Natural Background and Man-made Radioactivity

Professional Training Programs

Oak Ridge Associated Universities

Objectives

- To discuss the major sources of radiation exposure
- To become familiar with the organizations that provide information about radiation exposure
- To summarize and compare worldwide exposures to radiation to exposures in the U.S. and Canada

Introduction

- Two common sources of information about background radiation are the National Council on Radiation Protection and Measurement (NCRP) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).
  - NCRP Report No. 160, "*Ionizing Radiation Exposure of the Population of the United States*"
  - UNSCEAR 2008 Report, "*Sources and Effects of Ionizing Radiation*"
- This lecture will present information from both sources, highlighting sections of each report separately and summarizing sections as needed.

Introduction

NCRP Report 160

- Ubiquitous Background Exposure
- Medical Exposure of Patients
- Consumer Products and Activities
- Industrial, Security, Medical, Educational and Research Activities
- Occupational Exposure

UNSCEAR 2008

- Medical Exposure
- Public Exposure
  - Natural Sources
  - Enhanced Sources
  - Man-made for Peaceful Purposes
  - Man-made for Military Purposes
- Occupational Radiation Exposure
  - Natural Sources
  - Man-made for Peaceful Purposes
  - Man-made for Military Purposes

Introduction – Principal Radiation Dose Quantities used in NCRP Report 160

- Effective dose (*E*) – $(D_{T,R})*(w_R)*(w_T)$
  - mSv, µSv, mrem, µrem
- Collective effective dose (*S*)
  - person-Sv
- Average effective dose to an individual in a group exposed to a specific source (E_{Exp})
  - Person-Sv
- Effective dose per individual in the U.S. population whether exposed to the specific source or not (E_{US})

Ubiquitous Background Exposure

Medical Exposure of Patients

Consumer Products and Activities

Industrial, Security, Medical, Educational and Research Activities

Occupational Exposure

Ubiquitous Background Radiation

- Space Radiation
- Terrestrial Gamma Radiation
- Radon, Thoron and Their Short-Lived Decay Products
- Radionuclides in the Body

Space Radiation

- Solar energetic particles (solar events)
- Anomalous cosmic rays (interstellar space)
- Galactic cosmic rays (outside the solar system)
- Extragalactic cosmic rays (beyond our galaxy)

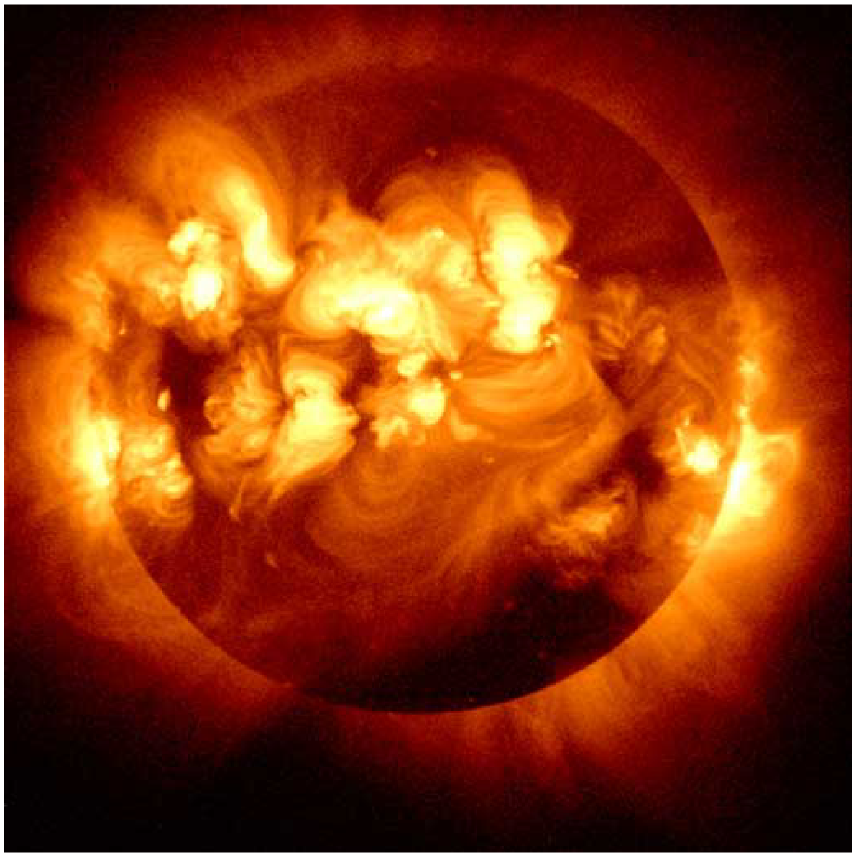
Space Radiation

- "The earth is continually bombarded by high energy particles that originate in outer space." (UNSCEAR-2000)
- Atmospheric interactions produce a cascade of reaction products.
- Cosmic ray exposures decrease in intensity with depth in the atmosphere.

Space Radiation Components

- Cosmic Rays
  - Primary
    - Nucleonic (98%)
      - Protons (85.5%)
      - Alpha Particles (~12%)
      - Heavier Nuclei (~1%)
    - Electron (2%)
  - Secondary
- Cosmogenic

Primary Cosmic Rays - Solar



- Composite image of multiple solar flares on the sun
- Energies – 10^3 eV (average)
- Source: science.nasa.gov
- Image credit: JAXA

Primary Cosmic Rays - Solar

by nuclear physicists and no original idea would be in-

Good luck!

holds a patent on the process.

travel—the inside stuff

RADIATION ALERT:

Will flying give you cancer?

A one-way New York-to-London flight exposes you to the same amount of radiation as a chest X-ray.

If you're a very frequent flyer, you may want to think again about how much you fly. A recent government report suggests that very frequent flyers and flight attendants (especially pregnant women) may exceed recommended levels of radiation exposure. The risk for occasional flyers is probably not worth worrying about.

The longer the flight and the higher the altitude, the higher the radiation exposure is. High-latitude flights (like New York to Europe) and over-the-North-Pole flights are bad news, too. A one-way New York-to-London flight exposes you to the same amount of radiation as a chest X-ray and may increase the risk of cancer or birth defects.

Extremely high solar flares (storms on the sun) only occur about once in a decade, but they can raise radiation levels in planes dramatically. What can you do?

- Be aware that frequent long-distance, high-altitude, over-the-pole flights may be hazardous, especially during pregnancy (and check with your company about insurance benefits for exposure to too much radiation).
- If you're pregnant, ask your physician how much radiation you've been exposed to (i.e., how many X-rays you've already had) during your pregnancy, and if you should fly.
- Call the Space Environment Services Center in Boulder CO (303) 497-3235. Extremely high solar flares are difficult to predict, but its hotline can give you a projected daily forecast of solar activity, so at least you will know whether the level is generally high or low before you board your flight.
- Ask the flight crew if the Federal Aviation Administration has issued a radiation alert. (High-altitude planes like the Concorde monitor radiation levels, but don't broadcast the amounts.) The captain can fly at a lower altitude if radiation is high.
- Write to Congress, the Department of Transportation, the Federal Aviation Administration and the airlines, and insist that they install radiation alert systems (which are not expensive) on all planes.

In the meantime, it makes good sense to be cautious.

Look out above: Solar flares could zap fliers

By Dan Vergano
USA TODAY

Frequent fliers have a new Y2K menace to worry about, a scientist warns: high-altitude radiation.

With the sun's 11-year cycle set to peak in 2000, New York-based health physicist Robert Barish says, solar flares, or sudden increases of intensity in the light of the sun, "could expose travelers and flight crews to the equivalent of 20 chest X-rays."

Barish wants the government to alert people who fly more than 75,000 miles a year that they could face a 1% higher risk of dying from cancer.

"The Europeans and Canadian airlines are concerned about this," unlike domestic carriers, says Emily Carter, national health coordinator of the Association of Professional Flight Attendants in Dallas.

Background radiation already increases with altitude, exposing fliers to the equivalent of a chest X-ray on many flights. So "half a million business travelers receive radiation exposures greater than permitted (by the EPA)," Barish says.

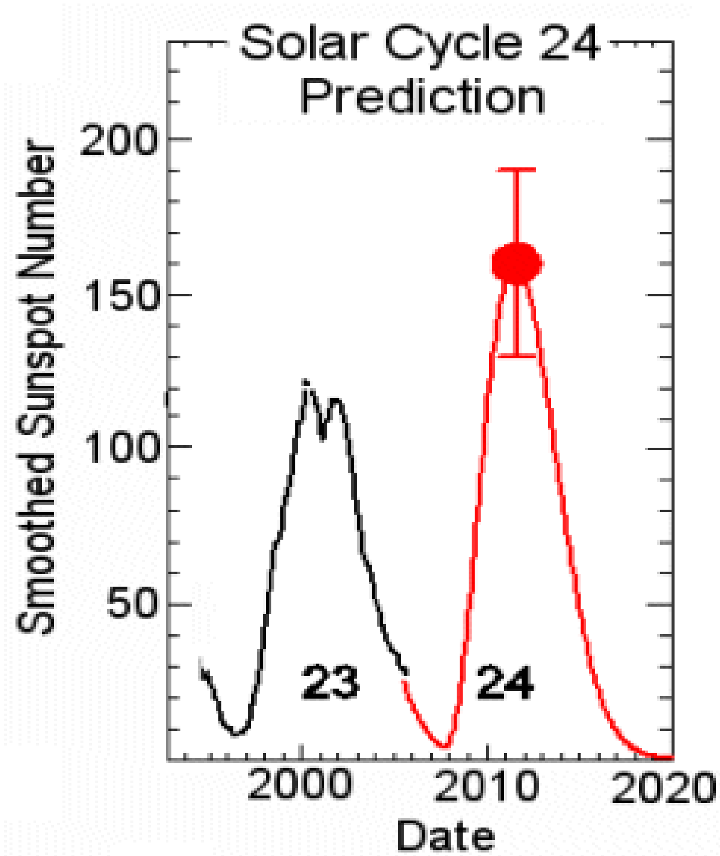
"It can't have too big an effect or we'd know about it by now," says Wallace Freidberg, head of the Federal Aviation Administration's radiobiology research team in Oklahoma City. "But I could be wrong."

He helped write a program, which is available at www.cami.jccbi.gov/AAM-600/610/600radio.html, that lets air travelers calculate their radiation exposure on a particular route.

But exposure on a flight occurs in low intensity over hours, says David Fuscus of the Air Transport Association. "It would be extraordinarily difficult for a passenger to fly to the point where it would make a difference to their health."

Primary Cosmic Rays - Solar

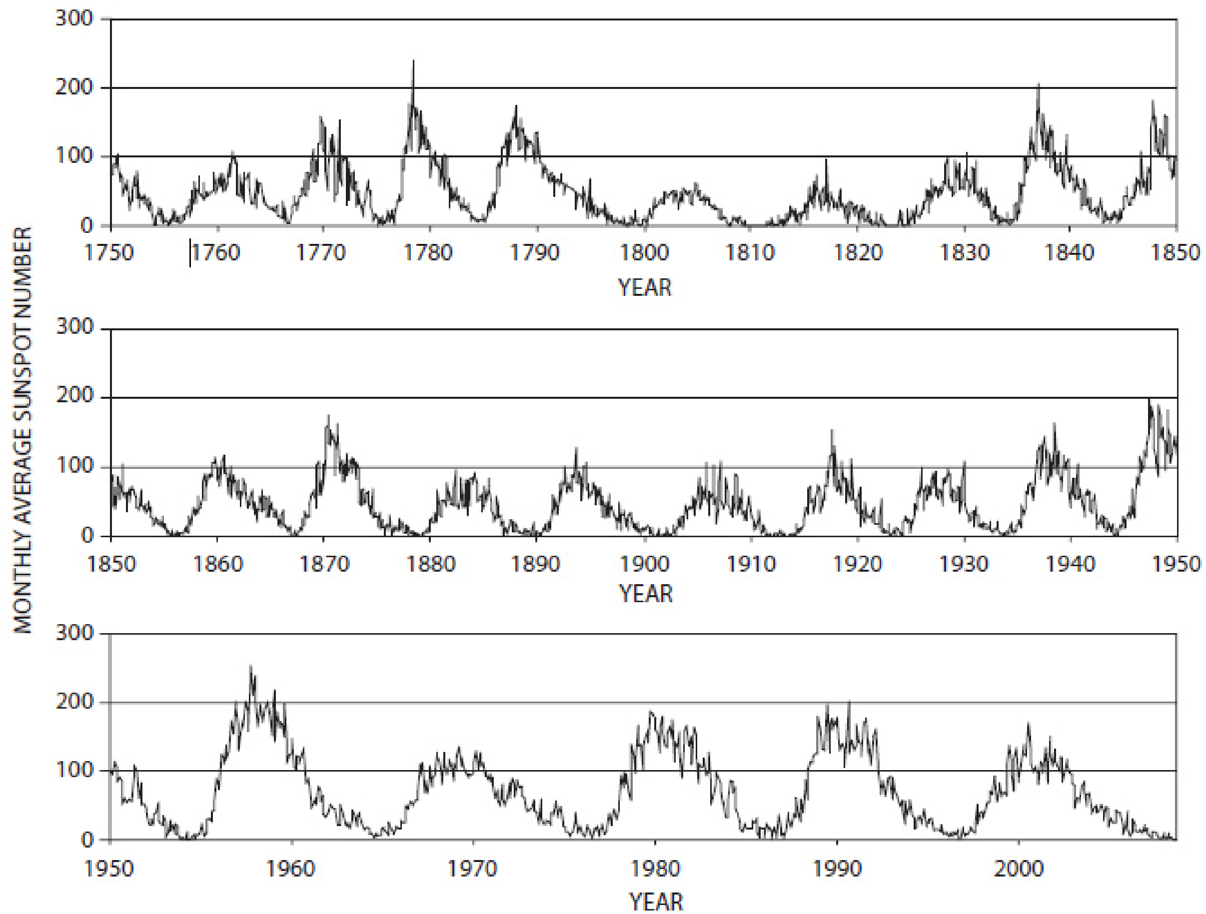
- "According to their analysis, the next Solar Maximum should peak around 2010 with a sunspot number of 160 plus or minus 25. This would make it one of the strongest solar cycles of the past fifty years—which is to say, one of the strongest in recorded history."



- Source: science.nasa.gov

Primary Cosmic Rays - Solar

Figure I. Variation in solar activity in terms of the historical monthly average sunspot numbers during solar cycles [N4]



Source: UNSCEAR-2008

Primary Cosmic Rays - Galactic

- Galactic Cosmic Rays (GCR) – highly charged particles originating outside of the solar system.
- Energies 10^8 to 10^{11} eV
- According to the National Space Biomedical Research Institute, GCR is the dominant radiation to be dealt with on the International Space Station and on Mars missions.

- Source: nsbri.org

Primary Cosmic Rays -Extragalactic

- Optical (left) and X-ray (right) images of SN 2006gy. The dimmer source at lower-left is the nucleus of the host galaxy. The brighter source at upper-right is the stellar explosion.
- Energies 10^{17} to 10^{20} eV
- Source: science.nasa.gov

Primary Cosmic Rays

- So…we have established that the earth is being bombarded with high energy solar, galactic and possibly extragalactic radiations.

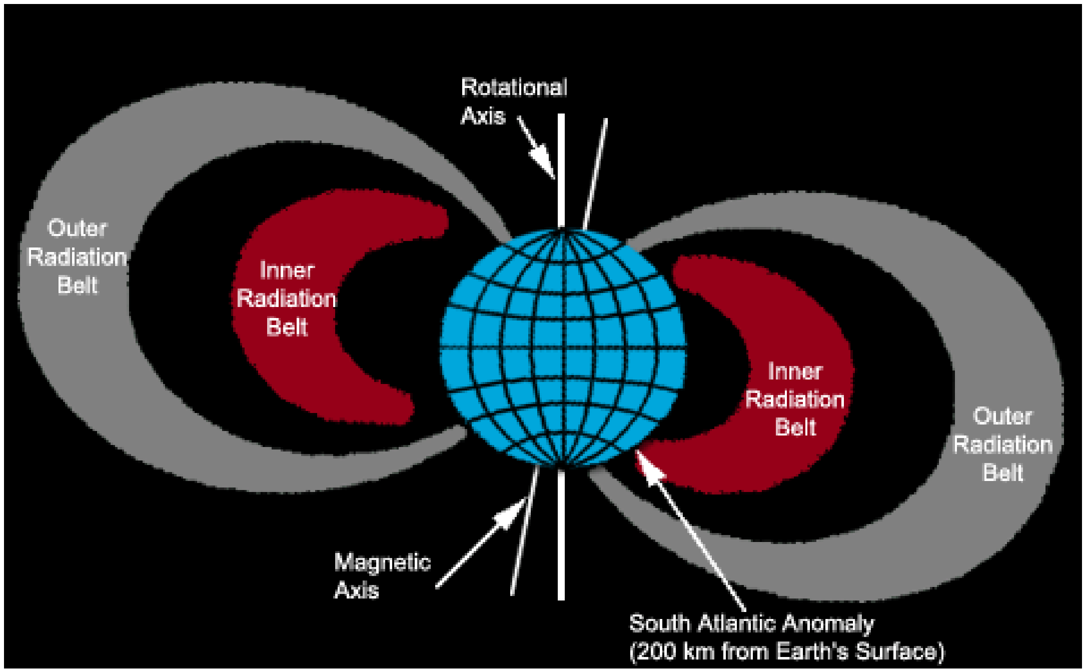
- How do we survive?

Primary Cosmic Rays

- We are protected in part by the earth's magnetic field.

- We are also protected by the interactions that take place in the atmosphere converting primary radiations into less harmful secondary radiations.

Primary Cosmic Radiation



- Source: Space Radiation Analysis Group, Johnson Space Center

- The primary radiations, composed of charged particles, are influenced by the earth’s magnetic field.

