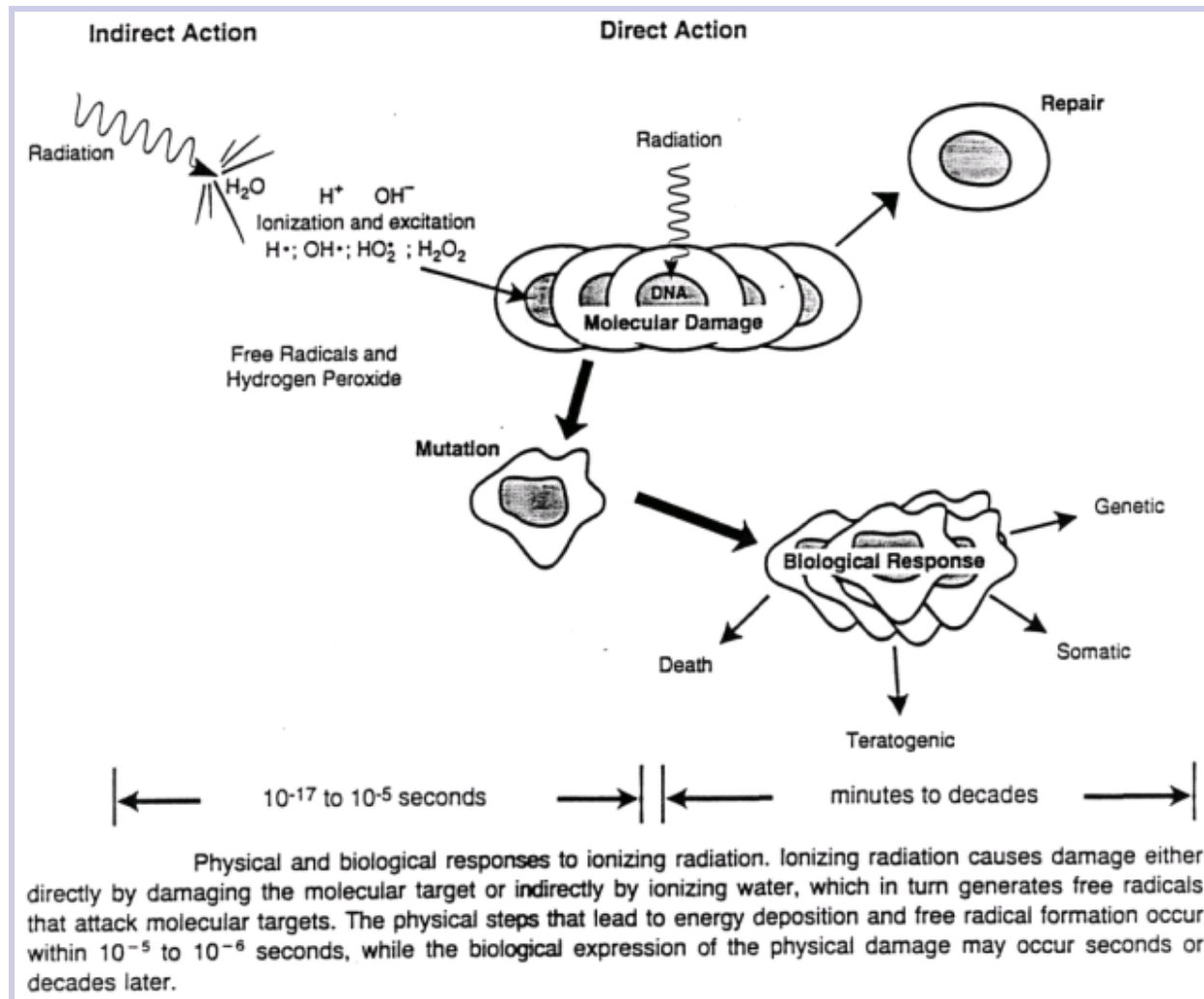
1. Directly Ionizing Radiation. Fast charged particles, which deliver their energy to matter directly, through many small Coulomb-force interactions along the particle's track.
2. Indirectly Ionizing Radiation. X- or γ -ray photons or neutrons (i.e., uncharged particles), which first transfer their energy to charged particles in the matter through which they pass in a relatively few large interactions. The resulting fast charged particles then in turn deliver the energy to the matter as above.

It will be seen that the deposition of energy in matter by indirectly ionizing radiation is thus a *two-step process*. In developing the concepts of radiological physics the importance of this fact will become evident.

Targets for Radiation Damage



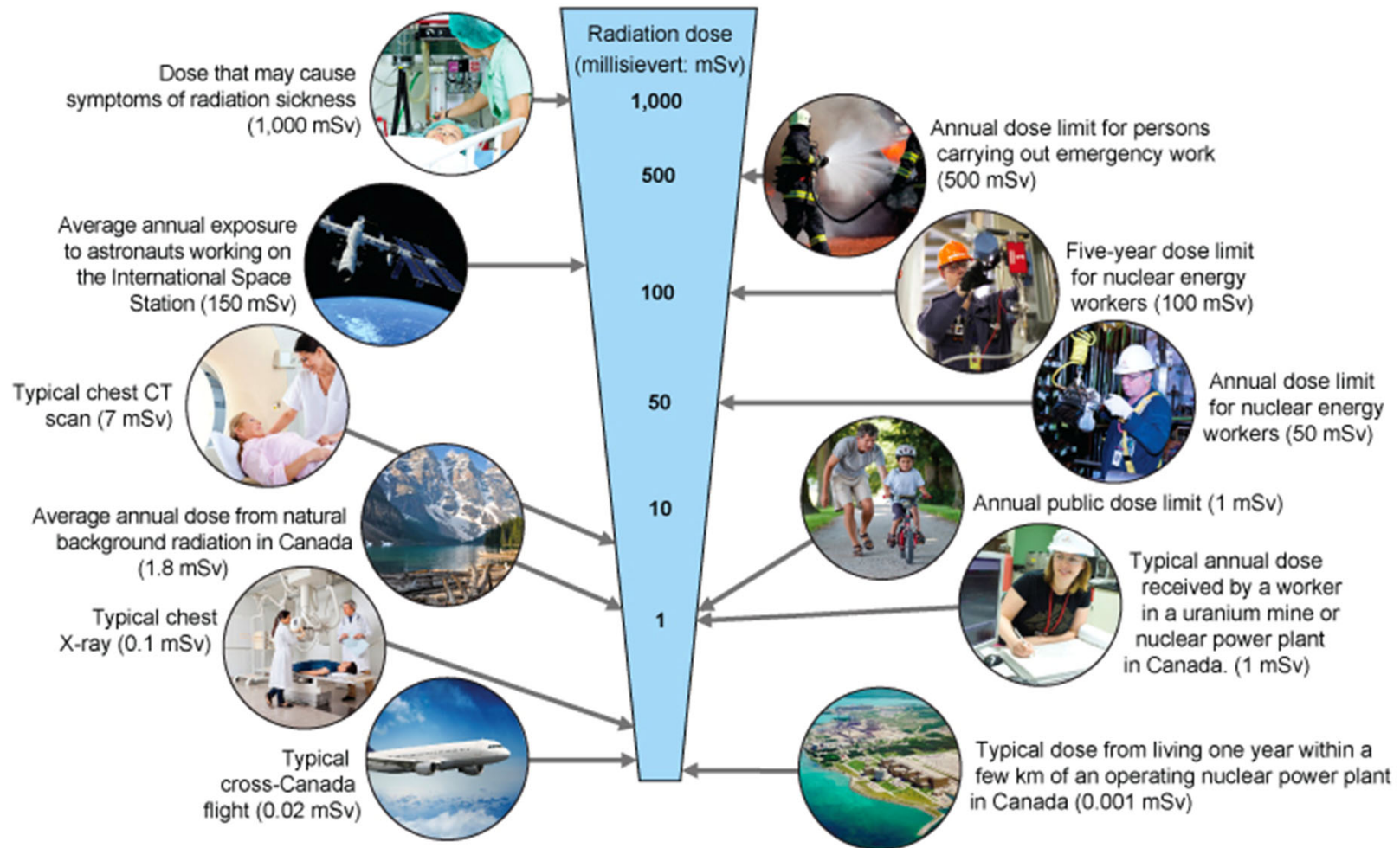
Direction and Indirect Radiation Effect





An Overview of Radiation Dose to the General Public

Radiation dose examples



Effective Radiation Dose

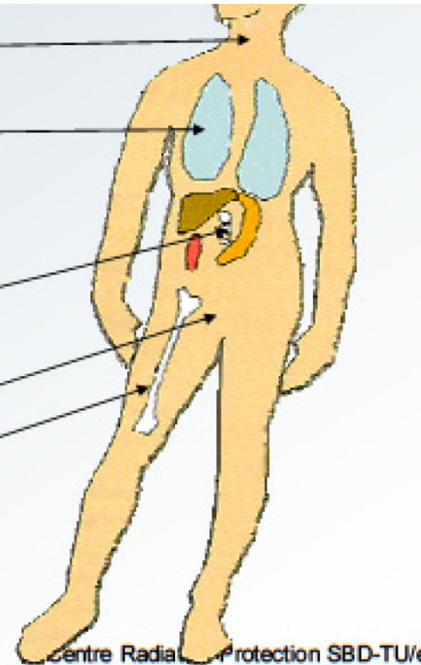
$$\text{Effective dose} = \sum_{\text{organ}} w_{\text{organ}} (w_R \times D_{\text{organ}}) (s_v)$$

Organ weighting factor

quality factor of
the radiation

$\frac{E}{m}$ (J/kg)

0.05	thyroid
0.05	breast tissue
0.12	lungs
0.05	esophagus
0.12	stomach
0.05	liver
0.12	colon
0.05	urinary bladder
0.20	reproductive organs
0.01	skin
0.12	red bone marrow
0.01	bone surface
0.05	rest of body
1.00	total



Centre Radia... Protection SBD-TU/e



Examples of Annual Dose Limits

Occupational Dose Limits for Adults

- An annual limit of 5 rem (0.05 Sv) total effective dose equivalent (TEDE).
- An annual limit of 50 rem (0.50 Sv) to an individual organ or tissue other than the lens of the eye, as determined by the deep-dose equivalent and the committed dose equivalent.
- An annual limit of 15 rem (0.15 Sv) to the lens of the eye.
- An annual limit of 50 rem (0.50 Sv) to the skin.
- An annual limit of 50 rem (0.50 Sv) to each of the extremities.