Primary Cosmic Radiation

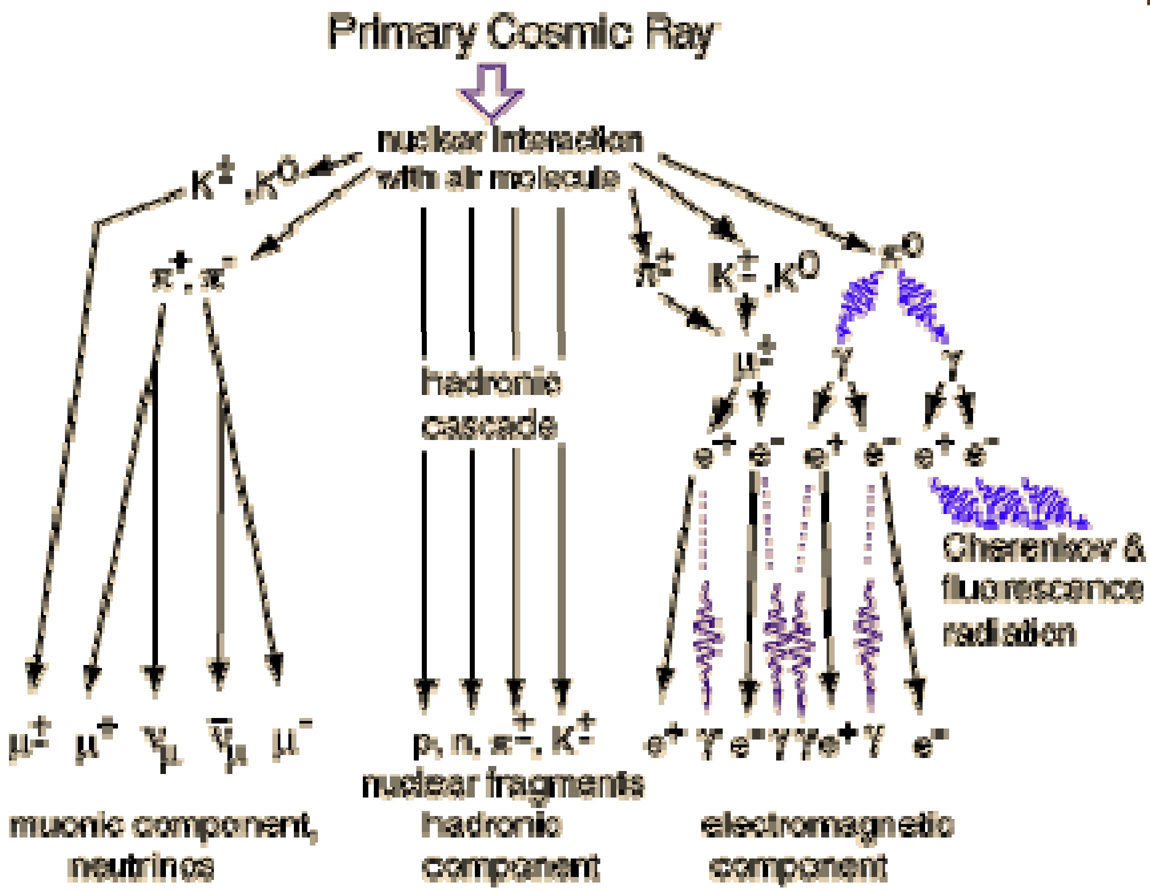
- The earth’s magnetic field reduces the intensity of cosmic radiation reaching the upper atmosphere…”
- “…only particles of higher energies can penetrate at lower geomagnetic latitudes…”
- “This produces the ‘geomagnetic latitude effect’, with intensities and dose rates minimal at the equator and maximum near the geomagnetic poles.” (UNSCEAR-2008)

Secondary Cosmic Radiation

- The primary radiations interact in the upper atmosphere to produce secondary radiations.

- Those radiations can interact to produce additional secondary radiations creating a cascade effect.

Production of Secondary Cosmic Radiation



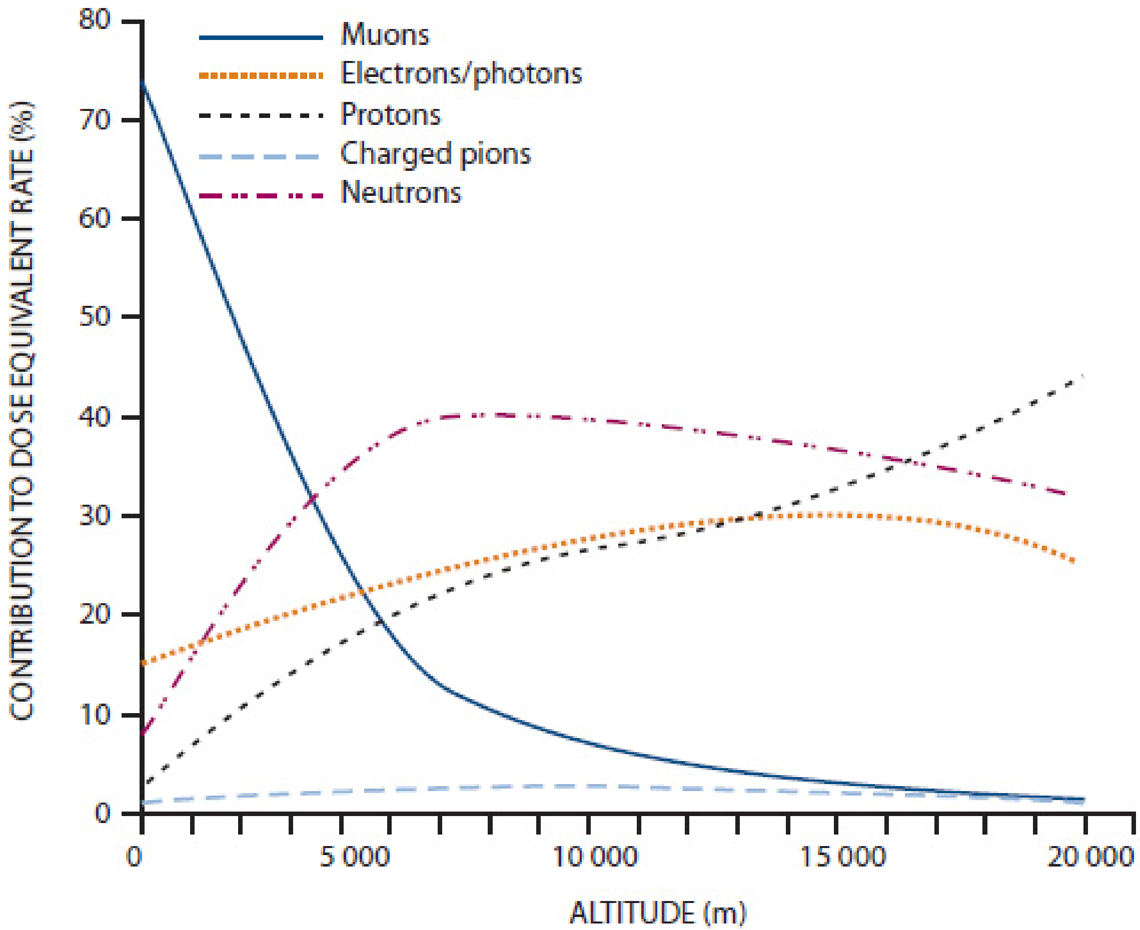
- Source: Department of Physics and Astronomy, Georgia State University

Secondary Cosmic Radiation

- Upper atmosphere –protons, neutrons, and pions (cosmic particle with a mass about 280 times that of an electron)

- Earth's surface – muons (elementary particle, classed as a lepton with 207 times the mass of an electron) electrons, and gamma rays

Components of Dose Equivalent



Source: UNSCEAR-2008, Fig. IV

Altitude and Latitude

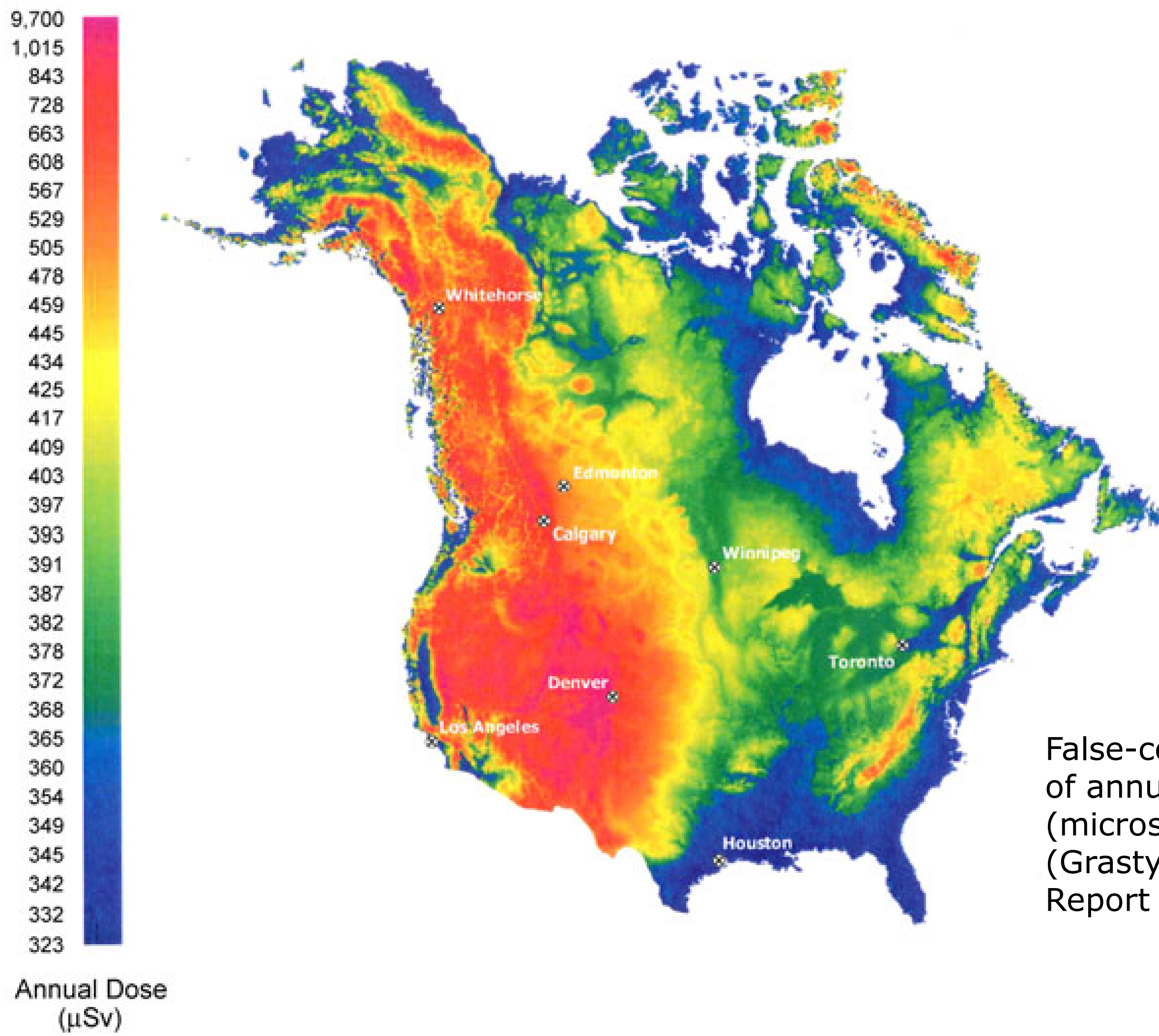
- Dose rate will change with both altitude and latitude.
- Obviously, the dose rate will increase with increasing altitude.
- The dose rate will also increase as we move toward the geomagnetic poles.

Altitude

Altitudinal Dependence on the Dose Equivalent Rate		
Altitude (ft)	Dose Equivalent Rate (mrem/yr)	Example
Sea Level	31	Los Angeles
5,000	55	Denver
10,000	137	Leadville, CO
30,000	1900	Normal Airplane
50,000	8750	SST Airliners
80,000	12,200	Spy Plane

Source: Gollnick 1988

Space Radiation



False-color plot of CARI-6 calculations of annual cosmic radiation doses (microsievert) in North America (Grasty and LaMarre, 2004). (NCRP Report 160, pg. 34)

Cosmogenic Radionuclides

- A minor contribution to the overall dose is generated from interactions of cosmic radiations in the atmosphere that produce radionuclides.

$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{1}_{1}p^{+} + ^{14}_{6}C$$

$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{3}_{1}H + ^{12}_{6}C$$

- Examples include ^{3}H, ^{7}Be, ^{14}C and ^{22}Na.

NCRP-Summary

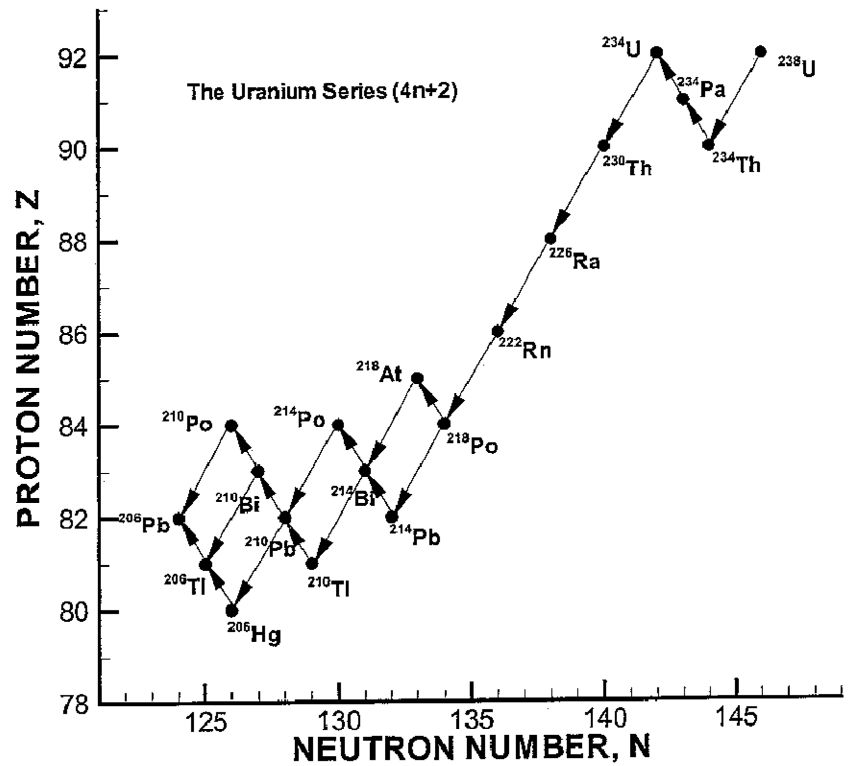
TABLES 3.14 NCRP Report 160 Annual Effective Doses to U.S. population from various background sources		
SOURCE	mSv/yr	mrem/yr
Cosmic	0.33	33
Cosmogenic	0.01	10
Terrestrial		
Inhaled		
In the Body		
Rounded Total		

Terrestrial Radionuclides

- Series
  - Long-lived parent decays through a series of steps until a stable isotope is reached
- Non-series
  - Decays to a stable isotope directly
  - K-40: $T^{1/2}$ = 1.28 billion years
  - Rb-87: $T^{1/2}$ = 48 billion years

Series Terrestrial Radionuclides

- Uranium Series
  - Parent – ^{238}U
  - Stable Isotope – ^{206}Pb
- Thorium Series
  - Parent – ^{232}Th
  - Stable Isotope – ^{208}Pb
- Actinium Series
  - Parent – ^{235}U
  - Stable Isotope – ^{207}Pb



Source: Lockheed Martin Chart of the Nuclides

Series Terrestrial Radionuclides

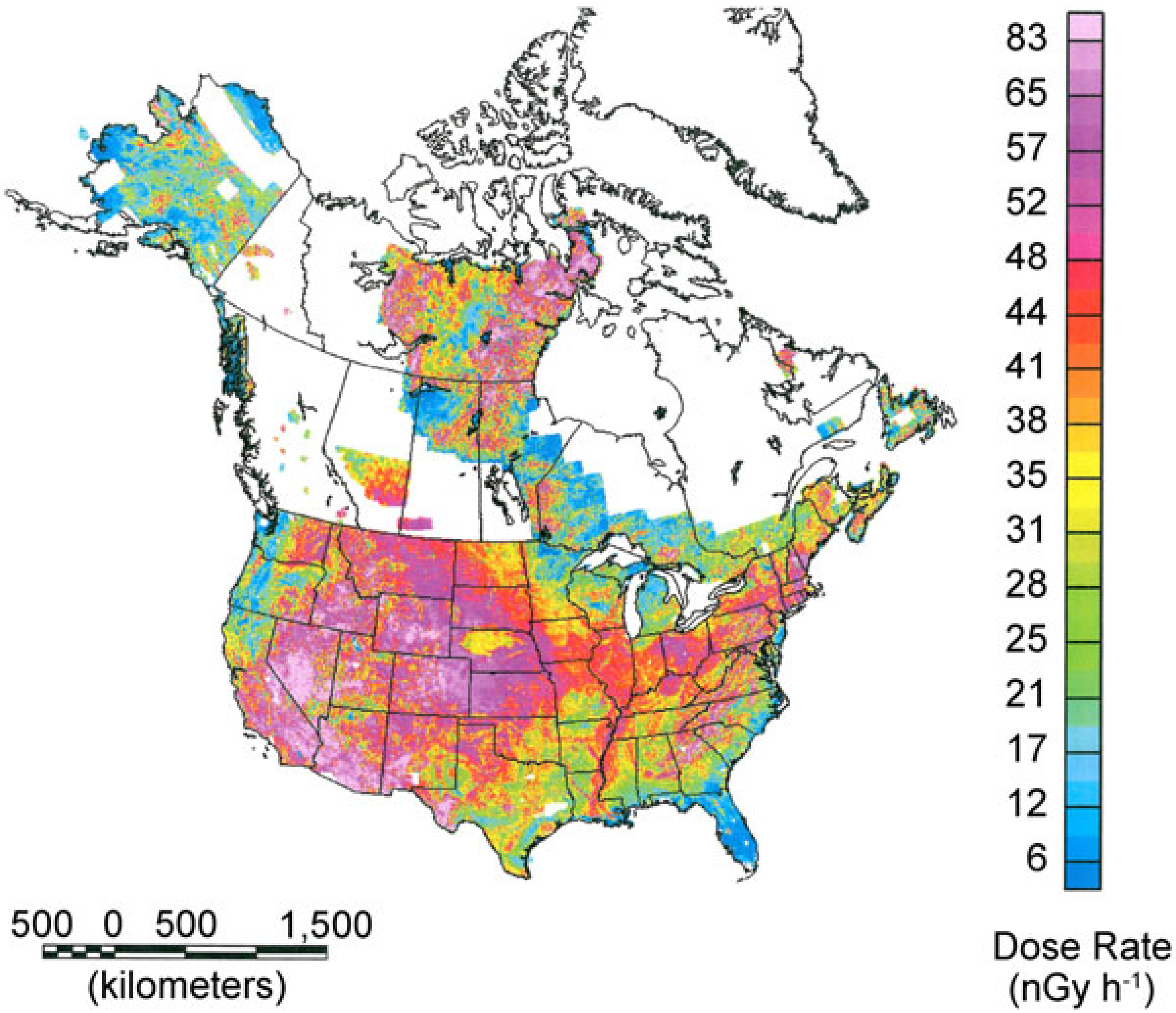
- Contains members with atomic numbers of 82 (lead) and higher
- Tend to exist in secular equilibrium
- Contains a radioisotope of the inert gas radon

Terrestrial Radionuclides

- The three terrestrial radionuclides that contribute the most significant external dose to the human body are ^{238}U, ^{234}Th, and ^{40}K.

- NCRP Report 160, reports the average annual effective dose from terrestrial radionuclides to be 0.21 mSv.

Terrestrial Gamma Radiation

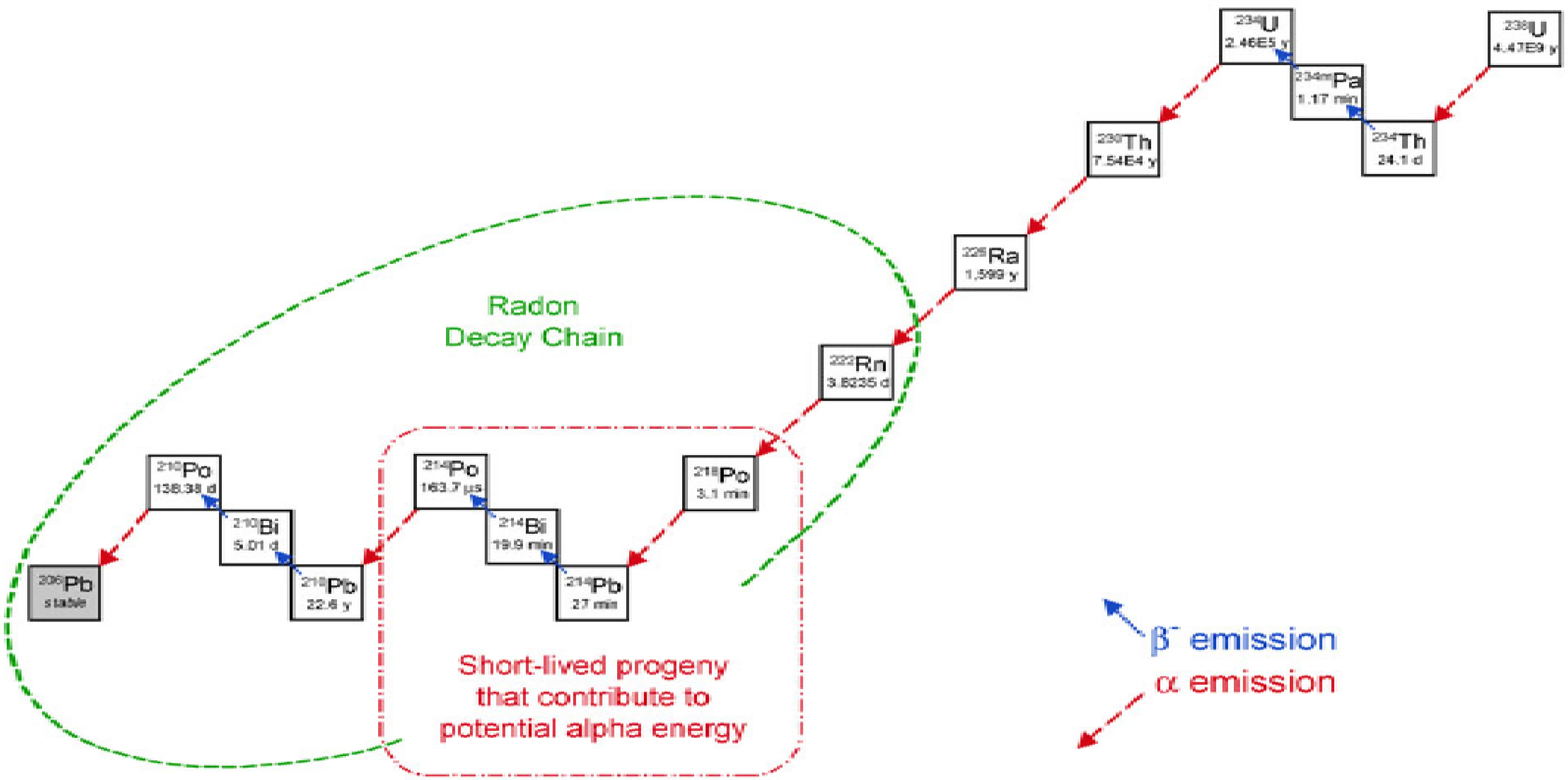


Plot of gamma-ray absorbed-dose rate in air from USGS data, with blue being the lowest (<6 nGy h−1) and lavender the highest (>83 nGy h−1) (Duval *et al., 2005). (*NCRP Report 160, pg. 42)

Radon, Thoron and Their Short-lived Decay Products

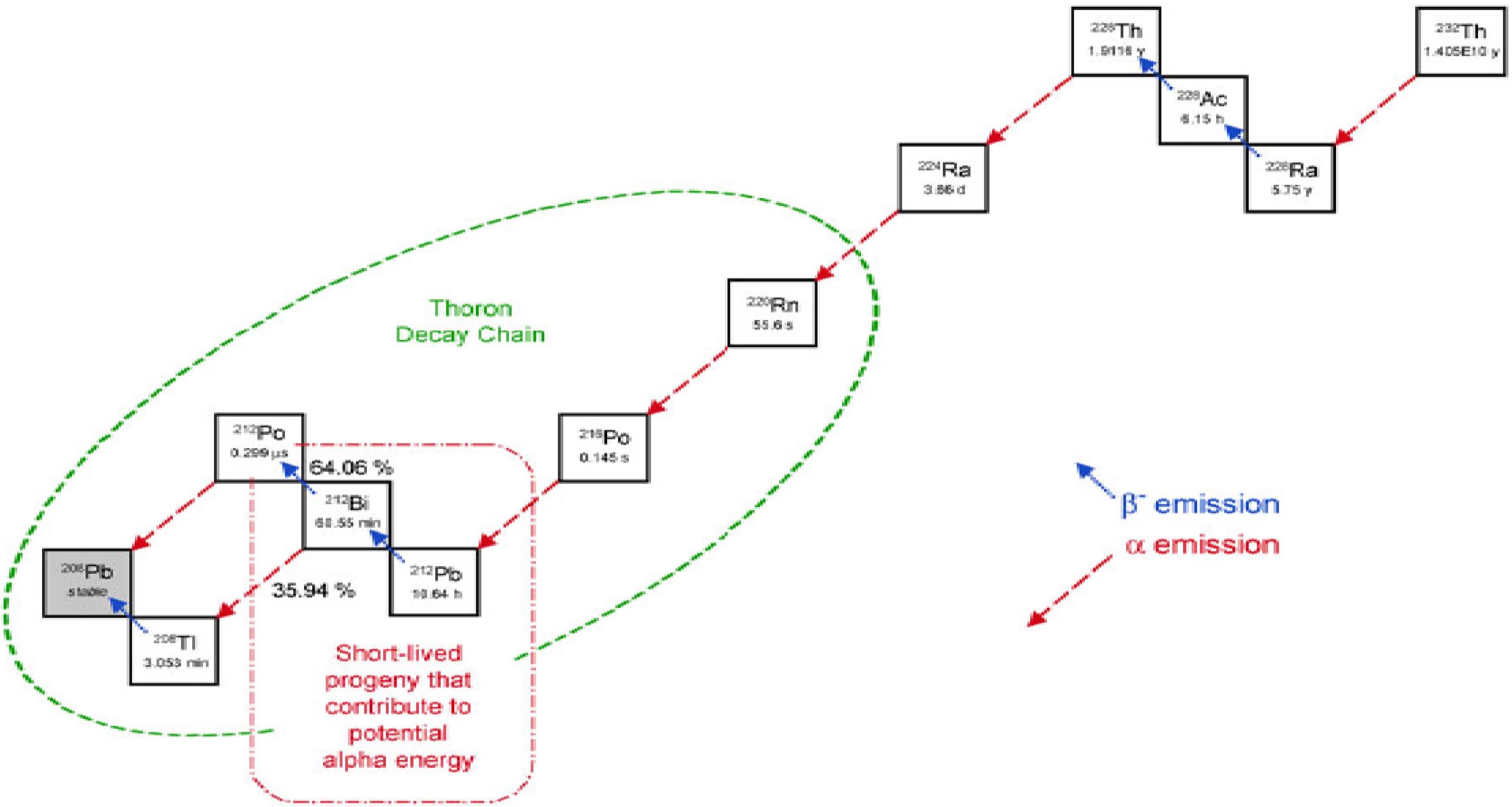
The most significant dose from natural background radiation results from the short-lived decay products of radon and thoron gas.

Radon, Thoron and Their Short-lived Decay Products



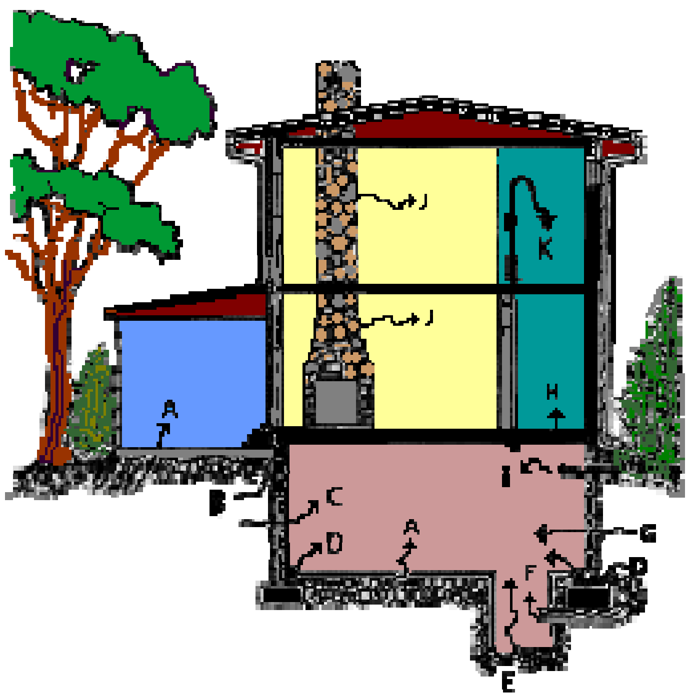
NCRP Report 160, pg. 27

Radon, Thoron and Their Short-lived Decay Products



NCRP Report 160, pg. 26

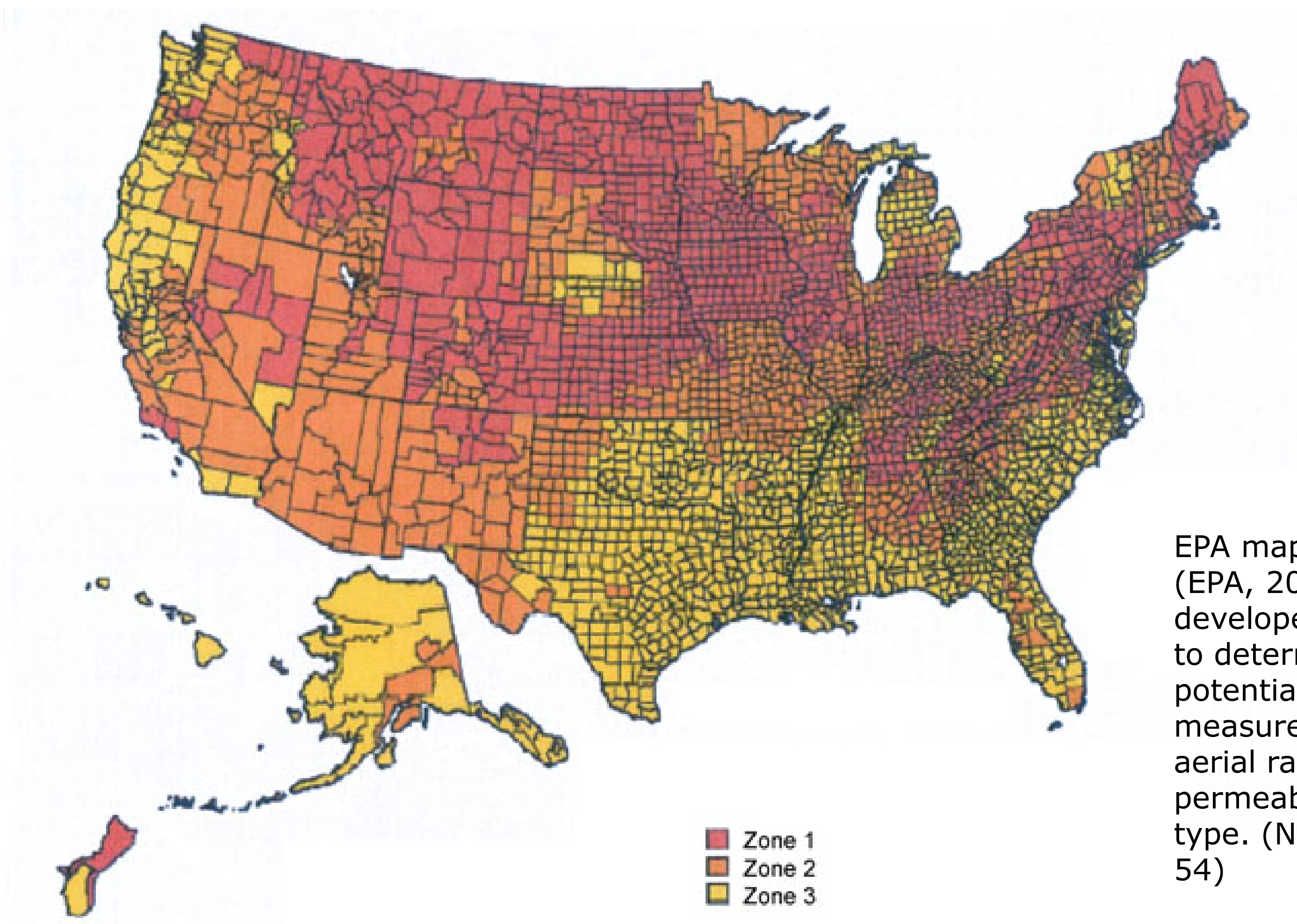
Radon, Thoron and Their Short-lived Decay Products



- A. Cracks in concrete slabs
- B. Spaces behind brick veneer walls that rest on uncapped hollow-brick foundation
- C. Pores and cracks in concrete blocks
- D. Floor-wall joints
- E. Exposed soil, as in a sump
- F. Weeping (drain) tile, if drained to open sump
- G. Mortar joints
- H. Loose fitting pipe penetrations
- I. Open tops of block walls
- J. Building materials such as some rocks
- K. Water (from some wells)

Entry ways for radon gas. Source: USEPA

Radon, Thoron and Their Short-lived Decay Products



EPA map of radon zones (EPA, 2007a). The map was developed using five factors to determine radon potential: indoor radon measurements, geology, aerial radiation mapping, soil permeability, and foundation type. (NCRP Report 160, pg. 54)

Radon, Thoron and Their Short-lived Decay Products

On average, a member of the public in the United States receives an annual effective dose of 2.12 mSv (212 mrem) from exposure to radon decay products and 0.16 mSv (16 mrem) from exposure to thoron decay products.

Radionuclides in the Body

Primordial radionulcides

- Uranium
- Thorium
- Radium
- Radon
- Polonium
- Bismuth
- Lead
- Potassium-40
- Rubidium-87

Cosmogenic

- Carbon-14

Radionuclides in the Body

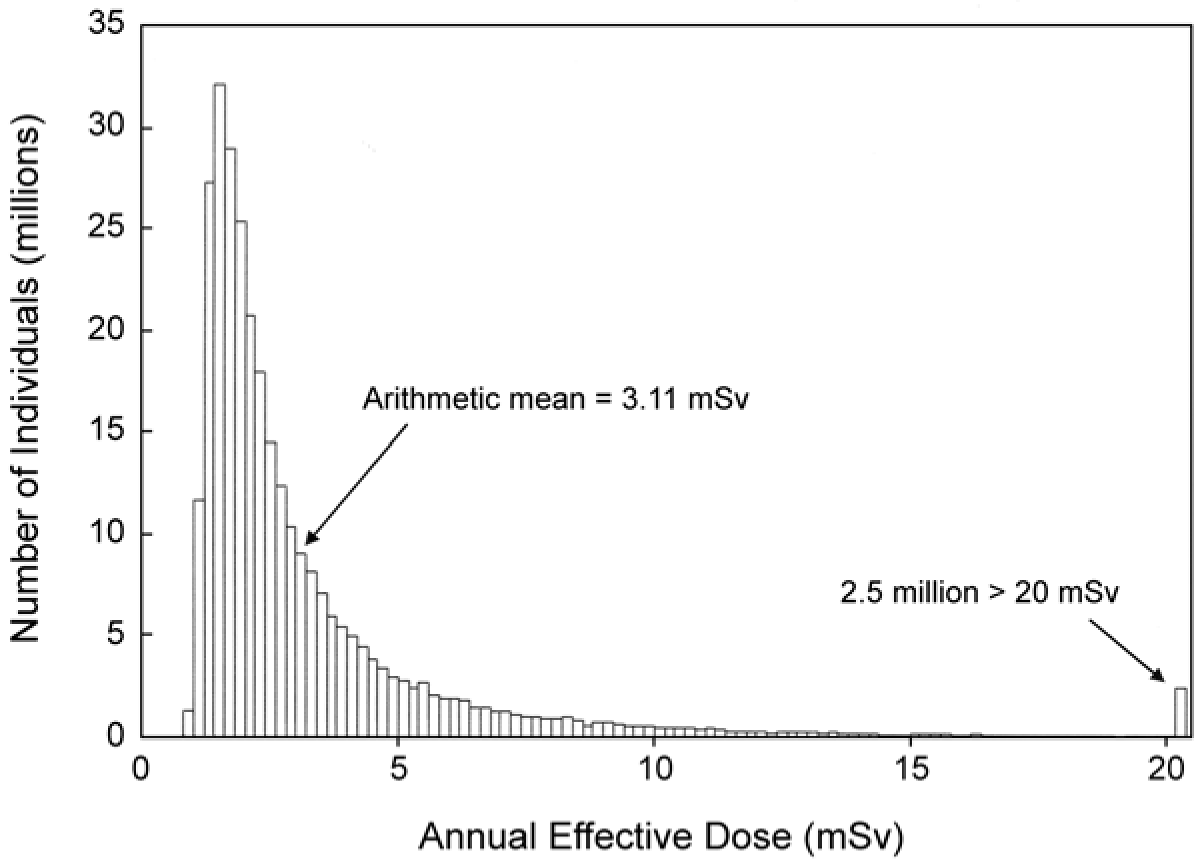
Enter the body by ingestion of food, milk and water or by inhalation

Source	Annual effective dose (mSv)
K-40	0.15
Th-232 and U-238 series	0.13
Other: C-14, Rb-87	0.01

NCRP-Summary

TABLES 3.14 NCRP Report 160 Annual Effective Doses to U.S. population from various background sources		
SOURCE	mSv/yr	mrem/yr
Cosmic	0.33	33
Cosmogenic	0.01	10
Terrestrial	0.21	21
Inhaled	2.28	228
In the Body	0.28	28
Rounded Total	3.11	311

Ubiquitous Background Radiation



NCRP Report 160, pg. 77

Ubiquitous Background Radiation

Collective effective dose (S): 930,000 person-Sv

Subcategories:

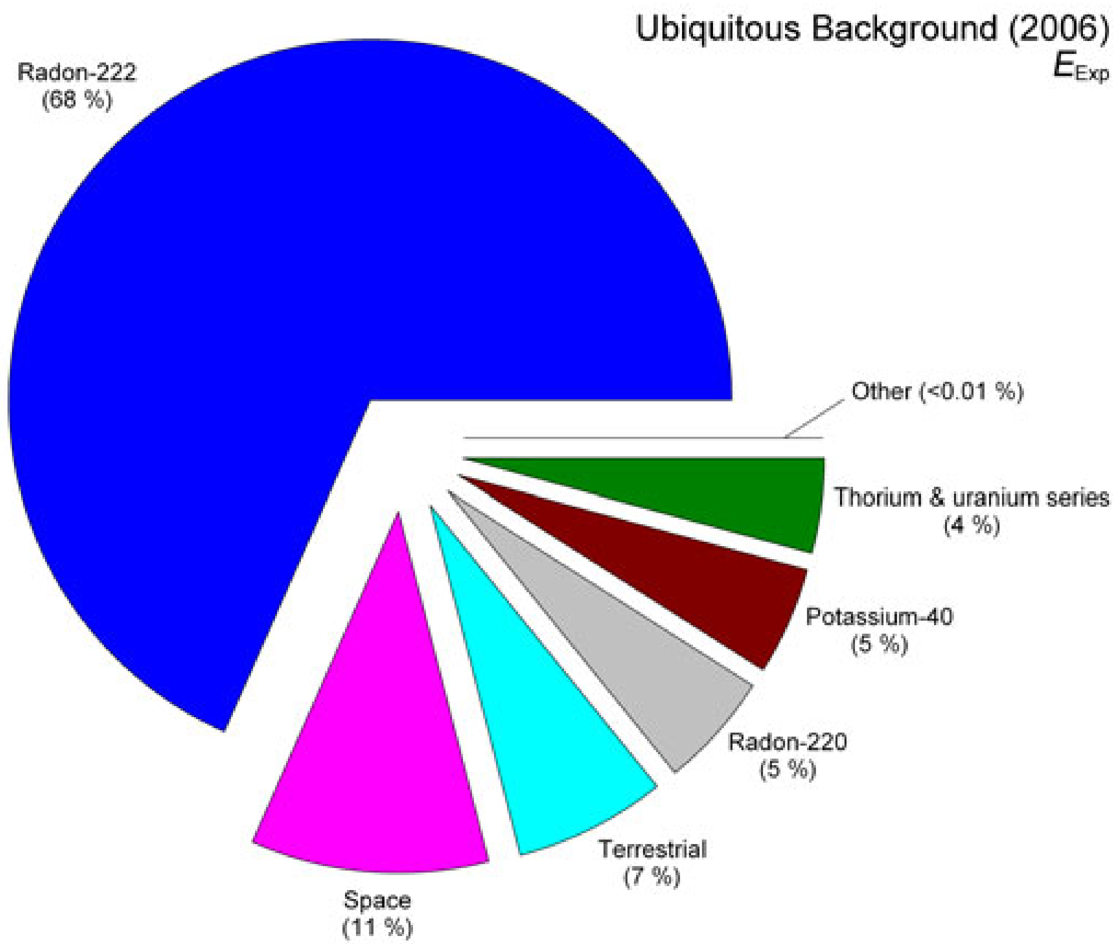
- Internal, inhalation (radon and thoron) – 73%
- External, space – 11%
- Internal, ingestion – 9%
- External, terrestrial – 7%

E_{US}: 3.1 mSv

Mean effective dose for the exposed group (E_{Exp}): 3.1 mSv

Group characteristics: all members of the population of the United States

Ubiquitous Background Radiation



NCRP Report 160, pg. 77

Medical Exposure of Patients

Ubiquitous Background Exposure

Consumer Products and Activities

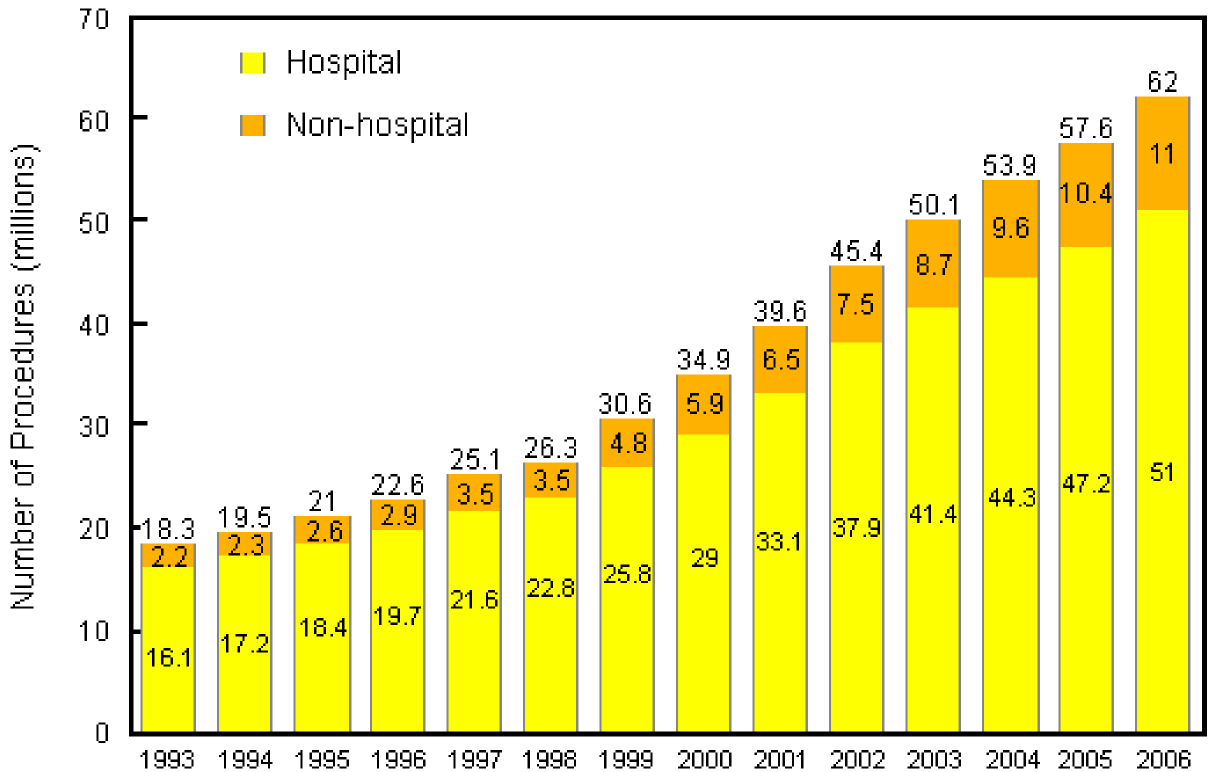
Industrial, Security, Medical, Educational and Research Activities

Occupational Exposures

Medical Exposure of Patients

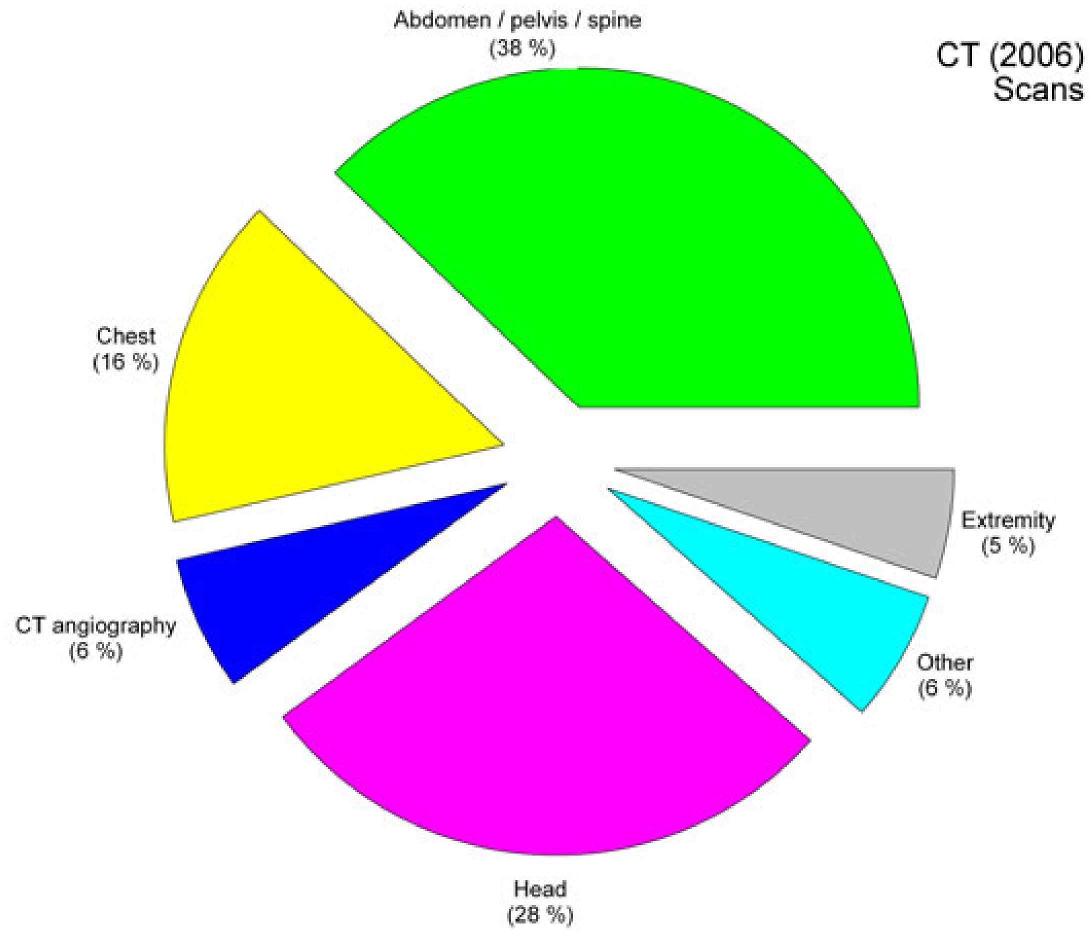
- Computed Tomography
- Conventional Radiography and Fluoroscopy
- Interventional Fluoroscopy
- Nuclear Medicine
- Radiotherapy (External Beam)

Computed Tomography



Number of CT procedures per year in the United States (millions), 1993 to 2006. Average growth: >10 % y–1. (NCRP Report 160, pg.91)

Computed Tomography



Percent contribution of various CT categories to total number of scans (67 million) *for 2006.* (NCRP Report 160, pg.95)

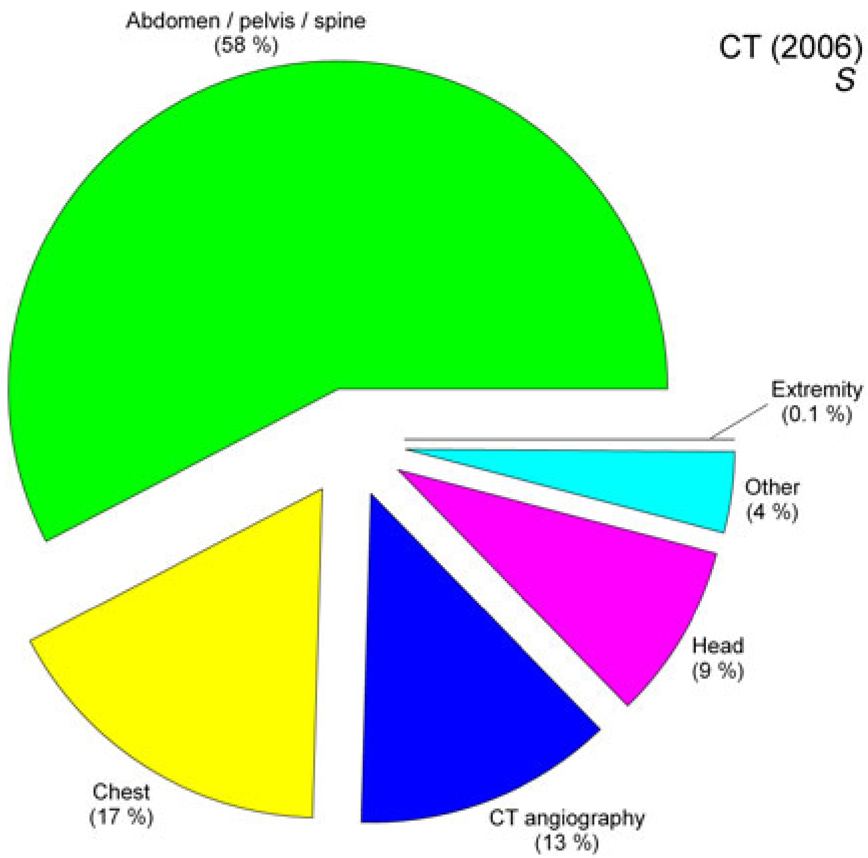
67 million CT scans in 2006

Computed Tomography

CT Category	Range for Effective Dose (per scan) (mSv)	Effective Dose (per scan) Used in the Calculation (mSv)
Head	0.9 – 4	2
Chest	4 – 18	7
Abdomen and pelvis	3 – 25	10
Extremity	0.1 – 1	0.1
Virtual colonography	5 – 15	10
Whole-body screening	5 – 15	10
Calcium scoring	1 – 12	2
Angiography: head	1 – 10	5
Angiography: heart	5 – 32	20
Other scans	1 – 10	5

Ranges for effective dose per scan for CT categories and the effective doses used in the calculations for 2006 for collective effective dose (all values are for adults). (NCRP Report 160, pg. 88)

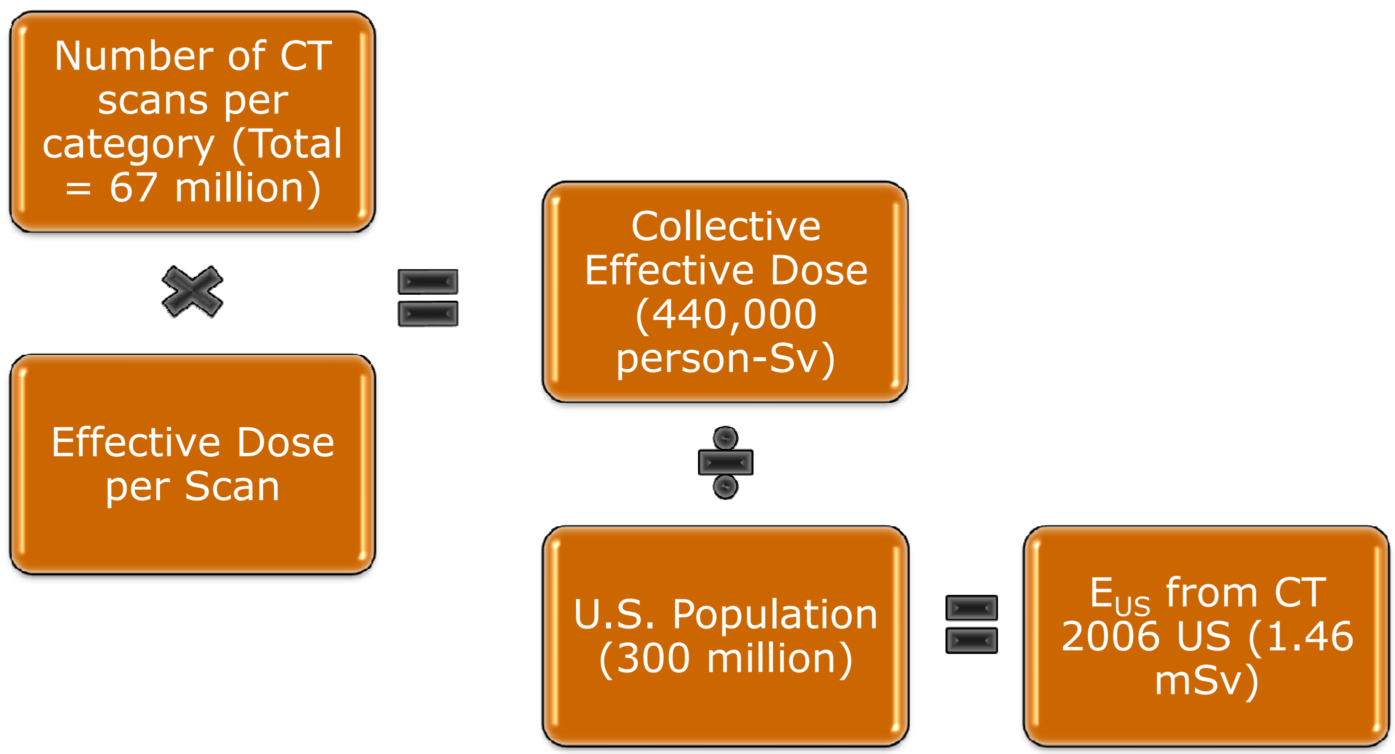
Computed Tomography



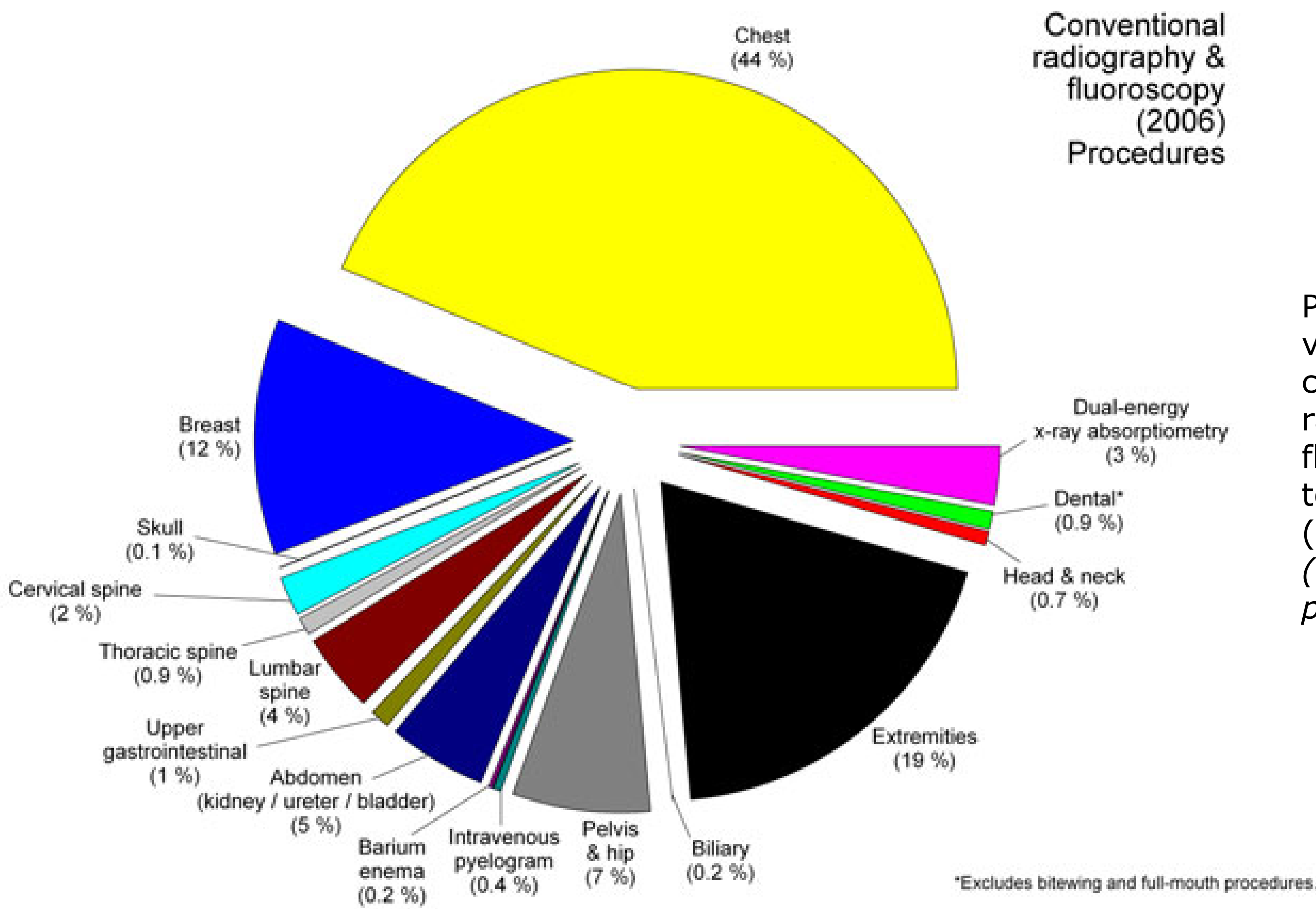
Percent contribution of various CT categories to *S (440,000 person-Sv) for 2006.* (NCRP Report 160, pg.95)