Dose Limits for Individual Members of the Public

- An annual limit of 0.1 rem (1 mSv) total effective dose equivalent (TEDE)
- An hourly limit from external sources of 0.002 rem (0.02 mSv) in unrestricted areas.

An Overview of Radiation Exposure to US Population

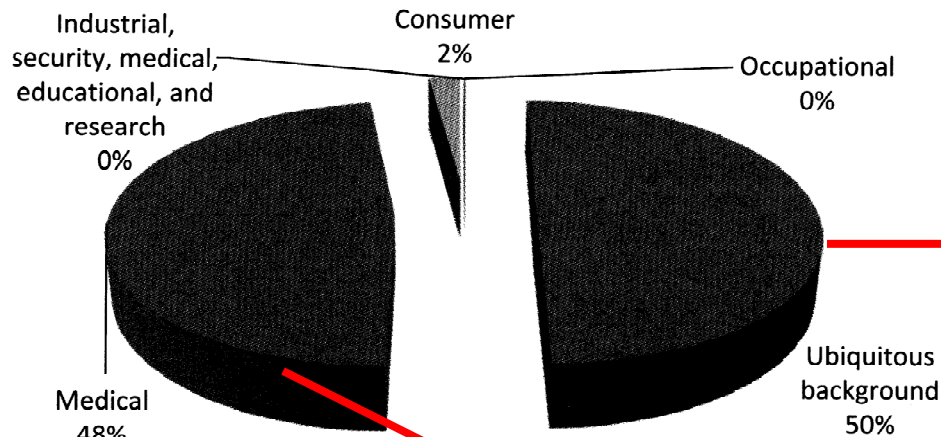


FIGURE 1.1 ♦ Exposure by Major Categories

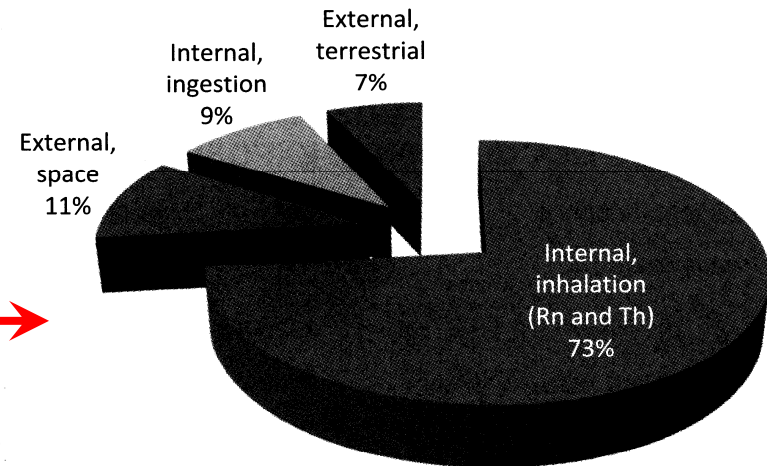


FIGURE 1.2 ♦ Ubiquitous Background

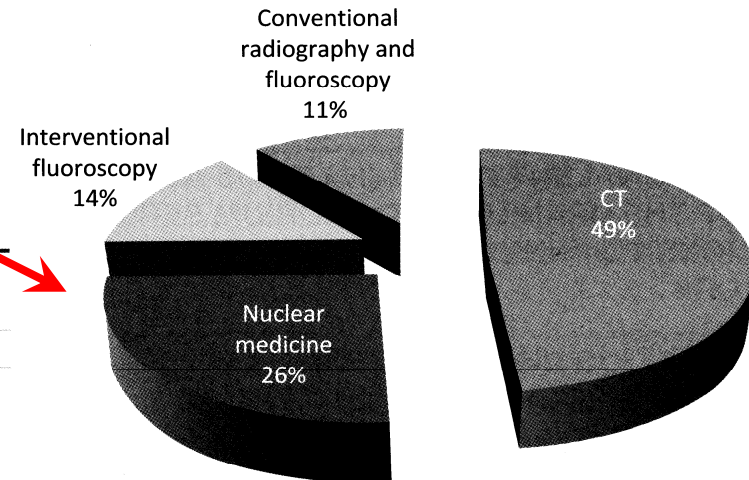


FIGURE 1.3 ♦ Medical

TABLE 1.4 COLLECTIVE EFFECTIVE DOSE (S), EFFECTIVE DOSE PER INDIVIDUAL IN THE US POPULATION (E_{US}), AND AVERAGE EFFECTIVE DOSE FOR THE EXPOSED GROUP (E_{Exp}) FROM MEDICAL PROCEDURES FOR 2006 (After NCRP Report No. 160, 2009)

Exposure Category	S (person-Sv)	E_{US} (mSv)	E_{Exp} (mSv)
Medical			
CT	440,000	1.47	^a
Nuclear medicine	231,000	0.77	^a
Interventional fluoroscopy	128,000	0.43	^a
Conventional radiography and fluoroscopy	100,000	0.33	^a
Total	899,000	3	^a

^aNot determined for the medical category because the number of patients exposed is not known, only the number of procedures.

An Overview of General Radiation Exposure

TABLE 1.1 MAJOR SOURCES OF IONIZING RADIATION

Source Category	Subcategory and Description	Effective Dose (mSv) to US Population	Effective Dose (mrem) to US Population
Natural Background	Radon and thoron (inhalation)	2.28	228
	Cosmic radiation	0.33	33
	Radioactive materials in the body (ingestion)	0.29	29
	Terrestrial radiation (external to the body)	0.21	21
Healing Arts	<i>Medical diagnosis and therapy</i>		
	Medical diagnosis (computed tomography and conventional radiography and fluoroscopy)	1.80	180
	Interventional fluoroscopy	0.43	43
	Radiotherapy (excluded from dose)		
	<i>Radiopharmaceuticals</i>		
	Nuclear medicine (diagnosis, therapy, research)	0.77	77
Consumer	Combustion of fossil fuels, road construction materials, consumer products	0.13	13
Industrial Activities	Industrial radiography, gauges, static eliminators, sterilizers, security, medical research and exposure to patients, education and research (particle accelerators, x-ray diffraction units, electron microscopes, neutron generators, tracers), nuclear power generation, government facilities, waste handling	0.003	0.3
Occupational	Health care workers (physicians, nurses, staff)	0.0018	0.18
	Aviation (pilots, flight attendants)	0.0018	0.18
	Commercial nuclear power (plant workers)	0.0004	0.04
	Industry and commerce	0.0004	0.04
	Education and research	0.0002	0.02
	Government, Department of Energy (DOE), military personnel	0.0001	0.01
Total	—	6.248	625



Medical Dose

An Overview of Radiation Exposure to US Population

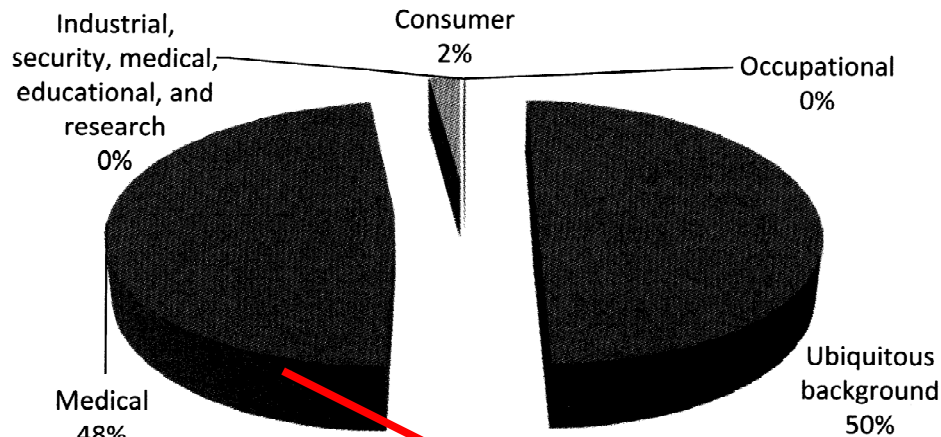


FIGURE 1.1 ♦ Exposure by Major Categories

TABLE 1.4 COLLECTIVE EFFECTIVE DOSE (S), EFFECTIVE DOSE PER INDIVIDUAL IN THE US POPULATION (E_{US}), AND AVERAGE EFFECTIVE DOSE FOR THE EXPOSED GROUP (E_{Exp}) FROM MEDICAL PROCEDURES FOR 2006 (After NCRP Report No. 160, 2009)

Exposure Category	S (person-Sv)	E_{US} (mSv)	E_{Exp} (mSv)
Medical			
CT	440,000	1.47	^a
Nuclear medicine	231,000	0.77	^a
Interventional fluoroscopy	128,000	0.43	^a
Conventional radiography and fluoroscopy	100,000	0.33	^a
Total	899,000	3	^a

^aNot determined for the medical category because the number of patients exposed is not known, only the number of procedures.