440,000 person-Sv in 2006

Computed Tomography



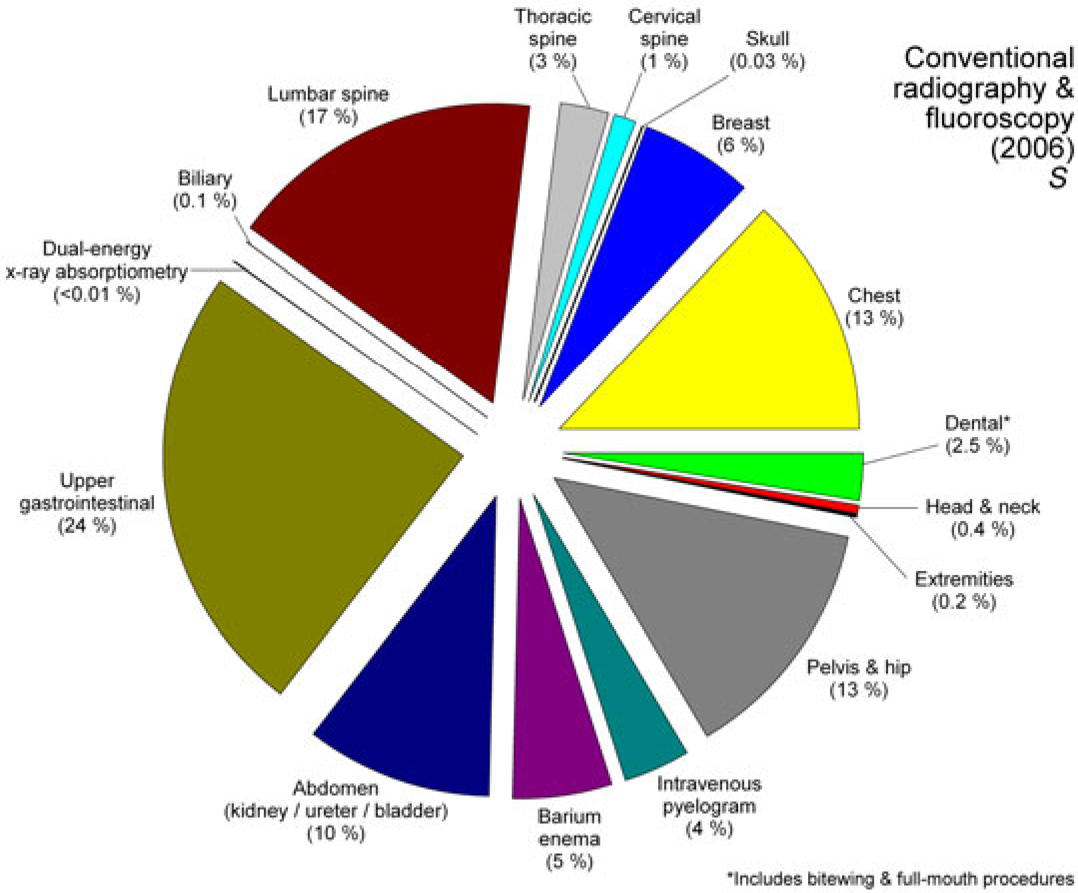
Conventional Radiography and Fluoroscopy



Percent contribution of various subcategories of conventional radiographic and fluoroscopic procedures to number of procedures (293 million) *for 2006. (NCRP Report 160, pg.104)*

293 million procedures in 2006

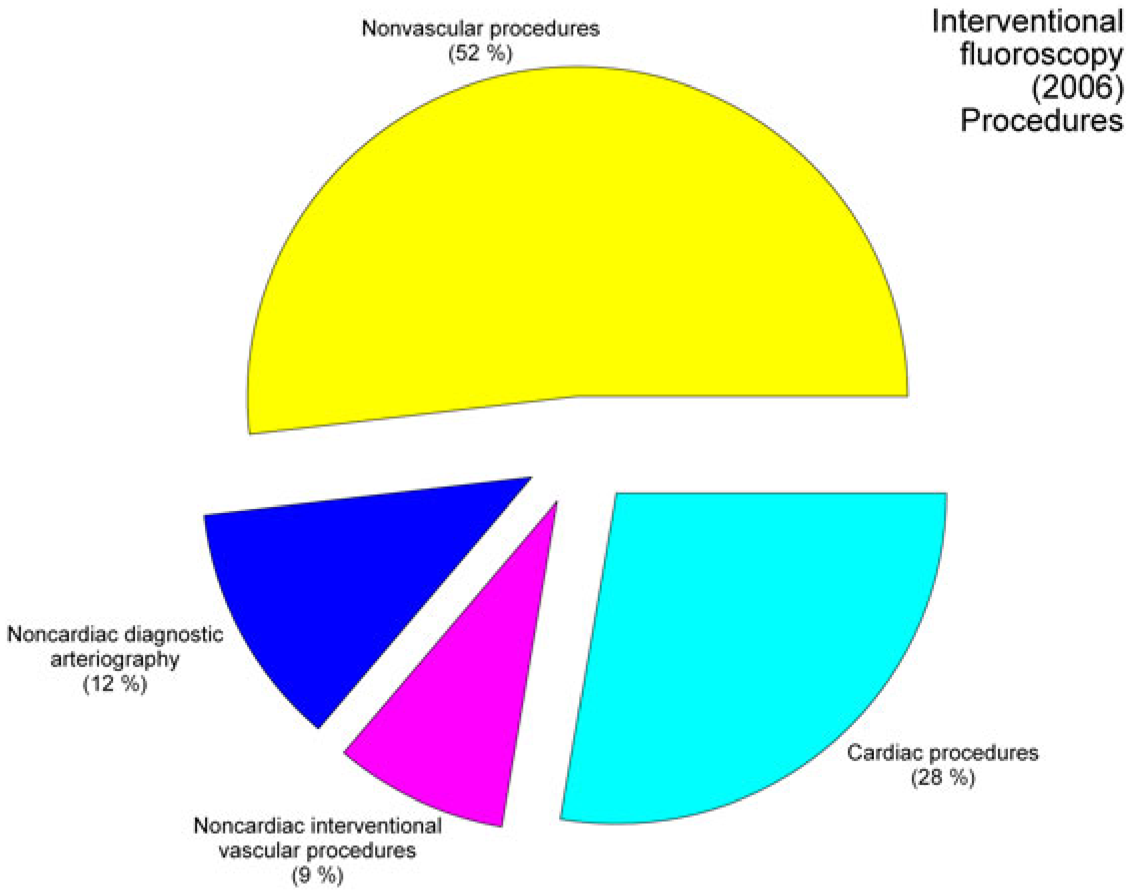
Conventional Radiography and Fluoroscopy



Percent contribution of various subcategories of conventional radiographic and fluoroscopic procedures to S (100,000 person-Sv) *for 2006. (NCRP Report 160, pg.104)*

100,000 person-Sv in 2006

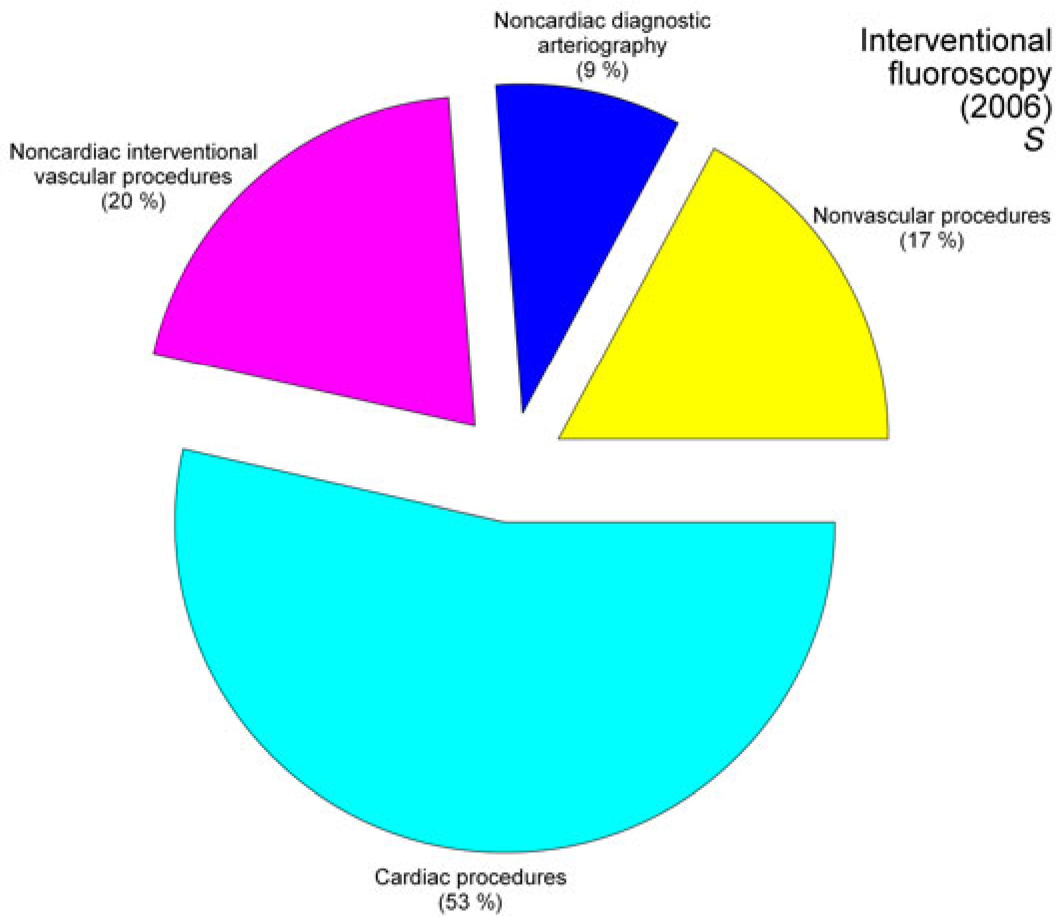
Interventional Fluoroscopy



Percent contribution of various groups of interventional-fluoroscopic procedures to number of procedures (16,700,000) for 2006.*(NCRP Report 160, pg.115)*

16.7 million procedures in 2006

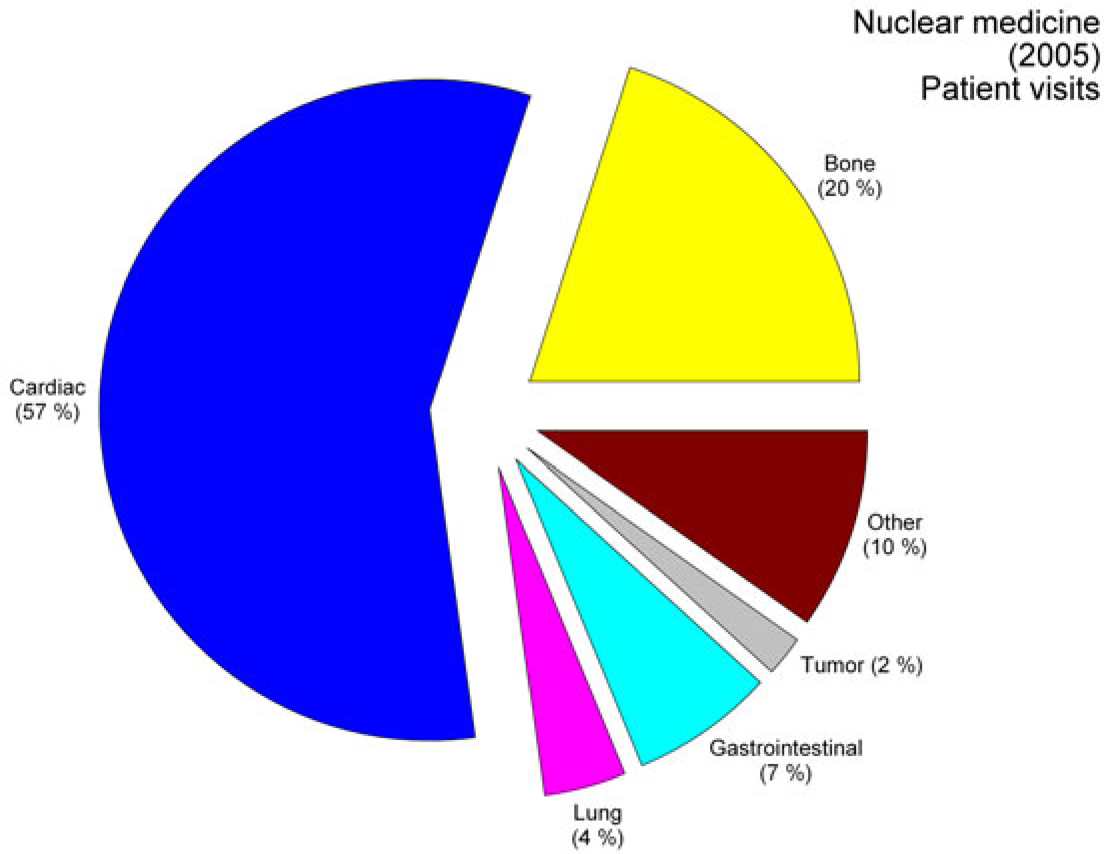
Interventional Fluoroscopy



Percent contribution of various groups of interventional-fluoroscopic procedures to S (128,000 person-Sv) for 2006. *(NCRP Report 160, pg.115)*

128,000 person-Sv in 2006

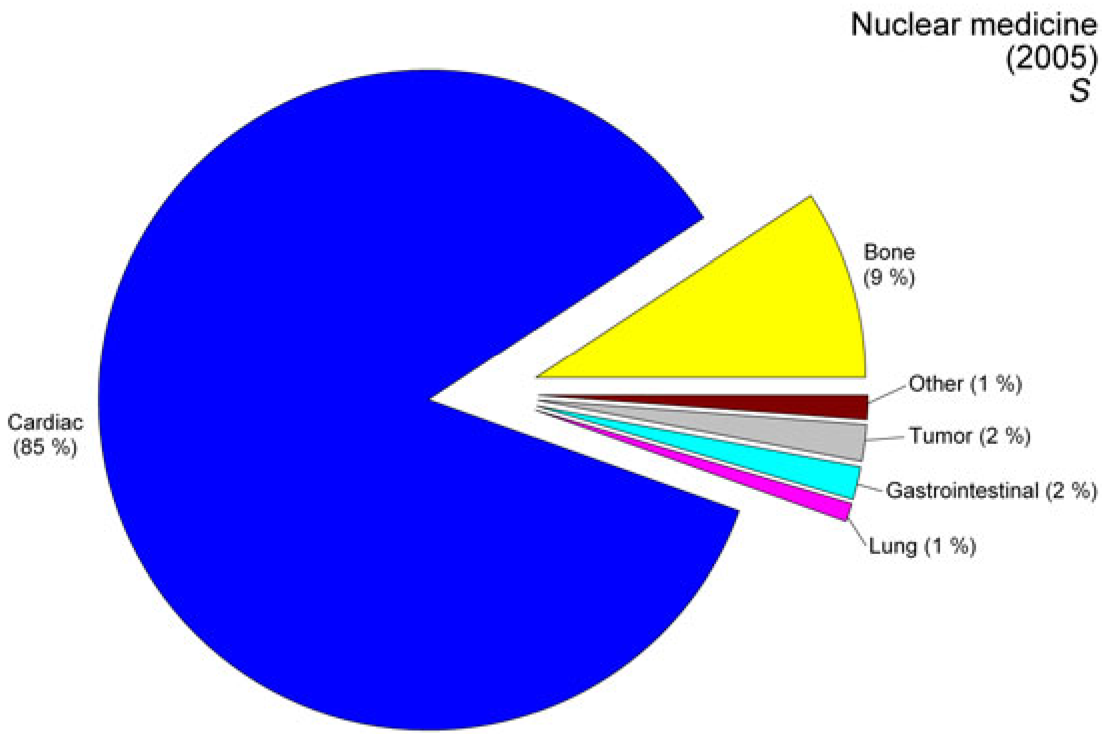
Nuclear Medicine



Percent contribution of various subcategories of nuclear medicine procedures to number of patient visits (17,220,000) *for 2005. (NCRP Report 160, pg.132)*

17.2 million procedures in 2005

Nuclear Medicine



Percent contribution of various subcategories of nuclear medicine procedures to *S (220,500 person-Sv) for 2005. (NCRP Report 160, pg.132)*

220,500 person-Sv in 2005

Radiotherapy (External Beam)

- Estimated 871,783 radiotherapy patients
- Collective Effective Dose (S): 354,165 person-Sv
- E_{US}: 1.18 mSv
- Per patient: 0.41 Sv

NCRP Report 160, pg. 139-140)

Medical Exposure of Patients

Collective effective dose (S): 900,000 person-Sv

- CT: 440,000 person-Sv
- NM: 231,000 person-Sv
- IF: 128,000 person-Sv
- CR&F: 100,000 person-Sv

Subcategories:

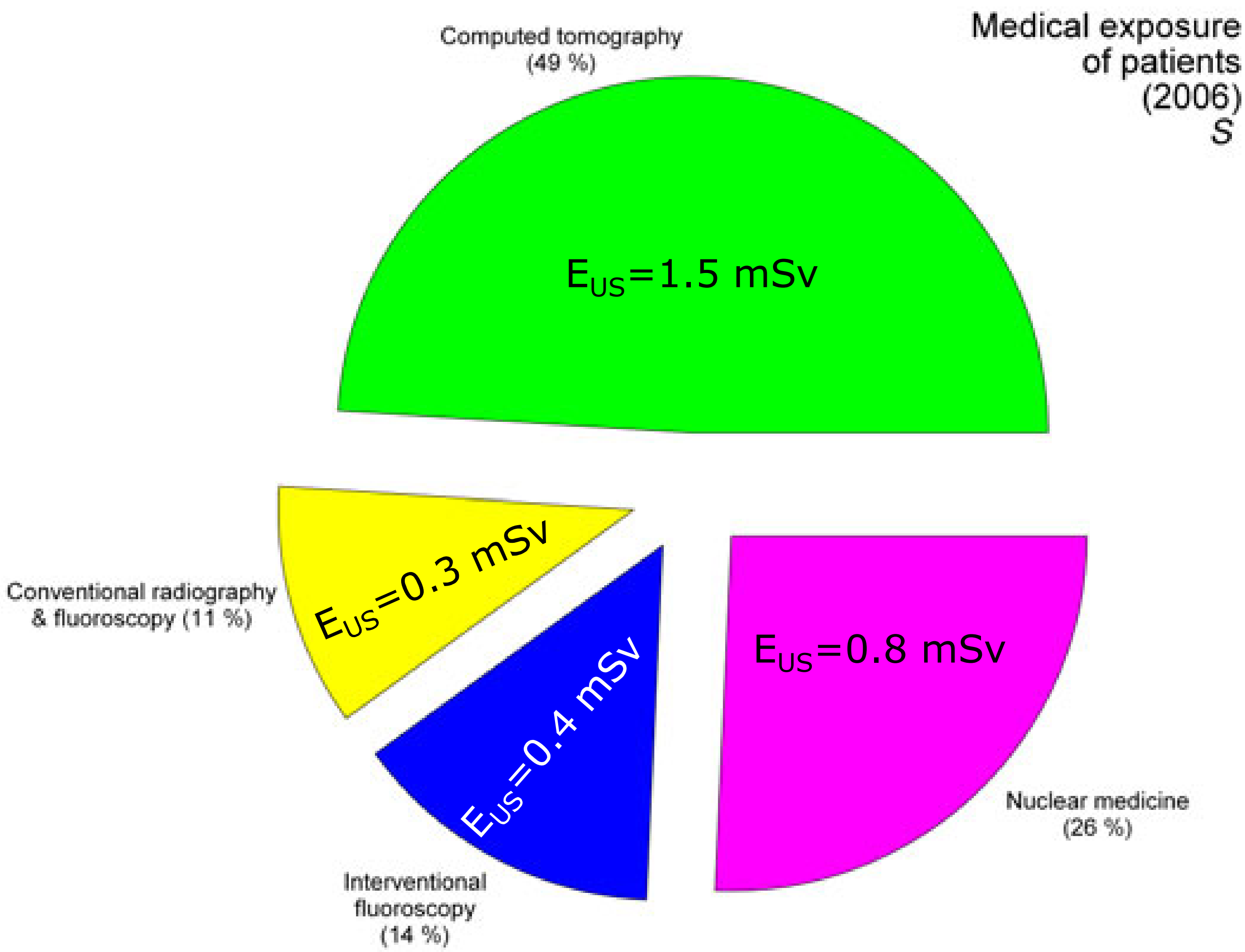
- Computed tomography– 49%
- Nuclear medicine– 26%
- Interventional fluoroscopy– 14%
- Conventional radiography and fluoroscopy– 11%

E_{US}: 3 mSv

Average effective dose for the exposed group (E_{Exp}): Not known, numbers of patients not known only numbers of procedures

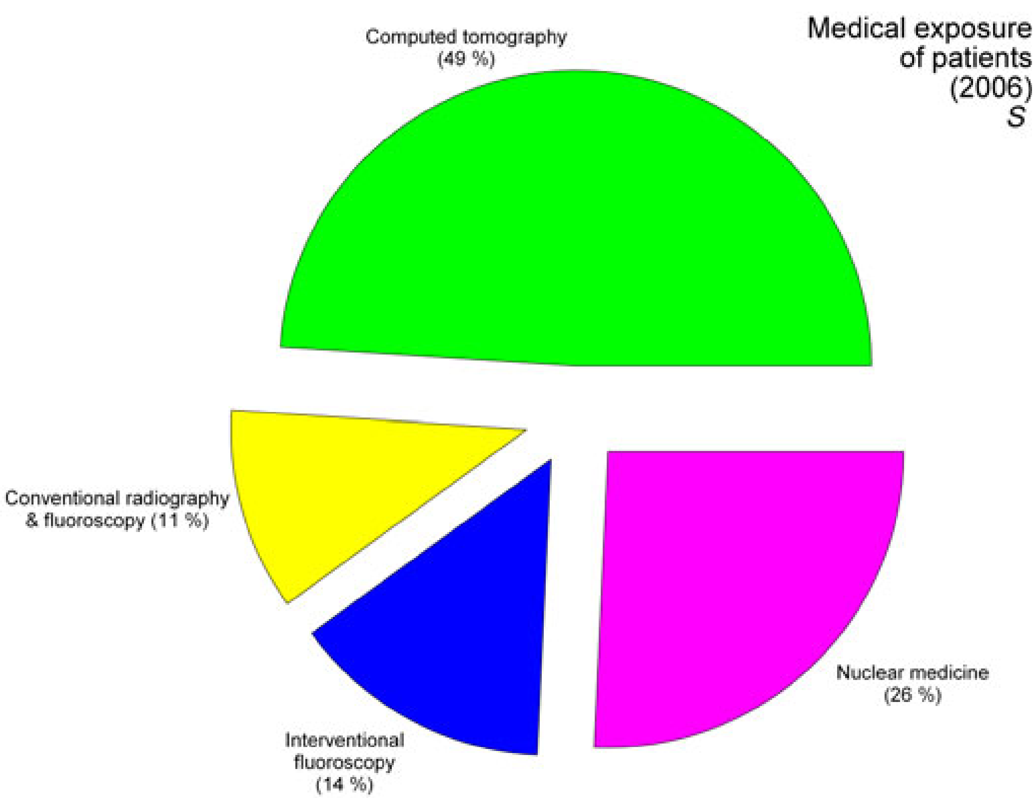
Group characteristics: for many situations, skewed to higher age groups and often to patients with serious health condition and limited remaining lifespans

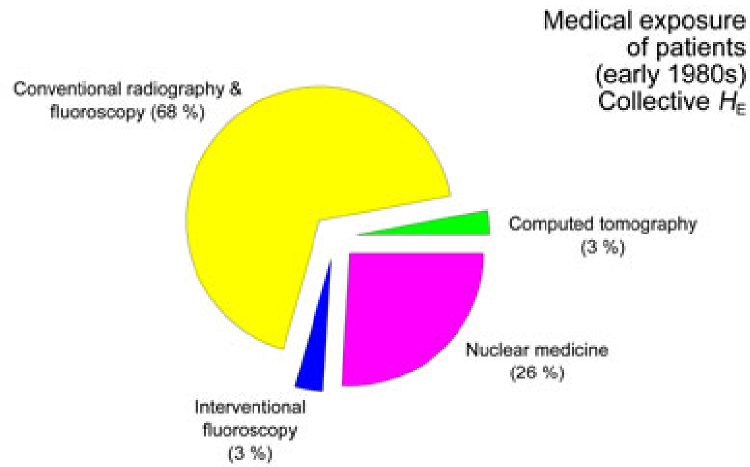
Medical Exposure of Patients



Medical Exposure of Patients

E_{US} for CT 2006: **1.47 mSv**
E_{US} for Medical 2006: **3.00 mSv**





E_{US} for CT 1987: **0.016 mSv**
E_{US} for Medical 1987: **0.53 mSv**

Consumer Products and Activities

Ubiquitous Background Exposure

Medical Exposure of Patients

Industrial, Security, Medical, Educational and Research Activities

Occupational Exposure

Consumer Products and Activities

- Television Receivers and Video Terminals
- Sewage Sludge and Ash
- Radioluminous Products (Tritium)
- Commercial Air Travel
- Tobacco Products
- Glass and Ceramics
- Building Materials
- Other Minor Contributors

NCRP Report 160: Table 5.8 – Summary of number of people exposed, average annual effective dose to an exposed individual and annual effective dose for consumer products and activities

Source	# of people exposed (millions)	E_{Exp} (µSv)	S (person-Sv)
Cigarette smoking	45	300	13,500
Building materials	150	70	10,500
Commercial air travel	_	_	10,300
Mining and agriculture	250	10	2,500
Other sources	_	_	1,000
Combustion of fossil fuels	455	5	920
Highway and road construction materials	6	40	240
Glass and ceramics	_	_	<10

Consumer Products and Activities

Collective effective dose (S): 39,000 person-Sv

Subcategories:

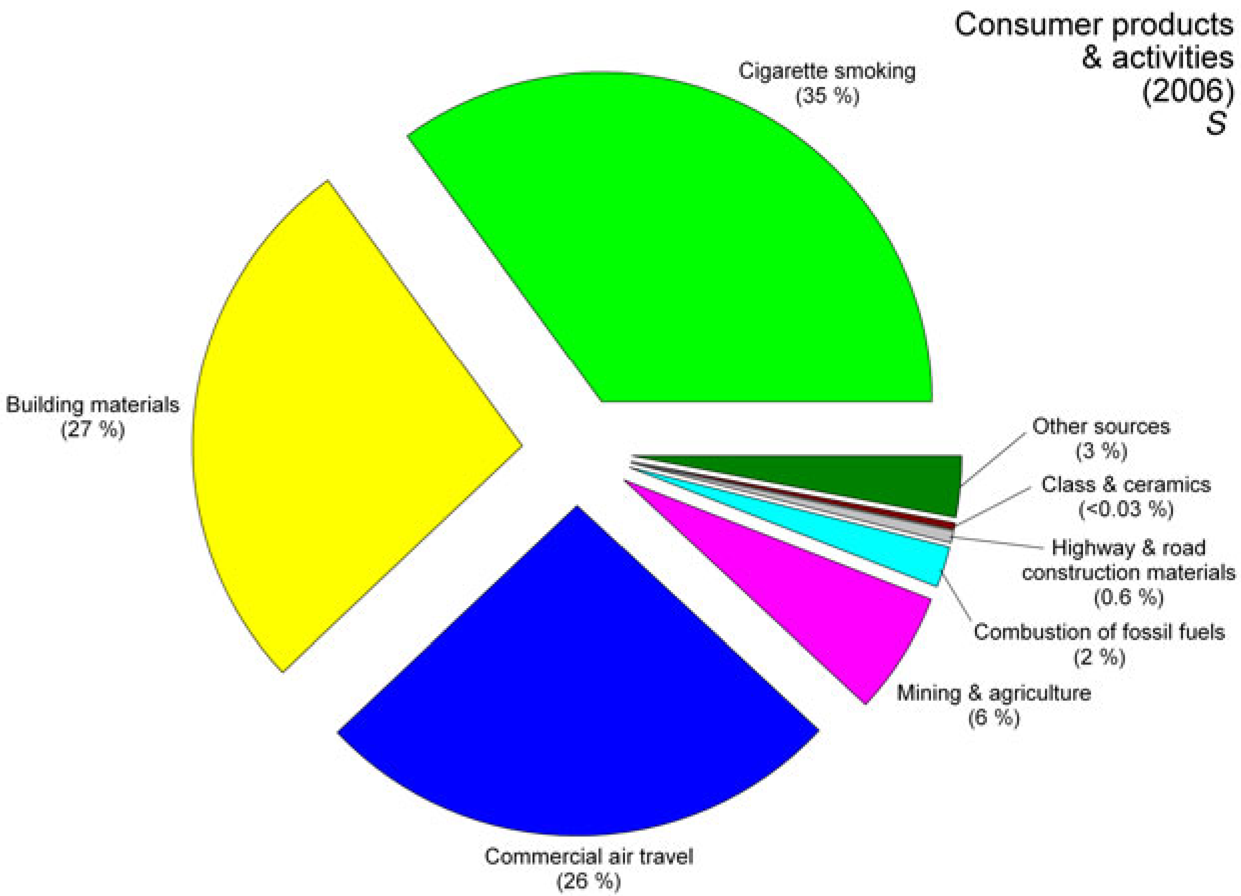
- Cigarette smoking – 35%, Building Materials – 27%
- Commercial air travel – 26%, Mining and agriculture – 6%
- Other sources – 3%, Combustion of fossil fuels – 2%
- Highway and road construction materials – 0.6%
- Glass and ceramics - <0.03%
- Television an video; sewage sludge and ash; self-illuminating signs - negligible

E_{US}: 0.1 mSv

Average effective dose for the exposed group (E_{Exp}): Not determined; variation: 0.001 to 0.3 Sv

Group characteristics: relatively large numbers of individuals, exposed to low doses

Consumer Products and Activities



Percent contribution of various sources of exposure to *S for* consumer products and activities (39,000 person-Sv) for 2006. (NCRP Report 160, pg. 170)

Industrial, Security, Medical, Educational and Research Activities

Ubiquitous Background Exposure

Medical Exposure of Patients

Consumer Products and Activities

Occupational Exposure

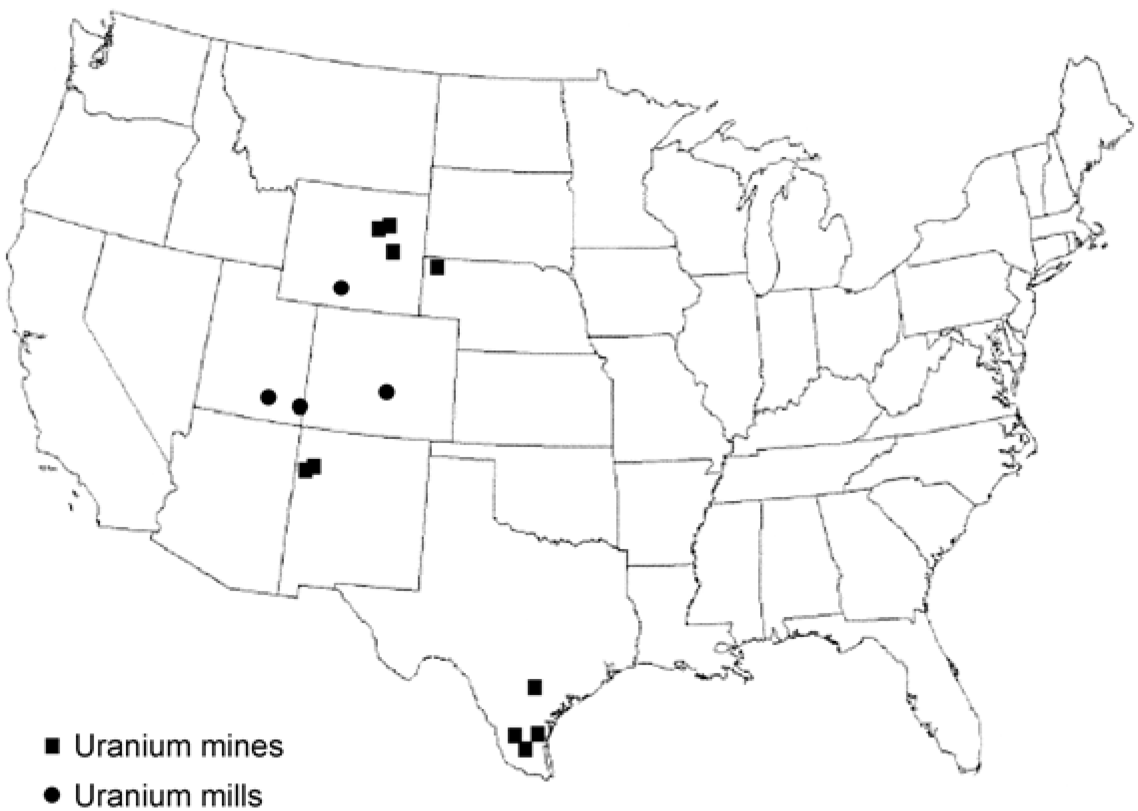
Industrial, Security, Medical, Educational and Research Activities

- Nuclear Power Generation
- U.S. Department of Energy Installations
- Decommissioning and Radioactive Waste
- Industrial, Medical, Educational and Research Activities
- Security Inspection Systems

NCRP Report 160: Table 6.1 – Summary of annual collective H_E to the regional population normalized to a 1 GWe reactor operating at full capacity 80% of the time (i.e., 0.8 GWe)

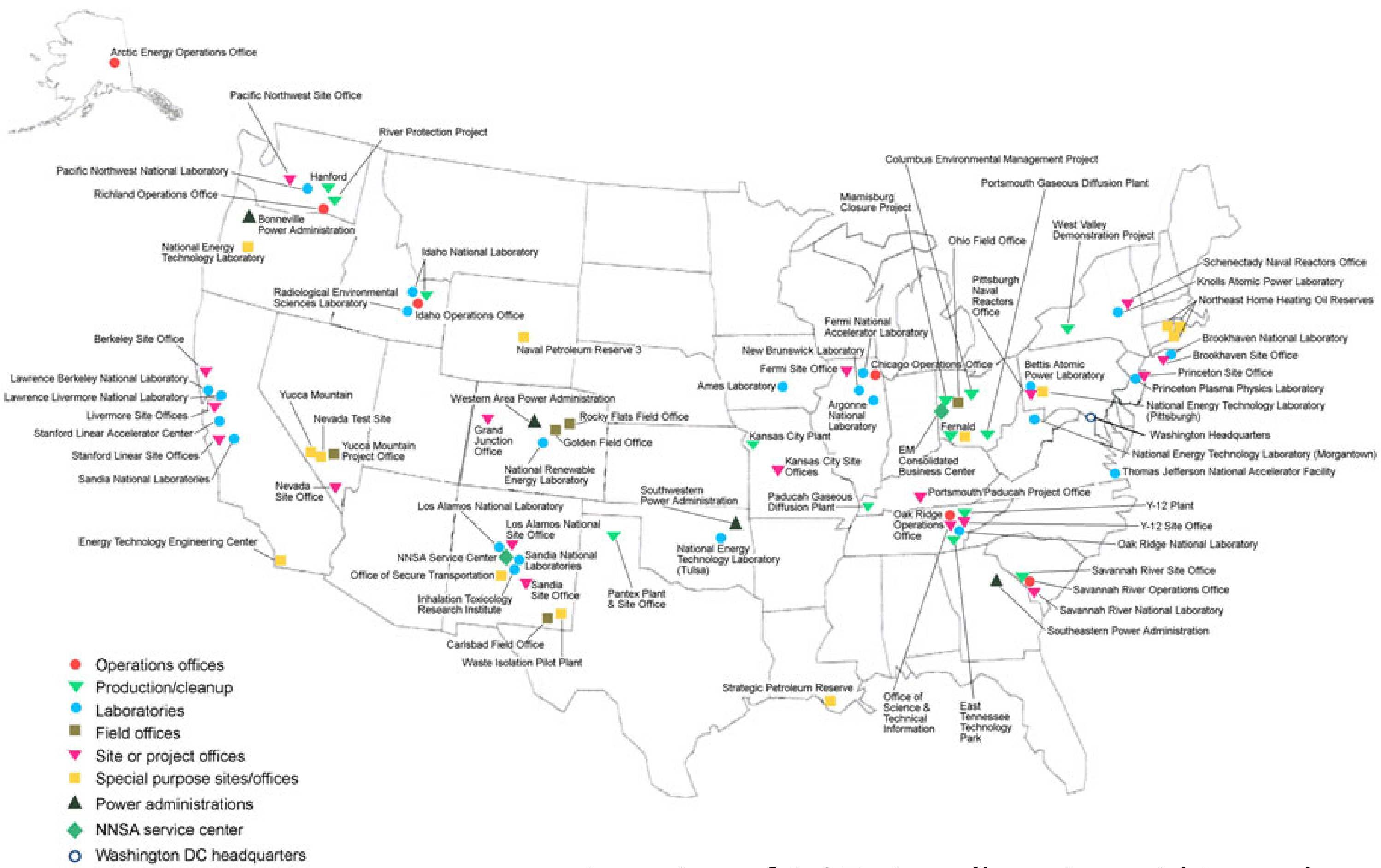
Facility	Annual Collective H_E (person-Sv)	Basis of Estimate
Mining	0.94	Weighted for 2 types of model mines [1/2 (open pit) + (3 (underground)]
Milling	0.25	0.4 (model mill)
Conversion	0.0003	Weighted for 2 plants (65% wet)
Enrichment	0.0001	Paducah plus Oak Ridge
Fabrication	0.00004	Weighted for 7 plants
Nuclear-power plants	0.048	1980 data for 47 plants
Low-level waste storage	-	No estimate available
Transportation Incident-free Accidents	 0.071 0.054	Excludes decommissioning waste
Total per 0.8 GWe	1.36	
Total for 90 Gwe (estimated 2006 production)	153	

Nuclear Power Generation



Location of uranium mines and mills in the United States as of November 2005 (EPA. 2007b). (NCRP Report 160, pg. 176)

U.S. Department of Energy Installations



Location of DOE sites (location within each state is not to scale) (DOE, 2006b). (NCRP Report 160, pg. 178)

U.S. Department of Energy Installations

- Exposures are estimated based on measured effluent data and direct dose at the site boundary
- Members of the public residing >80 km from a DOE facility – negligible dose
- Members of the public residing <80 km from a DOE facility – range of annual values for all DOE sites - <0.001 to 0.6 μSv

Decommissioning and Radioactive Waste

- Waste sites – 3 sites
- Decommissioning
- TENORM (Technologically-Enhanced Naturally-Occurring Radioactive Material) Waste Disposal
  - Soils in the United States
  - Geothermal energy waste
  - Oil and gas production waste
  - Water treatment waste
  - Waste water treatment waste
  - Aluminum production waste
  - Coal and coal ash
  - Copper production waste
  - Phosphate production
  - Rare earths
  - Titanium ores
  - Uranium mining overburden
  - Uranium in situ leach
  - Zircon

Industrial, Medical, Educational and Research Activities

NCRP Report 160: Table 6.3 – Derivation of estimates of annual collective effective dose to members of the public from medical, industry and commerce, and education and research activities			
Source	Estimate of Exposed Population	Average Dose per Person (mSv)	Collective Effective Dose (person-Sv)
Medical	74,000,000	0.0016	120
Industry and commerce	1,300,000	0.002	3
Education and research	840,000	0.0018	2
Total *S* for members of the public			125

Security Inspection Systems

- Cabinet x-ray systems
- Nonintrusive inspection (NII) equipment (Cargo scanners)
- Personnel security systems

Nonintrusive inspection (NII) equipment (Cargo scanners)

- Dose equivalent to individual inadvertently exposed (hidden) in container
  - X and gamma ray systems – 0.025 to 0.53 μSv
  - Linear-accelerator (electron beam) system – 115 μSv
  - PFNA (pulse fast neutron analysis) system – 315 μSv

- CBP, 2004: maxium dose rate of 0.5 μSv/hr and 2,000 hr/y as the maximum time of exposure – limits inspectors and members of the public to ≤ 1 mSv.

Personnel security systems

- General use: effective dose 0.1 μSv or less per scan
  - Typically utilize backscatter technology – effective dose ~0.03 μSv per scan
  - Airport screening
- Limited use: deliver an effective dose>0.1 μSv but are limited to ≤10 μSv per scan
  - Primarily used to scan prisoners

Industrial, Security, Medical, Educational and Research Activities

Collective effective dose (S): 1,000 person-Sv

Subcategories:

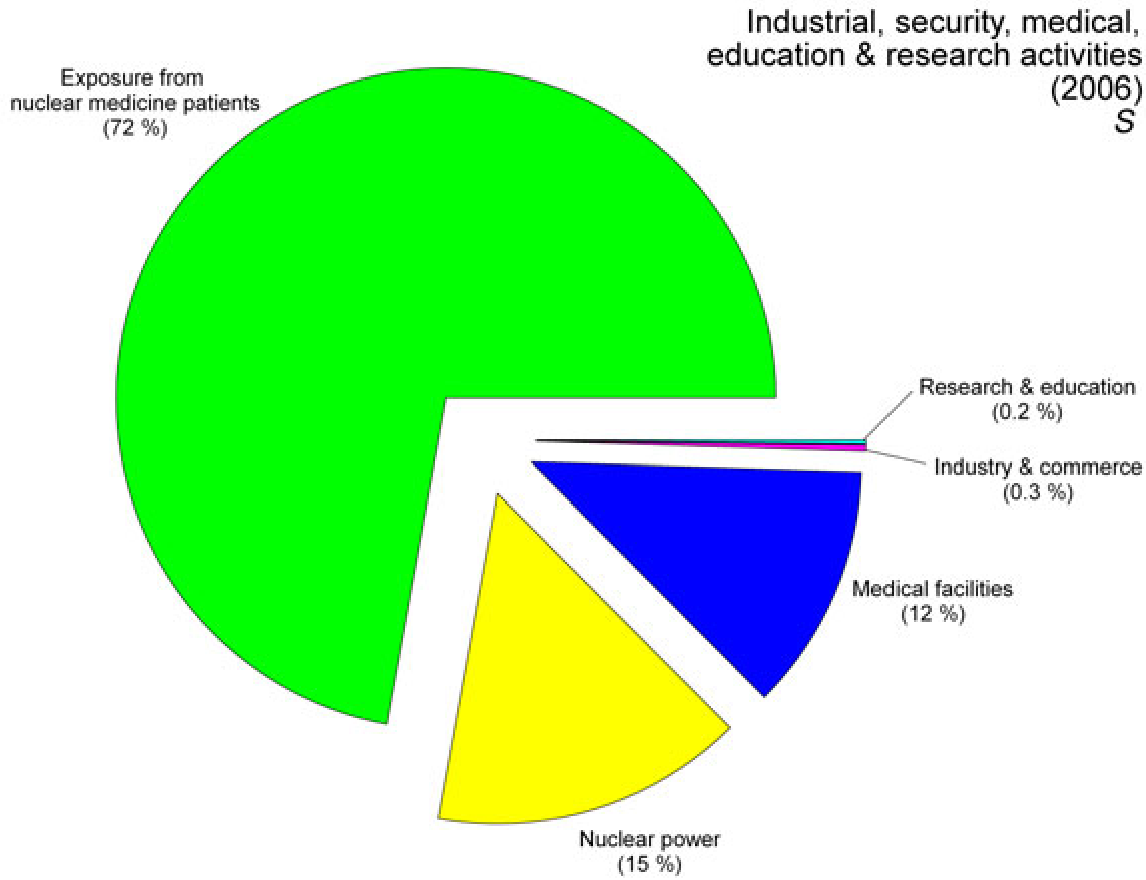
- Exposure from Nuc. Med. patients– 72%
- Nuclear power generation– 15%
- Industrial, medical, educational and research activities– 13%
- DOE installations, decommissioning and rad. waste, security inspection systems– <<1%

E_{US}: 0.003 mSv

Average effective dose for the exposed group (E_{Exp}): Not determined, magnitude: 0.001 to 0.01 mSv

Group characteristics: members of the public in proximity to these activities

Industrial, Security, Medical, Educational and Research Activities



Percent contribution of various sources of exposure to *S* for industrial, security, medical, educational and research activities (1,000 person-Sv) for 2006. (NCRP Report 160, 194)

Occupational Exposure

Ubiquitous Background Exposure

Medical Exposure of Patients

Consumer Products and Activities

Industrial, Security, Medical, Educational and Research Activities

Occupational Exposure

- Occupational Exposure from Medical Practices
- Commercial Aviation
- Industry and Commerce
- Commercial Nuclear Power Industry
- Academic Institutions
- Government, DOE and Military

Occupational Exposure

NCRP Report 160: Table 7.3 – Summary of occupational doses for U.S. workers					
Category	# of workers and doses	2003	2004	2005	2006
Medical	Monitored workers	1,957,088	2,220,861	2,352,976	2,519,693
	Workers with recordable dose	690,661	735,400	693,941	735,347
	Collective effective dose (person-Sv)	508	559	546	549
	Average effective dose (mSv)	0.74	0.76	0.79	0.75

Occupational Exposure

NCRP Report 160: Table 7.3 – Summary of occupational doses for U.S. workers					
Category	# of workers and doses	2003	2004	2005	2006
Aviation	Monitored workers	0	0	0	0
	# of airline crew	177,000	180,000	176,000	173,000
	Collective effective dose (person-Sv)	543	553	540	531
	Average effective dose (mSv)	3.07	3.07	3.07	3.07

Occupational Exposure

NCRP Report 160: Table 7.3 – Summary of occupational doses for U.S. workers

Category	# of workers and doses	2003	2004	2005	2006
Commercial Nuclear Power	Monitored workers	109,990	110,290	114,344	116,354
	Workers with recordable dose	55,967	52,873	57,566	58,788
	Collective effective dose (person-Sv)	120	104	115	110
	Average effective dose (mSv)	2.14	1.97	2.00	1.87

Occupational Exposure

NCRP Report 160: Table 7.3 – Summary of occupational doses for U.S. workers

Category	# of workers and doses	2003	2004	2005	2006
Industry and Commerce	Monitored workers	360,069	556,325	579,864	505,369
	Workers with recordable dose	112,671	133,926	125,257	134,105
	Collective effective dose (person-Sv)	98	114	117	109
	Average effective dose (mSv)	0.87	0.85	0.93	0.81

Occupational Exposure

NCRP Report 160: Table 7.3 – Summary of occupational doses for U.S. workers					
Category	# of workers and doses	2003	2004	2005	2006
Education and research	Monitored workers	351,309	504,948	514,267	437,007
	Workers with recordable dose	79,901	88,125	81,732	83,700
	Collective effective dose (person-Sv)	43	73	51	60
	Average effective dose (mSv)	0.54	0.83	0.62	0.72

Occupational Exposure

NCRP Report 160: Table 7.3 – Summary of occupational doses for U.S. workers					
Category	# of workers and doses	2003	2004	2005	2006
Government, DOE, military	Monitored workers	265,570	289,979	301,498	284,192
	Workers with recordable dose	36,559	26,788	33,934	30,591
	Collective effective dose (person-Sv)	44(24)	49(27)	38(17)	39(18)
	Average effective dose (mSv)	0.66	0.73	0.5	0.59

Occupational Exposure

NCRP Report 160: Table 7.3 – Summary of occupational doses for U.S. workers					
Category	# of workers and doses	2003	2004	2005	2006
All	Monitored workers	3,044,326	3,682,403	3,862,949	3,862,615
	Workers with recordable or estimated dose	1,152,759	1,227,112	1,168,430	1,215,531
	Total collective effective dose (person-Sv)	1,356	1,452	1,407	1,399
	Average effective dose (mSv)	1.16	1.17	1.19	1.13

Occupational Exposure

Collective effective dose (*S*): 1,400 person-Sv

Subcategories:

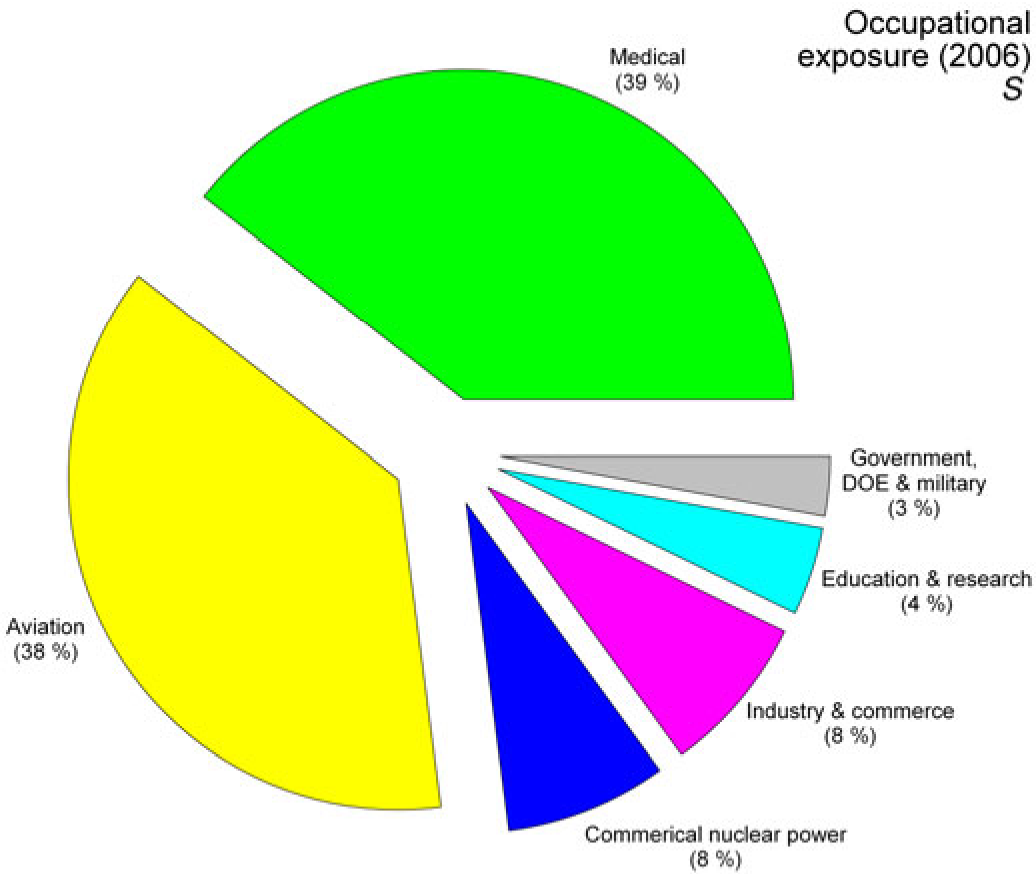
- Medical – 39%
- Aviation – 38%
- Commercial nuclear power– 8%
- Industry and commerce – 8%
- Education and research – 4%
- Government, DOE, military – 3%

E_{US}: 0.005 mSv

Average effective dose for the exposed group (E_{Exp}): 1.1 mSv, variation: 0.6 to 3.1 mSv

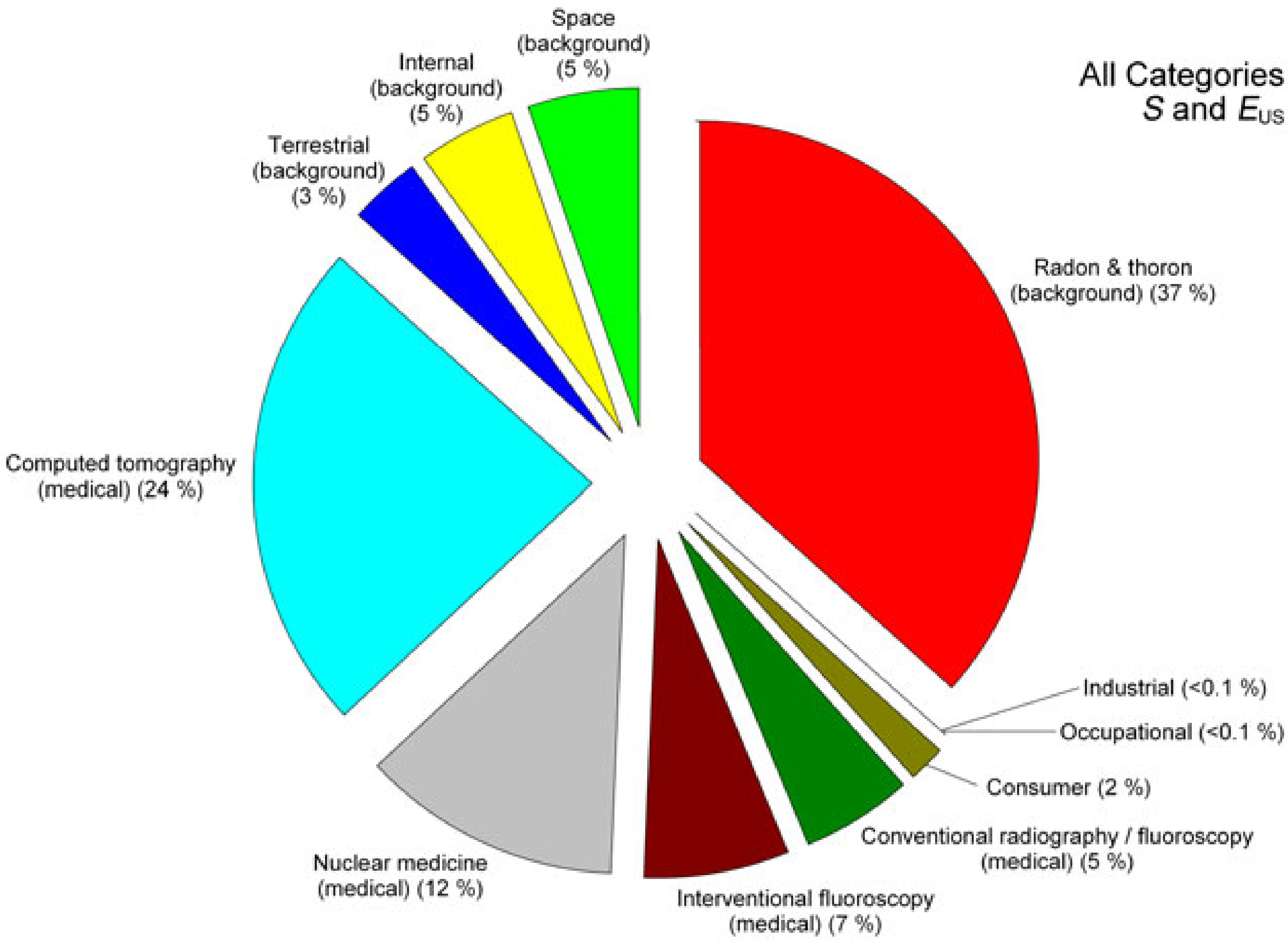
Group characteristics: all adults

Occupational Exposure



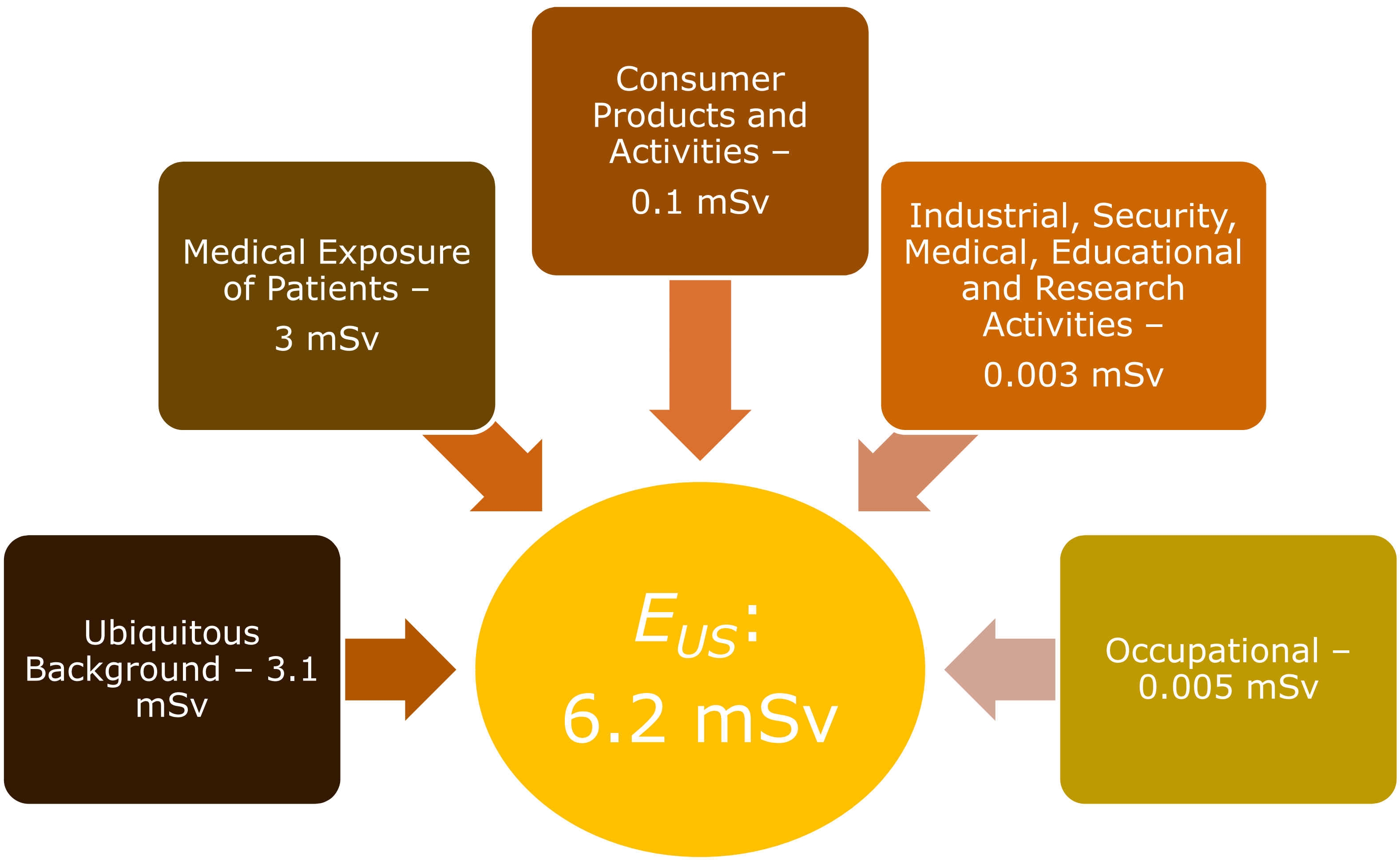
Percent contribution of various sources to *S* for occupational exposure (1,400 person-Sv) for 2006. (NCRP Report 160, pg. 205)