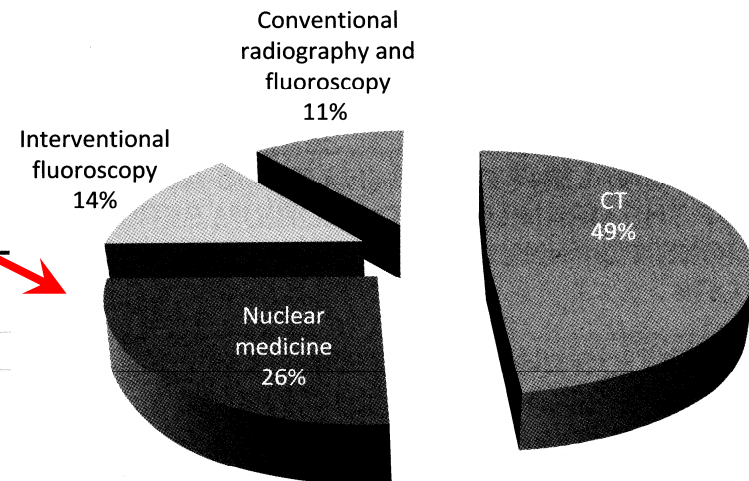
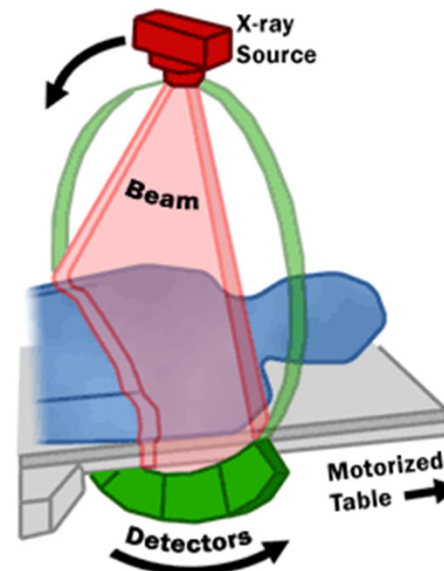


FIGURE 1.3 ♦ Medical

Modern X-ray Computed Tomography (CT)



(above) <https://www.fda.gov/radiation-emitting-products/medical-x-ray-imaging/what-computed-tomography>

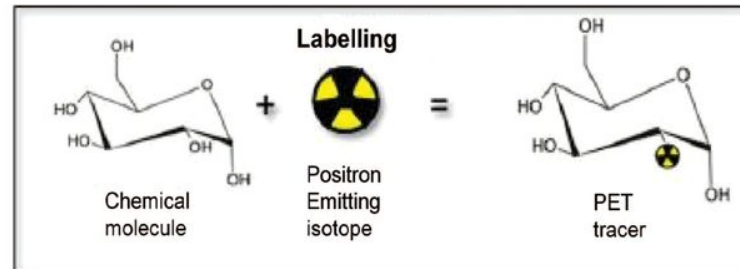
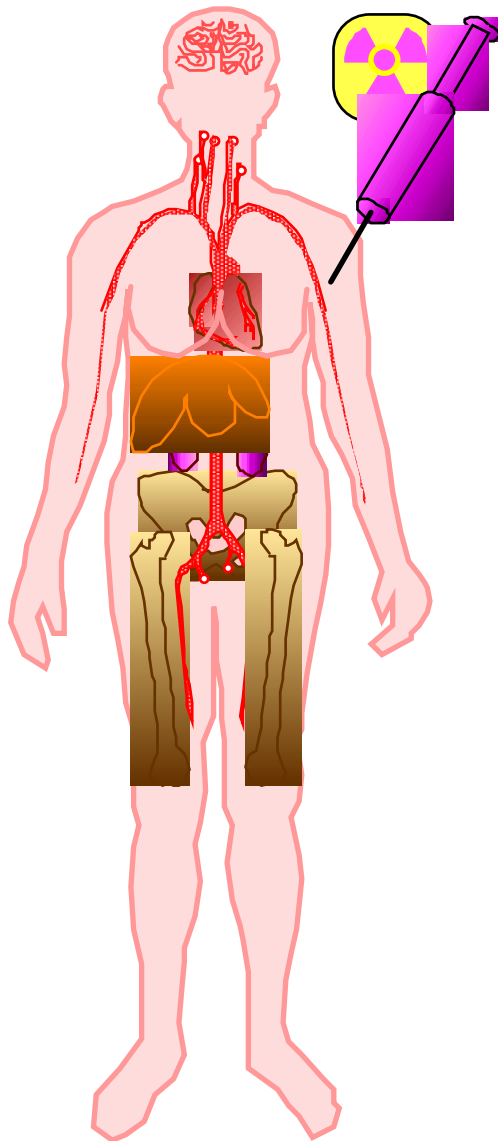


The table below shows typical effective radiation doses for a range of common cardiovascular imaging tests.	
Test	Typical Effective Dose Estimate (mSv)
Chest x-ray	0.1 mSv
Cardiac chest CT scan	16 mSv
Coronary angiogram	7 mSv
Coronary angioplasty/stent	15 mSv
Nuclear stress test	
Tc-99m	11.4 mSv
Thallium	16.9 mSv

Adapted from Chambers E., Fetterly CA, Holzer, K, et al. Radiation safety program for the cardiac catheterization laboratory. Catheterization and Cardiovascular Interventions. 2011;77:546-556. <http://www.scal.org/Publications/Guidelines.aspx>. Accessed February 18, 2012.

(above right) <https://www.secondscount.org/heart-resources/heart-resources-detail-2/secondscount-guide-to-radiation-safety-in-medical--4#.Y8cN2nbMK2E>

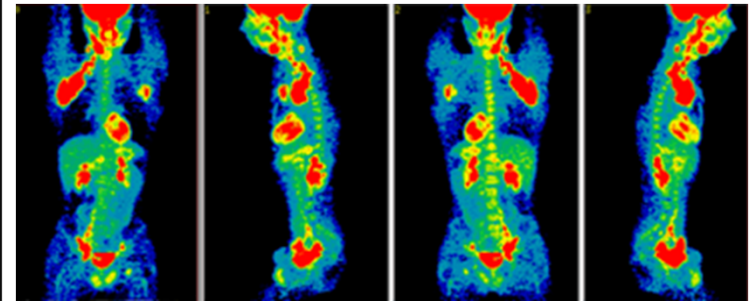
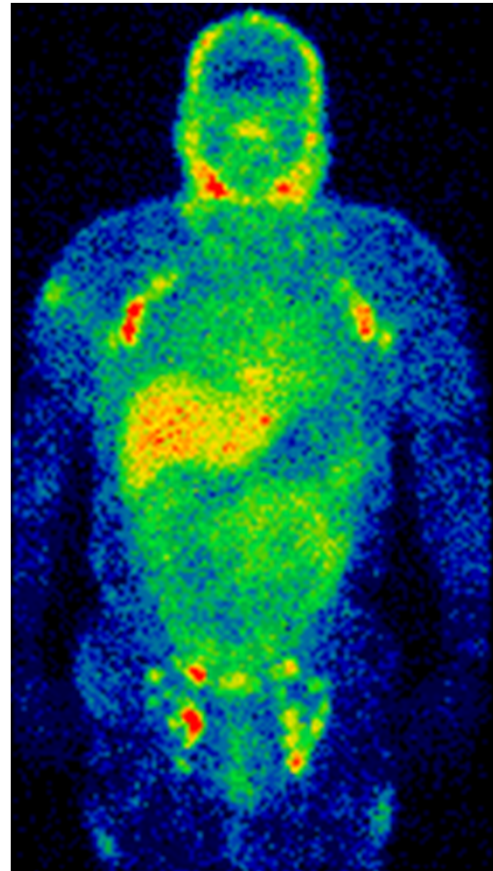
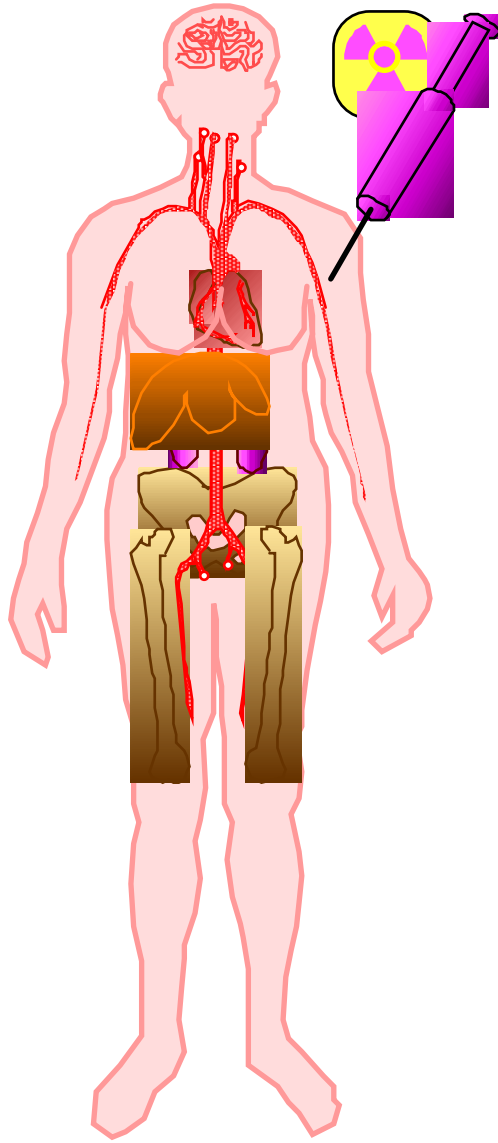
Nuclear Medicine



- Drug is labeled with radioisotopes that emit gamma rays.
- Drug localizes in patient according to metabolic properties of that drug.
- Trace (pico-molar) quantities of drug are sufficient.
- Radiation dose fairly small (<1 rem).

Drug Distributes in Body

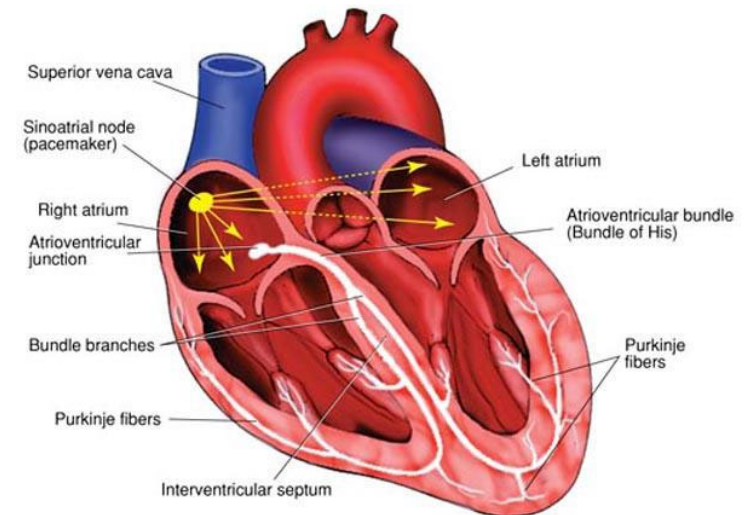
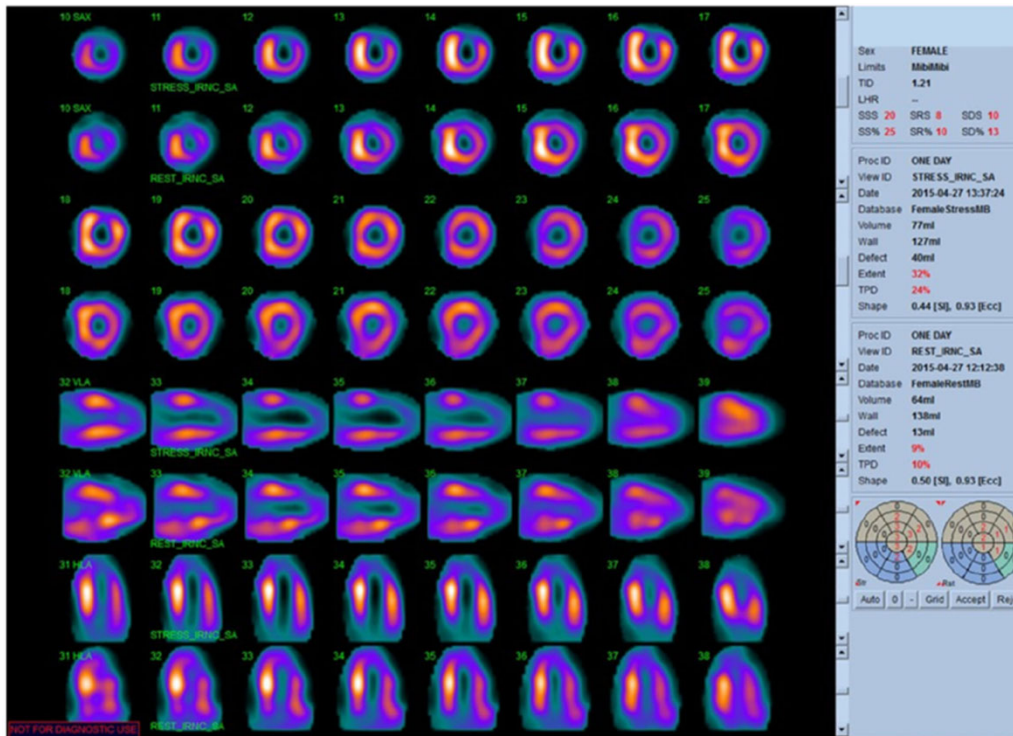
Nuclear Medicine



(Left and above) Typical emission tomography images

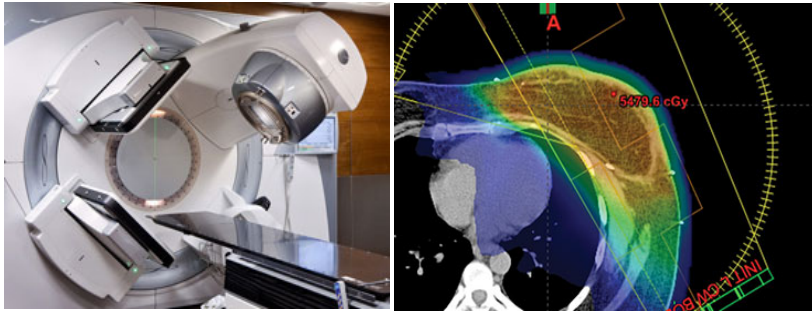
Is there anything that we do not like??

Tc-99m Sestamibi Myocardial Perfusion Imaging (MPI)



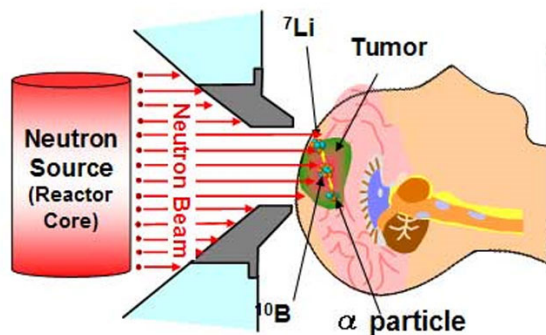
Exercise stress Tc-99m Sestamibi single day myocardial perfusion SPECT images of the female patient with a significant (80%) distal left main coronary artery disease. Classic features of the high-risk scan are present: severe partially reversible perfusion defect, involvement of the LAD and LCX territory, visual transient ischemic dilation and abnormal TID ratio (1.21). The patient presented with symptoms of stable atypical angina. No significant ECG or hemodynamic changes were noted during the stress portion of the test.

Therapeutic Applications of Ionizing Radiation and their Current Limitations

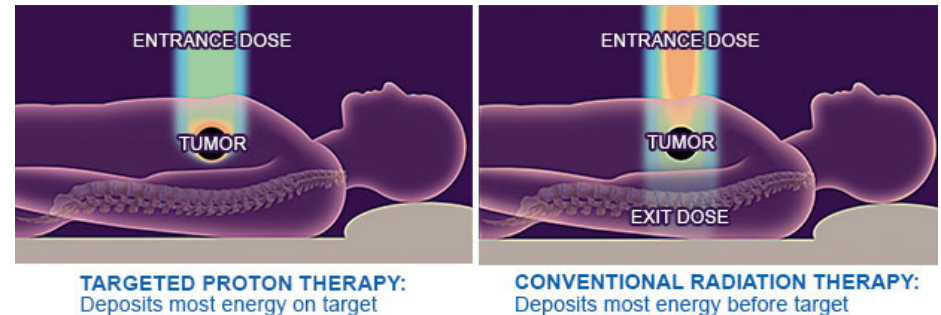
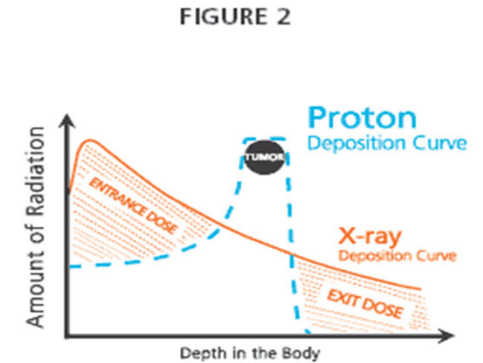
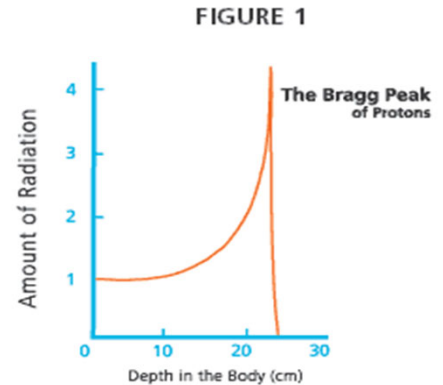


<http://www.onclive.com/web-exclusives/radiation-therapy-after-surgery-shows-no-survival-benefit-for-elderly-lung-cancer-patients>

Conventional radiation therapy



Boron neutron capture therapy



Proton therapy

- 50-60% of cancer patient worldwide go through radiation therapy.
- Typical Dose: 20-60Gy !! ("lethal dose": LD50/30 is 4 Gy).

Radiation Dose from Nuclear Medicine and External Radiotherapy Procedures

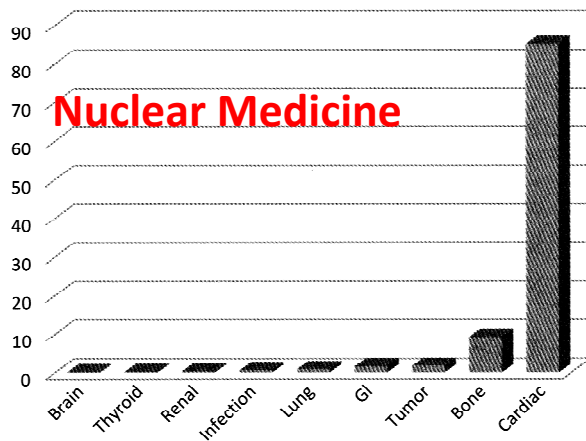


FIGURE 1.8 ♦ Percent Contributions to the Collective Effective Dose from Nuclear Medicine Procedures in the United States

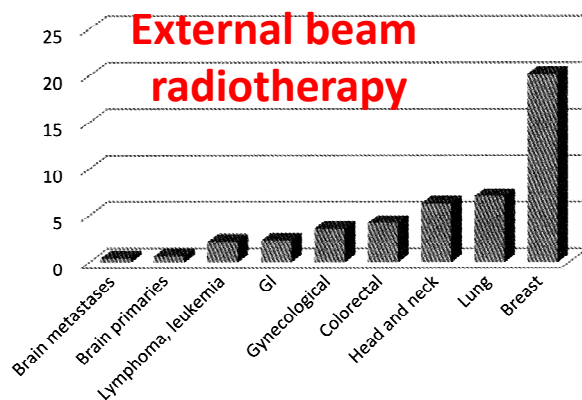


FIGURE 1.9 ♦ Percent Contributions to the Collective Effective Dose from External Beam Radiotherapy in the United States

TABLE 1.11 EFFECTIVE AND COLLECTIVE EFFECTIVE DOSES FROM EXTERNAL BEAM RADIO THERAPY IN THE UNITED STATES IN 2006 (After NCRP Report No. 160, 2009)^a

Treatment Site	Effective Dose (Sv)	Collective Effective Dose (Person-Sv)
Breast	0.337	71,632
Prostate	0.949	187,774
Lung	0.187	25,095
Head and neck	0.319	22,185
Colorectal	0.258	14,910
Gynecological	0.24	12,695
Brain metastases	0.031	1518
Brain primaries	0.059	2312
GI	0.233	8216
Lymphoma, leukemia	0.333	7828
Total	—	354,165

^a $E_{US} = 1.18 \text{ mSv}$.