Summary – NCRP Report 160



Percent contribution of various sources of exposure to the total collective effective dose (1,870,000 person-Sv) and the total effective dose per individual in the U.S. population (6.2 mSv) for 2006. (NCRP Report 160, pg.11)

Summary – NCRP Report 160



UNSCEAR 2008
Annex A

Diagnostic Radiology

Nuclear Medicine

Radiation Therapy

UNSCEAR 2008 Report: Medical Radiation Exposures

Health Care Level	Numbers of physicians
I	At least 1 per 1,000
II	1 for 1,000 to 2,999
III	1 for 3,000 to 10,000
IV	1 for more than 10,000

UNSCEAR 2008 Report:
Diagnostic Radiology and Nuclear Medicine

Table 4. Annual collective effective dose from all diagnostic exposures (including those due to diagnostic medical and dental radiology, and due to diagnostic nuclear medicine procedures)

Health-care level	*Population (millions)*	*Annual collective effective dose (man Sv)*			
		Medical	*Dental*	*Nuclear medicine*	*Total*
I	1 540	2 900 000	9 900	186 000	3 100 000
II	3 153	1 000 000	1 300	16 000	1 000 000
III	1 009	33 000	51	82[a]	33 000
IV	744	24 000	38		24 000
World	6 446	4 000 000	11 000	202 000	4 200 000

[a] Refers to health-care levels III-IV.

UNSCEAR 2008 Report: Radiation Therapy

Table 3. Estimated annual number of radiation therapy treatments[a] in the world (1997–2007)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Population (millions)*	*Annual number of teletherapy treatments*		*Annual number of brachytherapy treatments[b]*		*Annual number of all radiotherapy treatments*	
		Millions	*Per 1 000 population*	*Millions*	*Per 1 000 population*	*Millions*	*Per 1 000 population*
I	1 540	3.5	2.2	0.18	0.12	3.6	2.4
II	3 153	1.2	0.4	0.20	0.06	1.4	0.4
III	1 009	0.06	0.06	(<0.05)[c]	(<0.01)[c]	0.1	0.06
IV	744	(0.03)[c]	(<0.01)[c]	(<0.01)[c]	(<0.005)[c]	(0.03)[c]	(0.01)[c]
World[d]	6 446	4.7	0.73	0.4	0.07	5.1	0.8

a Complete courses of treatment.
b Excluding treatments with radiopharmaceuticals.
c Assumed value in the absence of data.
d Global data include several countries not represented by levels I–IV.

UNSCEAR 2008 Report: Summary

Table 7. Trends in the global use of radiation for diagnosis: diagnostic medical radiological examinations
From UNSCEAR Global Surveys of Medical Radiation Usage and Exposures

Survey	*Annual number of examinations (millions)*	*Annual frequency (per 1 000 population)*	*Annual collective effective dose (1 000 man Sv)*	*Annual per caput dose (mSv)*
1988 [U7]	1 380	280	1 800	0.35
1993 [U6]	1 600	300	1 600	0.3
2000 [U3]	1 910	330	2 300	0.4
2008	3 143	488	4 000	0.62

UNSCEAR 2008 Report: Summary

Table 6. Global annual total collective effective dose

Source	*Annual collective effective dose (man Sv)*	*Contribution (%)*
Natural background	16 000 000	79
Diagnostic medical radiology	4 000 000	20
Diagnostic dental radiology	11 000	<0.1
Nuclear medicine	202 000	1.0
Fallout	32 000	<0.1
Total	20 200 000	100

UNSCEAR 2008 Report: Summary

Table 5. Global annual per caput effective dose

Source	*Annual per caput effective dose (mSv)*	*Contribution (%)*
Natural background	2.4	79
Diagnostic medical radiology	0.62	20
Diagnostic dental radiology	0.001 8	<0.1
Nuclear medicine	0.031	1.1
Fallout	0.005	<0.2
Total	3.1	100

UNSCEAR 2008
Annex B

Public Exposure

Natural Sources

Enhanced Sources

Man-made for Peaceful Purposes

Man-made for Military Purposes

Occupational Radiation Exposure

Natural Sources

Man-made for Peaceful Purposes

Man-made for Military Purposes

UNSCEAR 2008 – Public / Natural

Table 12. Public exposure to natural radiation

Source of exposure		*Annual effective dose (mSv)*	
		Average	*Typical range*
Cosmic radiation	Directly ionizing and photon component	0.28	
	Neutron component	0.10	
	Cosmogenic radionuclides	0.01	
	Total cosmic and cosmogenic	0.39	0.3–1.0[a]
External terrestrial radiation	Outdoors	0.07	
	Indoors	0.41	
	Total external terrestrial radiation	0.48	0.3–1.0[b]
Inhalation	Uranium and thorium series	0.006	
	Radon (^{222}Rn)	1.15	
	Thoron (^{220}Rn)	0.1	
	Total inhalation exposure	1.26	0.2–10[c]
Ingestion	^{40}K	0.17	
	Uranium and thorium series	0.12	
	Total ingestion exposure	0.29	0.2–1.0[d]
Total		2.4	1.0–13

[a] Range from sea level to high ground elevation.
[b] Depending on radionuclide composition of soil and building material.
[c] Depending on indoor accumulation of radon gas.
[d] Depending on radionuclide composition of foods and drinking water.

UNSCEAR 2008 – Public / Enhanced

- Metal mining and smelting
- Phosphate industry
- Coal mining and power production from coal
- Oil and gas drilling
- Rare earth and titanium oxide industries
- Zirconium and ceramics industries
- Applications of radium and thorium

UNSCEAR 2008 – Public / Man-made for Peaceful Purpose

Nuclear power production

- Uranium mining and milling
- Uranium enrichment and fuel fabrication
- Nuclear power reactors
- Fuel reprocessing
- Globally dispersed radionuclides
- Solid waste disposal

UNSCEAR 2008 – Public / Man-made for Peaceful Purpose

- Transportation of nuclear and radioactive material
  - Land
  - Sea
  - Air
- Other
  - Production of radioisotopes
  - Research reactors
  - Consumer products

UNSCEAR 2008 – Public / Man-made for Peaceful Purpose

Table 31. Summary of annual per caput doses due to peaceful uses of atomic energy (μSv)

Local component		
Nuclear fuel cycle and energy generation	Mining and milling	25
	Fuel fabrication	0.2
	Reactor operation	0.1
	Reprocessing	2
Other uses	Transport of radioactive waste	<0.1
	By-products	0.2
Regional component		
Nuclear fuel cycle and energy generation	Fuel fabrication	<0.01
	Reactor operation	<0.01
	Reprocessing	0.02
Solid waste disposal and global component		
Nuclear fuel cycle and energy generation	Globally dispersed radionuclides	0.2
Other uses	Disposal of radioactive waste	<0.01

UNSCEAR 2008 – Public / Man-made for Military Purpose

- Nuclear Tests
  - Global Fallout
  - Underground Tests
  - Nuclear weapons production
- Residues in the environment
  - Nuclear test sites
  - Sites contaminated by non-nuclear tests

UNSCEAR 2008 – Occupational / Natural

- Cosmic ray exposures of aircrew and space crew
- Exposures in extractive and processing industries
- Gas and oil extraction
- Radon exposure in workplaces other than mines

UNSCEAR 2008 – Occupational / Natural

Table 57. Estimated worldwide levels of annual exposure due to natural sources of radiation for the period 1995–2002
Data from the UNSCEAR Global Survey of Occupational Radiation Exposures and the literature

Workplace	*Monitored workers (10^3)*	*Annual collective effective dose (man Sv)*	*Average annual effective dose (mSv)*
Coal mining	6 900	16 560	2.4
Other mining (excluding uranium mining)	4 600	13 800	3.0
Workplaces other than mines	1 250	6 000	4.8
Aircrew	300	900	3.0
Total	13 050	37 260	2.9

UNSCEAR 2008 – Occupational / Man-made for Peaceful Purpose

- Nuclear power production
- Medical uses of radiation
- Industrial uses of radiation
- Miscellaneous

UNSCEAR 2008 – Summary on Occupational

Table 91. Global occupational exposures due to the nuclear fuel cycle and natural sources of radiation

Practice	*Monitored workers (10^3)*	*Average annual collective effective dose (man Sv)*	*Average annual effective dose to monitored workers (mSv)*
Nuclear fuel cycle			
1995–1999			
Mining	22	85	3.9
Milling	3	4	1.6
Enrichment	17	1	0.1
Fuel fabrication	22	30	1.4
Reactor operation	448	779	1.5
Reprocessing	59	61	1.1
Research	96	37	0.4
Total	670	1 000	1.4
2000–2002			
Mining	12	22	1.9
Milling	3	3	1.1
Enrichment	18	2	0.1
Fuel fabrication	20	28	1.6
Reactor operation	437	600	1.0
Reprocessing	76	68	0.9
Research	90	36	0.4
Total	660	800	1.0
Natural sources of radiation			
1995–1999 and 2000–2002			
Coal mining	6 900	16 560	2.4
Other mining	4 600	13 800	3.0
Workplaces other than mines	1 250	6 000	4.8
Aircrew	300	900	3.0
Total	13 050	37 260	2.9

UNSCEAR 2008 – Summary on Occupational

Table 92. Global occupational exposures associated with man-made and natural sources of radiation

Source of exposure	*1975–1979*	*1980–1984*	*1985–1989*	*1990–1994*	*1995–1999*	*2000–2002*
Number of monitored workers (10^3)						
Natural radiation				6 500	13 050	13 050
Nuclear fuel cycle	560	800	888	800	670	660
Medical uses	1 280	1 890	2 220	2 320	7 440	7 440
Industrial uses	530	690	560	700	790	869
Military activities	310	350	400	420	378	331
Miscellaneous	140	180	160	360	476	565
Total (man-made)	2 820	3 910	4 228	4 600	9 754	9 865
Total	2 820	3 910	4 228	11 100	22 804	22 915
Annual collective effective dose (man Sv)						
Natural radiation				11 700	37 260	37 260
Nuclear fuel cycle	2 300	3 000	2 500	1 400	1 000	800
Medical uses	1 000	1 140	1 030	760	3 540	3 540
Industrial uses	870	940	510	360	315	289
Military activities	420	250	250	100	52	45
Miscellaneous	70	40	20	40	53	56
Total (man-made)	4 660	5 370	4 310	2 660	4 960	4 730
Total	4 660	5 370	4 310	14 360	42 220	41 990
Average annual effective dose (mSv)						
Natural radiation				1.8	2.9	2.9
Nuclear fuel cycle	4.4	3.7	2.6	1.8	1.4	1.0
Medical uses	0.8	0.6	0.5	0.3	0.5	0.5
Industrial uses	1.6	1.4	0.9	0.5	0.4	0.3
Military activities	1.3	0.7	0.7	0.2	0.1	0.1
Miscellaneous	0.5	0.3	0.2	0.1	0.1	0.1
Total (man-made)	1.7	1.3	1.0	0.6	0.5	0.4
Total	1.7	1.3	1.0	0.8	0.9	0.8

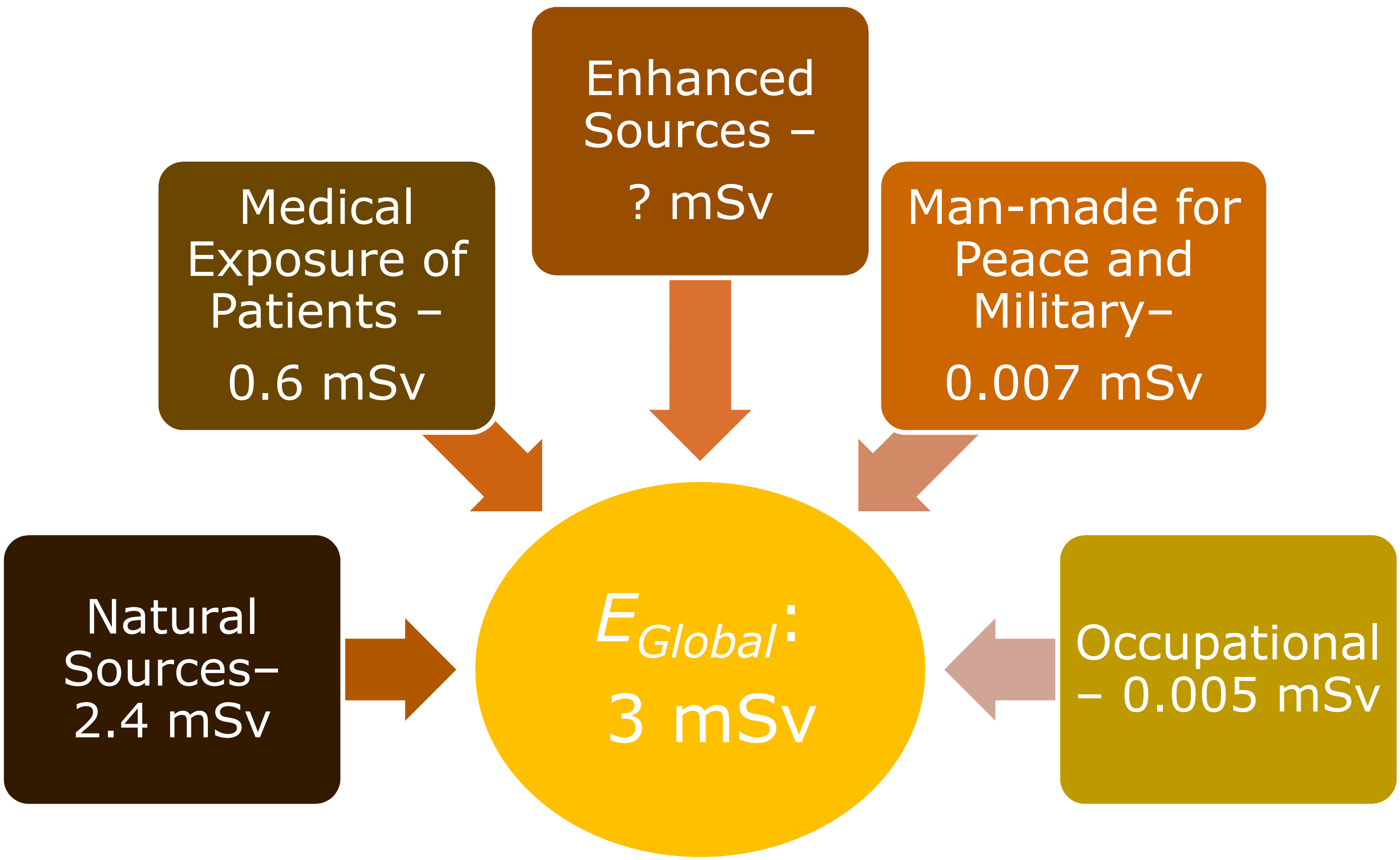
Summary – UNSCEAR Report 2008

Table 1. Annual average doses and ranges of individual doses of ionizing radiation by source
(Millisieverts[a])

Source or mode	*Annual average dose (worldwide)*	*Typical range of individual doses*	*Comments*
Natural sources of exposure			
Inhalation (radon gas)	1.26	0.2–10	The dose is much higher in some dwellings.
External terrestrial	0.48	0.3–1	The dose is higher in some locations.
Ingestion	0.29	0.2–1	
Cosmic radiation	0.39	0.3–1	The dose increases with altitude.
Total natural	**2.4**	**1–13**	**Sizeable population groups receive 10-20 millisieverts (mSv).**
Artificial sources of exposure			
Medical diagnosis (not therapy)	0.6	0-several tens	The averages for different levels of health care range from 0.03 to 2.0 mSv; averages for some countries are higher than that due to natural sources; individual doses depend on specific examinations.
Atmospheric nuclear testing	0.005	Some higher doses around test sites still occur.	The average has fallen from a peak of 0.11 mSv in 1963.
Occupational exposure	0.005	~0–20	The average dose to all workers is 0.7 mSv. Most of the average dose and most high exposures are due to natural radiation (specifically radon in mines).
Chernobyl accident	0.002[b]	In 1986, the average dose to more than 300,000 recovery workers was nearly 150 mSv; and more than 350,000 other individuals received doses greater than 10 mSv.	The average in the northern hemisphere has decreased from a maximum of 0.04 mSv in 1986. Thyroid doses were much higher.
Nuclear fuel cycle (public exposure)	0.000 2[b]	Doses are up to 0.02 mSv for critical groups at 1 km from some nuclear reactor sites.	
Total artificial	**0.6**	**From essentially zero to several tens**	**Individual doses depend primarily on medical treatment, occupational exposure and proximity to test or accident sites.**

[a] Unit of measurement of effective dose.
[b] Globally dispersed radionuclides. The value for the nuclear fuel cycle represents the maximum per caput annual dose to the public in the future, assuming the practice continues for 100 years, and derives mainly from globally dispersed, long-lived radionuclides released during reprocessing of nuclear fuel and nuclear power plant operation.

Summary – UNSCEAR Report 2008



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