Occupational Dose

Occupational Dose for US Workers

TABLE 1.15 OCCUPATIONAL DOSES FOR US WORKERS IN 2006

(After NCRP Report No. 160, 2009)

Category	Description	Numbers of Workers and Doses
Medical	Monitored workers Workers with recordable dose <i>S</i> (person-Sv) Average effective dose ^a (mSv)	
Aviation	Monitored airline crew Number of airline crew <i>S</i> (person-Sv) Average effective dose ^b (mSv)	
Commercial Nuclear Power	Monitored workers Workers with recordable dose <i>S</i> (person-Sv) Average effective dose ^a (mSv)	
Industry and Commerce	Monitored workers Workers with recordable dose <i>S</i> (person-Sv) Average effective dose ^a (mSv)	
Education and Research	Monitored workers Workers with recordable dose <i>S</i> (person-Sv) Average effective dose ^a (mSv)	
Government, DOE, Military^c	Monitored workers Workers with recordable dose <i>S</i> (person-Sv) Average effective dose ^a (mSv)	
Total Monitored Workers	—	
Total Workers with Recordable or Estimated Dose	—	
Total <i>S</i> (Person-Sv)	—	
Average Effective Dose^d (mSv)	—	1.13

^aFor those with recordable dose.

^bBased on an estimate for 2006.

^cBased on 2004 data.

^dValues in parenthesis exclude the portion of the collective dose for which information on the number of workers with recordable dose is not available [for 2006: 21 (39–18) person-Sv is excluded]. The average effective dose is 18 person-Sv divided by 30,591 workers with recordable dose (= 0.59 mSv).

^eBased on workers with recordable dose.

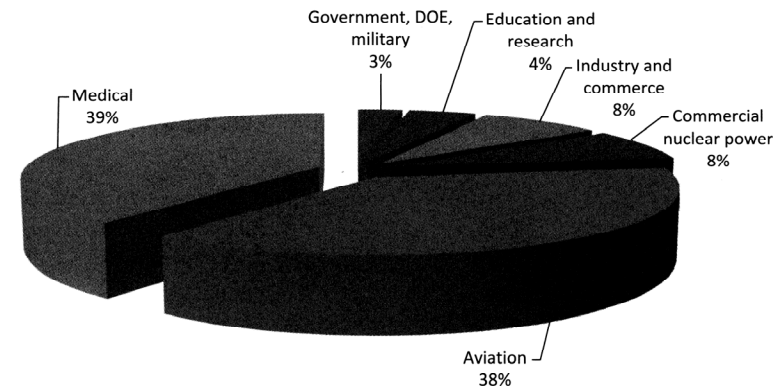


FIGURE 1.12 ♦ Percent Contributions to US Collective Effective Dose by Occupation

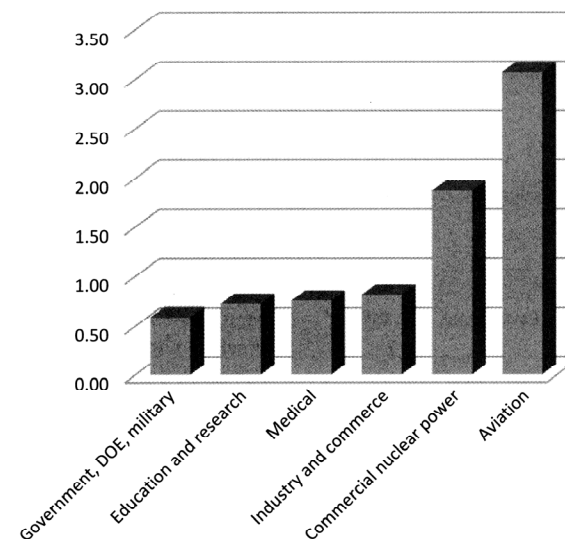


FIGURE 1.13 ♦ Average Effective Dose by Occupation



Radiation Dose from Consumer Products

Radiation Dose from Consumer Products

TABLE 1.12 ANNUAL COLLECTIVE EFFECTIVE DOSE (S) FROM CIGARETTES (After NCRP Report No. 160, 2009)

	<i>E</i> per Smoker (mSv)	<i>S</i> (Person-Sv) ^a
<i>Men</i>	0.09–0.6	2,250–15,000
Average	0.32	8100
<i>Women</i>	0.08–0.5	1600–10,000
Average	0.27	5400
Total	—	13,500

^aBased on 25 million males and 20 million females smoking 18 and 15 cigarettes per day, respectively.

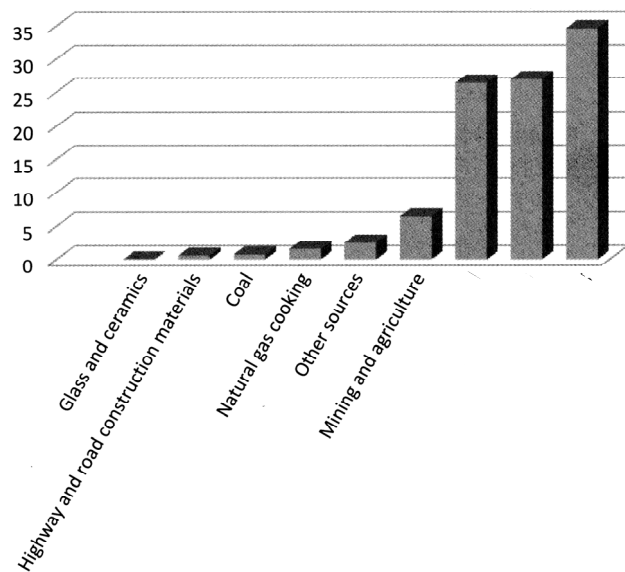


FIGURE 1.10 ♦ Percent Contributions to the Collective Effective Dose from Consumer Products and Activities in the United States

TABLE 1.13 ANNUAL EFFECTIVE DOSE TO AN EXPOSED INDIVIDUAL (*E*_{Exp}) AND COLLECTIVE EFFECTIVE DOSE (*S*) FROM CONSUMER PRODUCTS AND ACTIVITIES IN THE UNITED STATES IN 2006 (After NCRP Report No. 160, 2009)^a

Source	<i>E</i> _{Exp} (μSv)	<i>S</i> (Person-Sv)
Cigarette smoking	300	13,500
Building materials	70	10,500
Commercial air travel	—	10,300
Mining and agriculture	10	2500
Other sources	—	1000
Combustion of fossil fuels	—	—
Natural gas cooking	4	620
Coal	1	300
Highway and road construction materials	40	240
Glass and ceramics	—	<10
Total	—	38,970

^a*E*_{US} = 1.18 mSv.

An Overview of Radiation Exposure to US Population

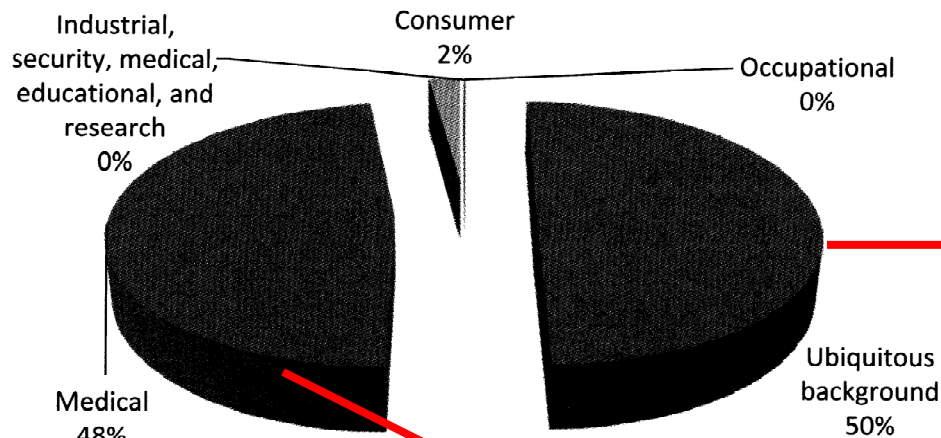


FIGURE 1.1 ♦ Exposure by Major Categories

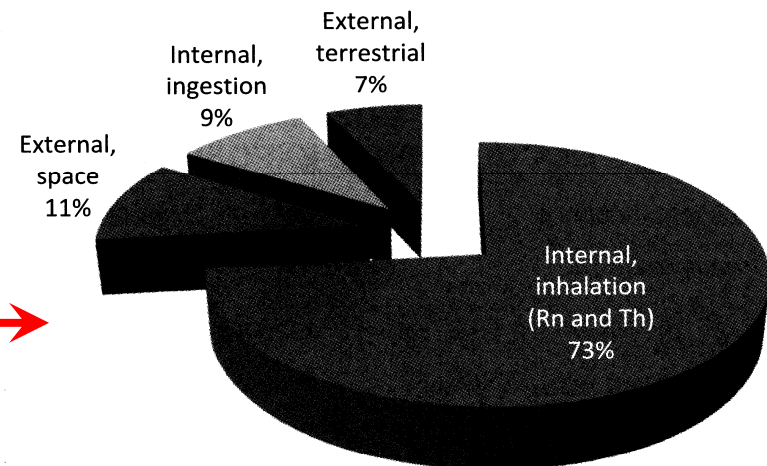


FIGURE 1.2 ♦ Ubiquitous Background

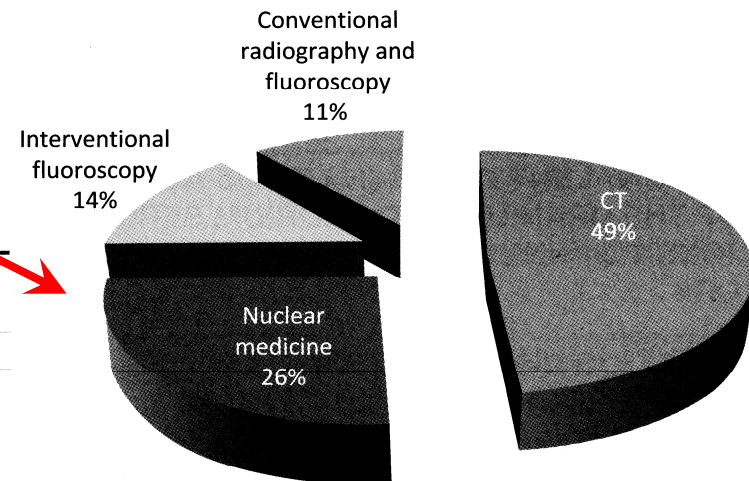


FIGURE 1.3 ♦ Medical

TABLE 1.4 COLLECTIVE EFFECTIVE DOSE (S), EFFECTIVE DOSE PER INDIVIDUAL IN THE US POPULATION (E_{US}), AND AVERAGE EFFECTIVE DOSE FOR THE EXPOSED GROUP (E_{Exp}) FROM MEDICAL PROCEDURES FOR 2006 (After NCRP Report No. 160, 2009)

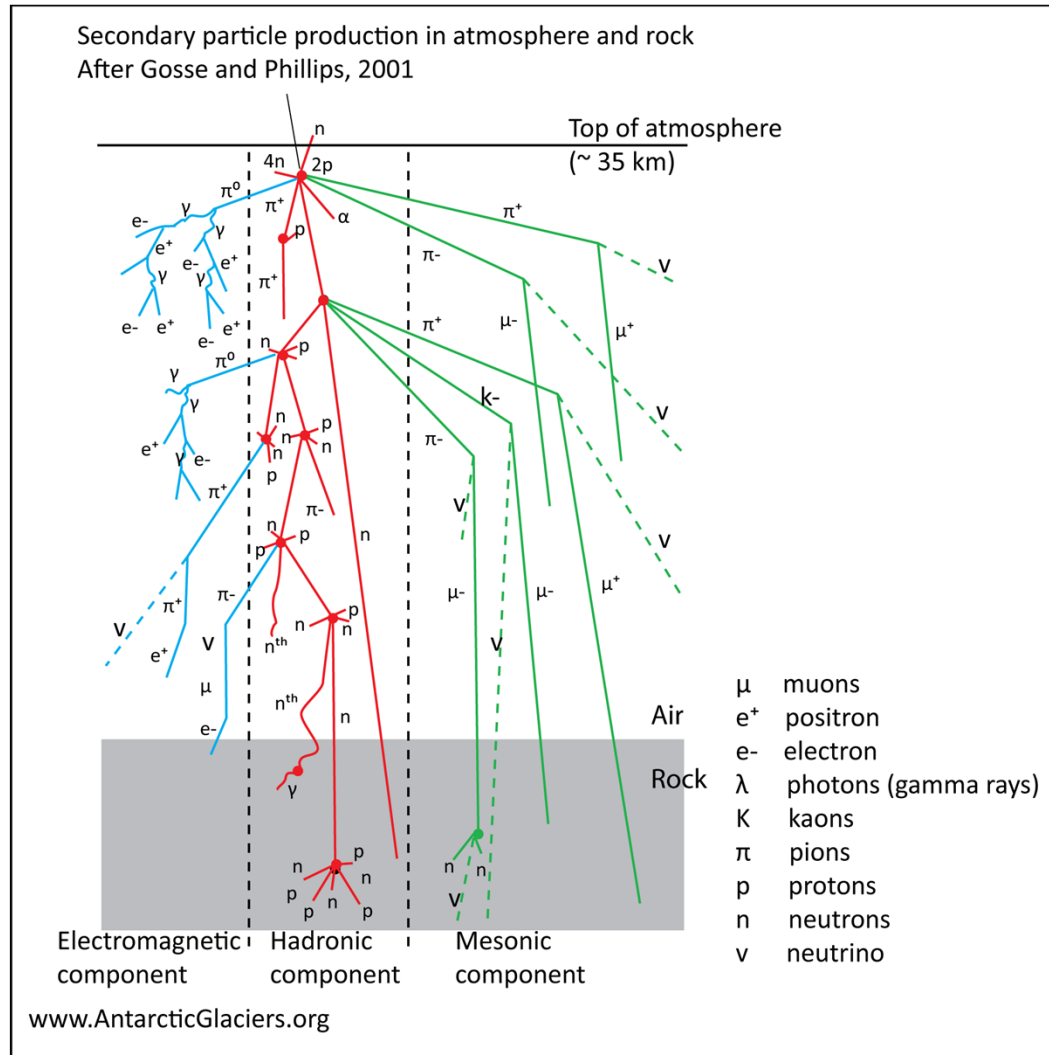
Exposure Category	S (person-Sv)	E_{US} (mSv)	E_{Exp} (mSv)
Medical			
CT	440,000	1.47	^a
Nuclear medicine	231,000	0.77	^a
Interventional fluoroscopy	128,000	0.43	^a
Conventional radiography and fluoroscopy	100,000	0.33	^a
Total	899,000	3	^a

^aNot determined for the medical category because the number of patients exposed is not known, only the number of procedures.



Environmental Radiation

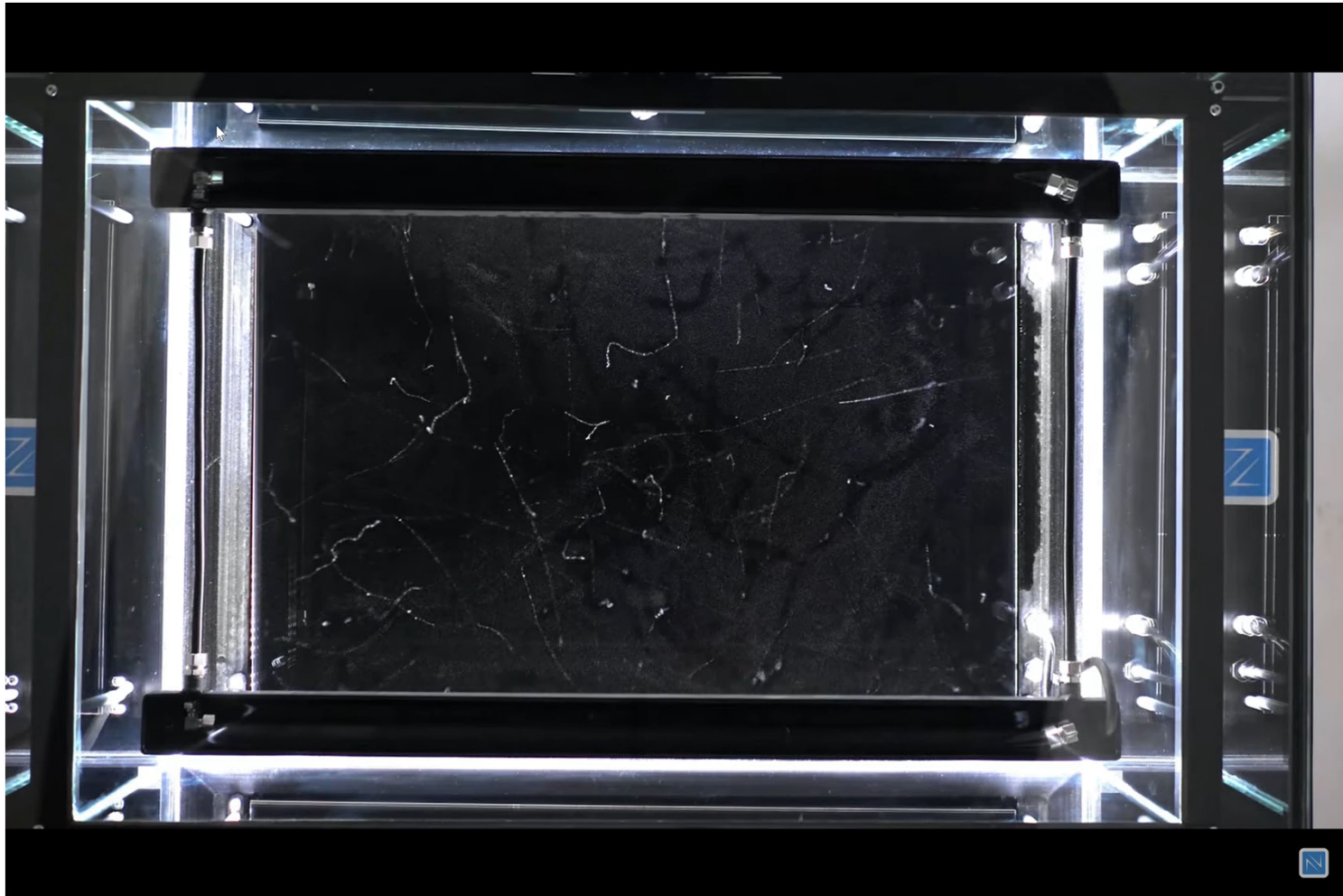
Cosmic Rays Radiation



The cosmic ray shower

- It is now known that most cosmic rays are atomic nuclei. Most are hydrogen nuclei, some are helium nuclei, and the rest heavier elements.
- The relative abundance changes with cosmic ray energy — the highest energy cosmic rays tend to be heavier nuclei.
- Although many of the low-energy cosmic rays come from our Sun, the origins of the highest-energy cosmic rays remain unknown and a topic of much research.
- This drawing illustrates air showers from very high-energy cosmic rays.

Tracks of Beta and Alpha Particles in Air



<https://www.thenakedscientists.com/forum/index.php?topic=47630.0>

Formation of Cosmogenic Nuclides

Formation of cosmogenic nuclides

As the cascade of reactions propagates down through the atmosphere, the nuclear particle flux becomes dominated by neutrons + minor mesonic flux. These secondary fast nucleons continue to produce cosmogenic nuclides in the atmosphere, hydrosphere & lithosphere by breaking apart target atoms through spallation interactions. Eventually, the particles have insufficient energy to cause spallation.

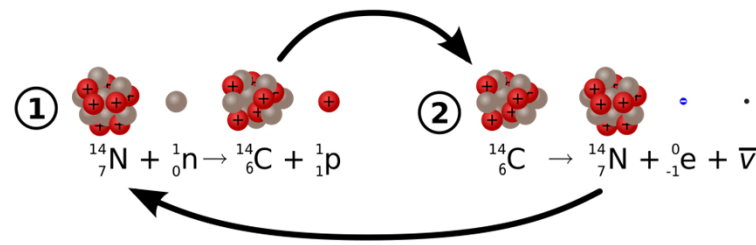
Isotopes formed by the action of cosmic rays

Isotope	Mode of formation	half life
³ H (tritium)	¹⁴ N(n, ¹² C)T	12.3 y
⁷ Be	Spallation (N and O)	53.2 d
¹⁰ Be	Spallation (N and O)	1,387,000 y
¹¹ C	Spallation (N and O)	20.3 m
¹⁴ C	¹⁴ N(n,p) ¹⁴ C	5,700 y
¹⁸ F	¹⁸ O(p,n) ¹⁸ F and Spallation (Ar)	110 m
²² Na	Spallation (Ar)	2.6 y
²⁴ Na	Spallation (Ar)	15 h
²⁸ Mg	Spallation (Ar)	20.9 h
²⁶ Al	Spallation (Ar)	717,000 y
³¹ Si	Spallation (Ar)	157 m
³² Si	Spallation (Ar)	153 y
³² P	Spallation (Ar)	14.3 d
^{34m} Cl	Spallation (Ar)	34 m
³⁵ S	Spallation (Ar)	87.5 d
³⁶ Cl	³⁵ Cl (n,γ) ³⁶ Cl	301,000 y
³⁷ Ar	³⁷ Cl (p,n) ³⁷ Ar	35 d
³⁸ Cl	Spallation (Ar)	37 m
³⁹ Ar	³⁸ Ar (n,γ) ³⁹ Ar	269 y
³⁹ Cl	⁴⁰ Ar (n,np) ³⁹ Cl & spallation (Ar)	56 m
⁴¹ Ar	⁴⁰ Ar (n,γ) ⁴¹ Ar	110 m
⁴¹ Ca	⁴⁰ Ca (n,γ) ⁴¹ Ca	102,000 y
⁸¹ Kr	⁸⁰ Kr (n,γ) ⁸¹ Kr	229,000 y
¹²⁹ I	Spallation (Xe)	15,700,000 y

Applications in geology listed by isotope [edit]

Commonly measured long lived cosmogenic isotopes

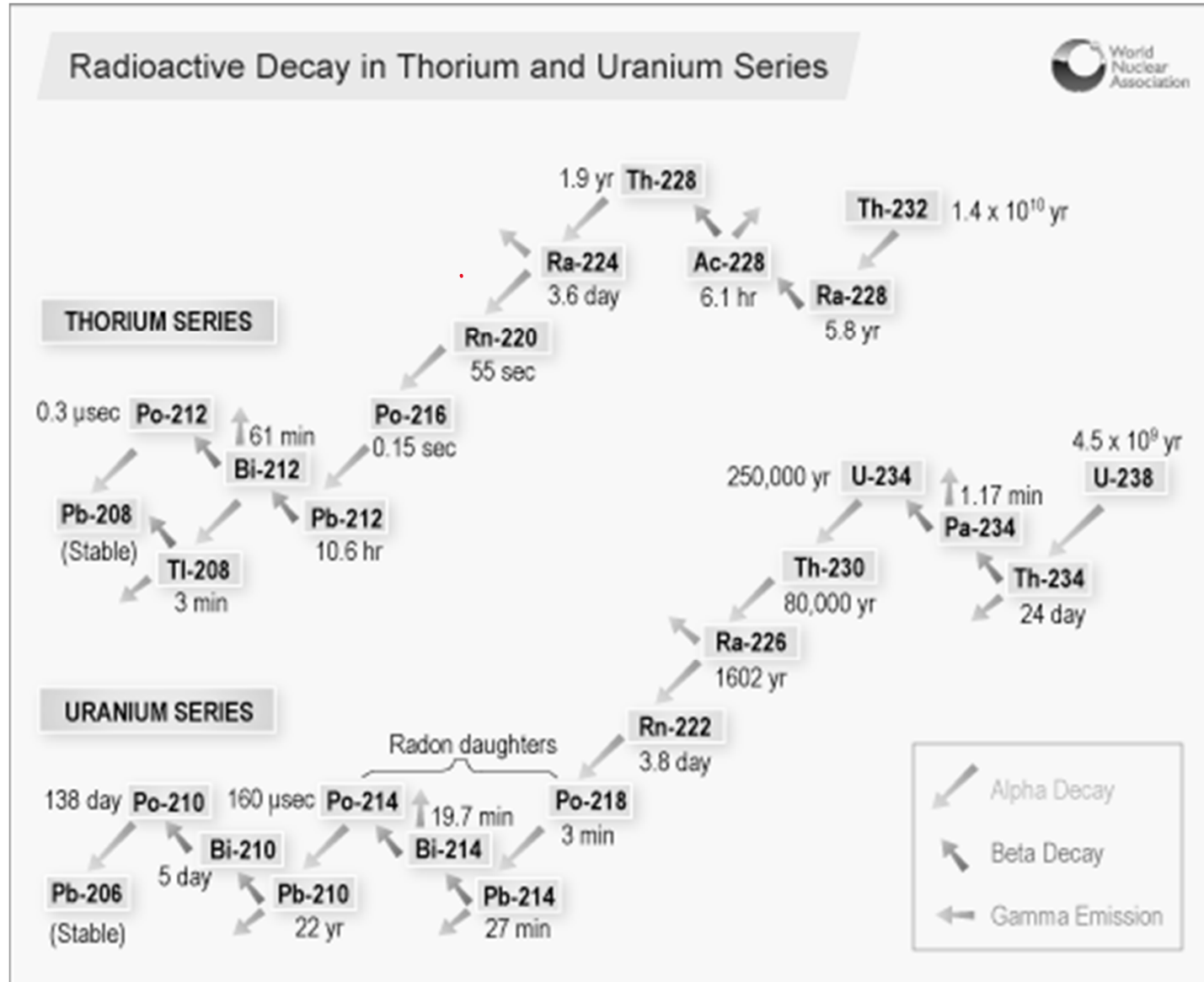
element	mass	half-life (years)	typical application
beryllium	10	1,387,000	exposure dating of rocks, soils, ice cores
aluminium	26	720,000	exposure dating of rocks, sediment
chlorine	36	308,000	exposure dating of rocks, groundwater tracer
calcium	41	103,000	exposure dating of carbonate rocks
iodine	129	15.7 million	groundwater tracer
sulfur	35	0.24	water residence times
sodium	22	2.6	water residence times
tritium	3	12.32	water residence times
argon	39	269	groundwater tracer
krypton	81	229,000	groundwater tracer



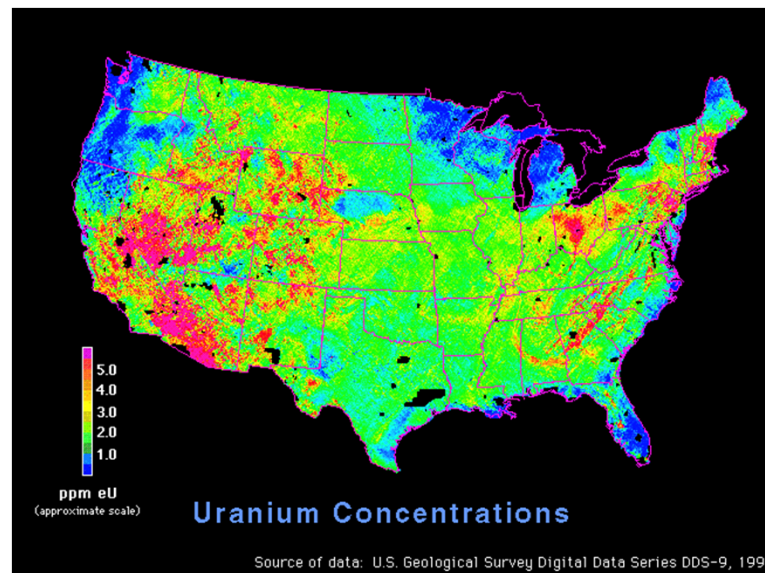
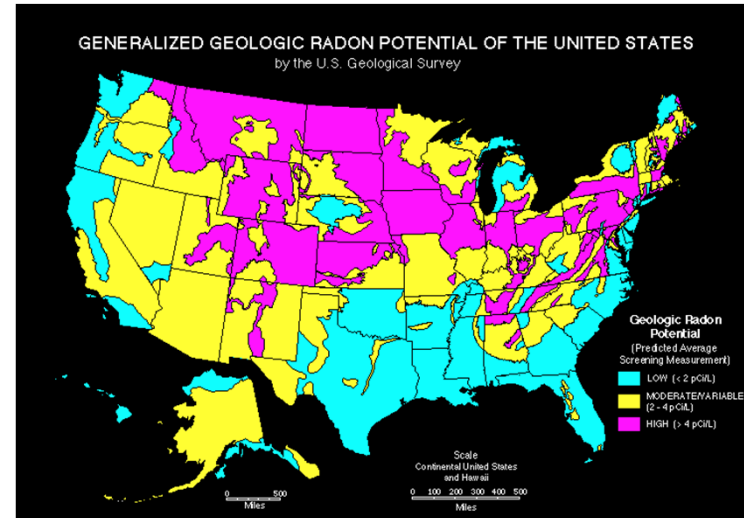
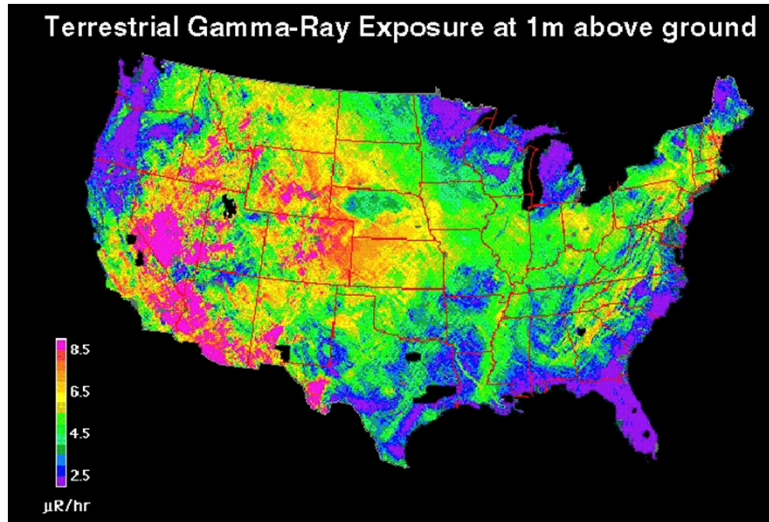
<https://en.wikipedia.org/wiki/Carbon-14>

Naturally Occurring Radioactive Materials (NORM)

- All of the heavy elements ($Z > 83$) found in nature are radioactive and decay by **alpha and beta emission**. $^{209}_{83}\text{Bi}$ is the only stable nuclide with an atomic number greater than that of lead ($Z=82$).
- All of the **naturally occurring heavy radionuclides** belong to one of the three series, the **uranium series**, the **thorium series**, and the **actinium series**.
- Several other elements, outside the uranium, actinium and thorium series, are also found to have radioactive isotopes, such as ^{40}K , ^{87}Rb etc.
- Other naturally occurring radionuclides are **of cosmogenic origin**. Only those produced as a results of cosmic ray interactions with constituents of the atmosphere results in any mentionable exposure to man: ^3H , ^7Be , ^{14}C and ^{22}Na .



Terrestrial Naturally Occurring Radioactive Materials (NORM)



Internal Dose from Indoor Radon

(more detailed discussions coming soon ...)

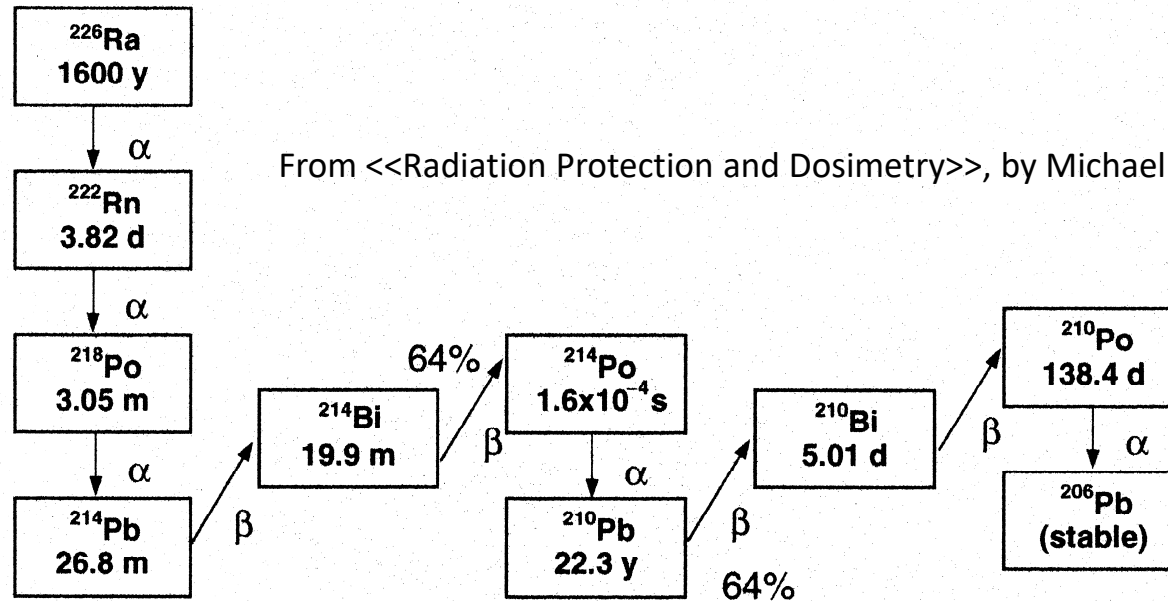


Figure 3.11 The ^{226}Ra decay series.

We can continue on with a species D, E, F, and so on, but the relationships among the species obviously become more complicated and are difficult to categorize. If Species A is very long-lived, however, relative to other members of the chain, after a long time (seven to ten half-lives of the longest-lived progeny species), all the members of the chain will be in secular equilibrium and decaying with the half-life of Species A, and all having the same activity as Species A. An important example is the ^{226}Ra decay series (Figure 3.11).

An Overview of Radiation Exposure to US Population

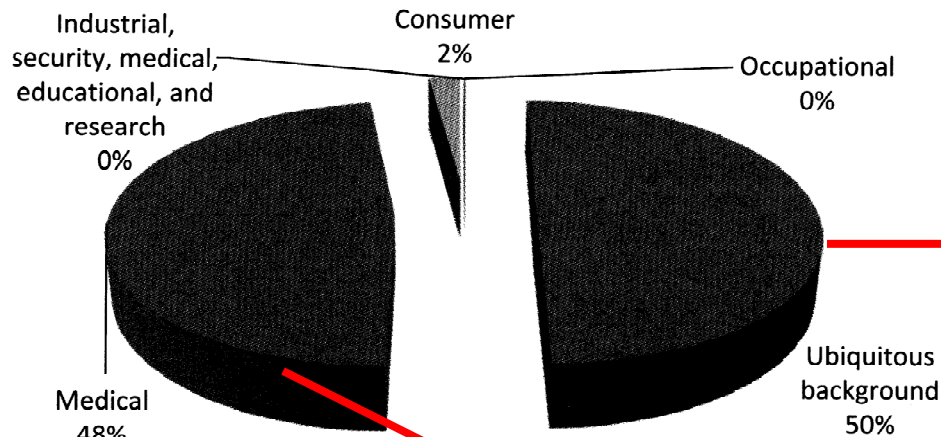


FIGURE 1.1 ♦ Exposure by Major Categories

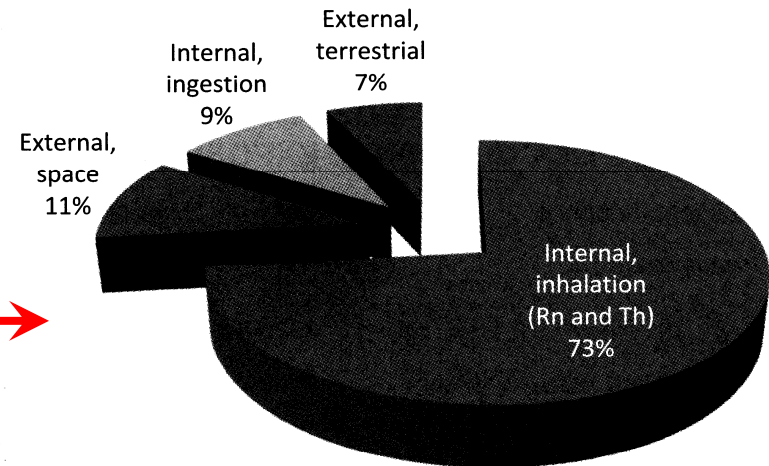


FIGURE 1.2 ♦ Ubiquitous Background

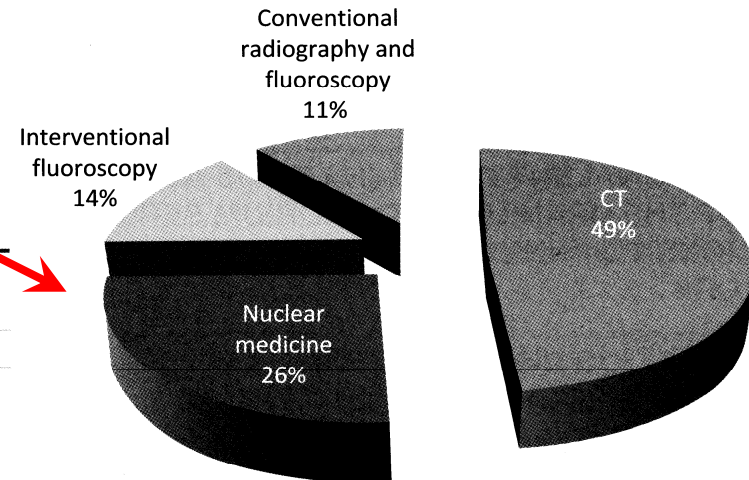


FIGURE 1.3 ♦ Medical

TABLE 1.4 COLLECTIVE EFFECTIVE DOSE (S), EFFECTIVE DOSE PER INDIVIDUAL IN THE US POPULATION (E_{US}), AND AVERAGE EFFECTIVE DOSE FOR THE EXPOSED GROUP (E_{Exp}) FROM MEDICAL PROCEDURES FOR 2006 (After NCRP Report No. 160, 2009)

Exposure Category	S (person-Sv)	E_{US} (mSv)	E_{Exp} (mSv)
Medical			
CT	440,000	1.47	^a
Nuclear medicine	231,000	0.77	^a
Interventional fluoroscopy	128,000	0.43	^a
Conventional radiography and fluoroscopy	100,000	0.33	^a
Total	899,000	3	^a

^aNot determined for the medical category because the number of patients exposed is not known, only the number of procedures.



Topics Concerned in this Course

The scientific and engineering aspects of health physics are concerned mainly with: (1) the physical measurements of different types of radiation and radioactive materials, (2) the establishment of quantitative relationships between radiation exposure and biological damage, (3) the movement of radioactivity through the environment, and (4) the design of radiologically safe equipment, processes, and environments. Clearly, health physics is

From Cember, page 1.