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Radiation MADNESS!

Supplementary Material for CFB3333/PHY3333

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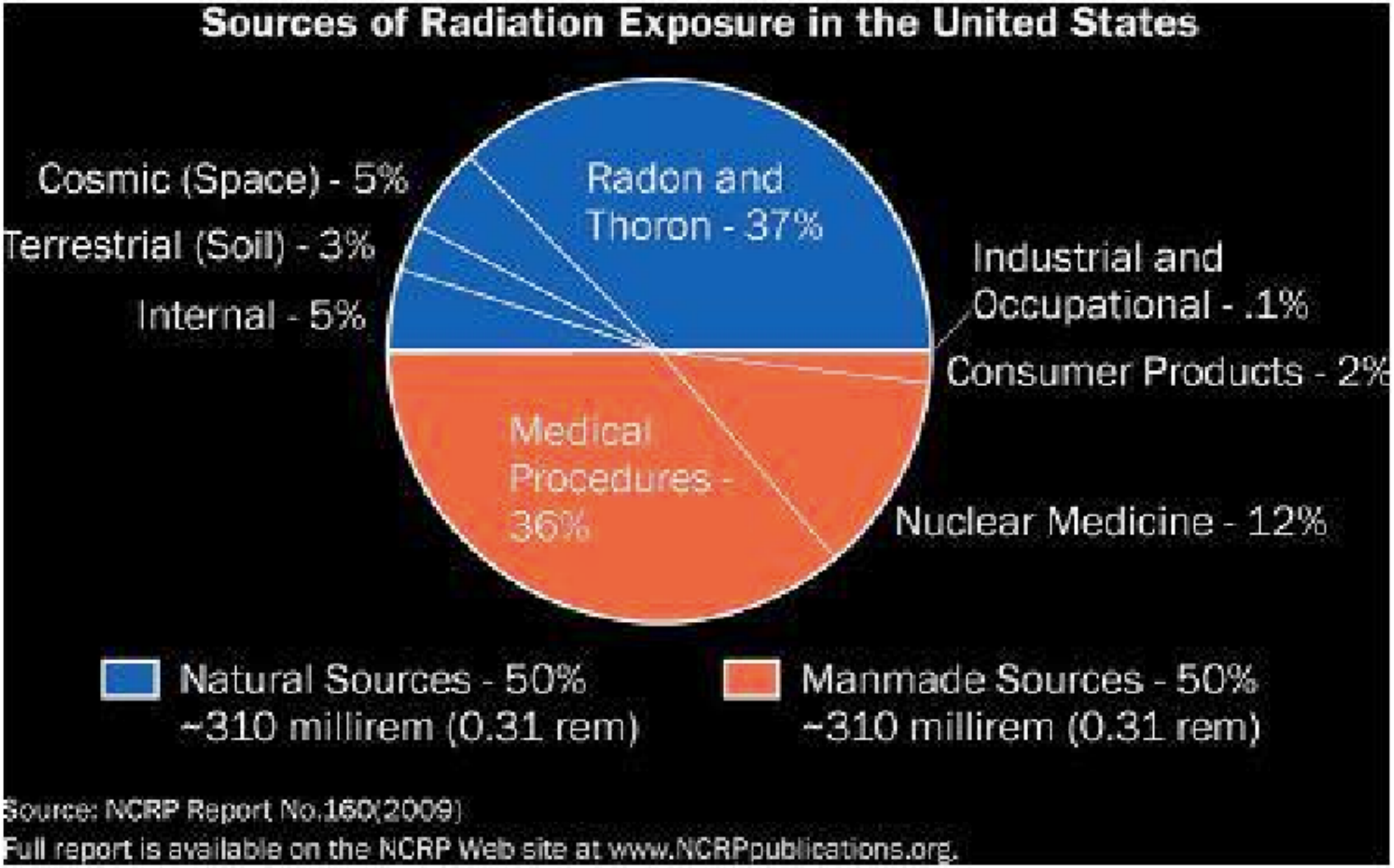
HAVE YOU EVER BEEN EXPOSED TO RADIATION?

(raise your hand if you have NEVER been exposed to radiation)

WHAT IS RADIATION?

Radiation - Defined

- What is radiation?
  - the transmission of energy from one point in space to another (implies a lack of physical contact between the two bodies – sender and receiver)
  - this can be done by electromagnetic waves or by particles (e.g. electrons, atomic nuclei, protons, neutrons, . . .)
  - "radiation" is also a word applied to describe the transmitting particle or wave
    - e.g. "beta radiation" is the transport of energy by an electron from a source to a target
  - Current standard measurement is "sieverts" (Sv) - a dose of 1Sv ALL AT ONCE will make you sick. The degree of sickness or damage from radiation all depends of the duration of time over which a dose is received.



100 millirem = 1 milli-Sievert (mSv). Humans in the U.S. receive about 6.2 mSv of total background radiation in a typical year. The Nuclear Regulatory Commission (NRC) recommends that its licensees allow no more than 1mSv additional exposure from the workplace each year; for those working with radiation, no more than 50 mSv additional per year.

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WHO IS MOST EXPOSED TO RADIATION?

Most Exposed People

- Airline Crews (cosmic ray radiation)
- Industrial Radiography
- Medical radiology and nuclear medicine
- Uranium miners
- Nuclear power plant and nuclear fuel reprocessing plant workers
- Research laboratories (university, government, and private)

A BRIEF HISTORY OF OUR UNDERSTANDING OF RADIATION

Electricity, Magnetism, and Light

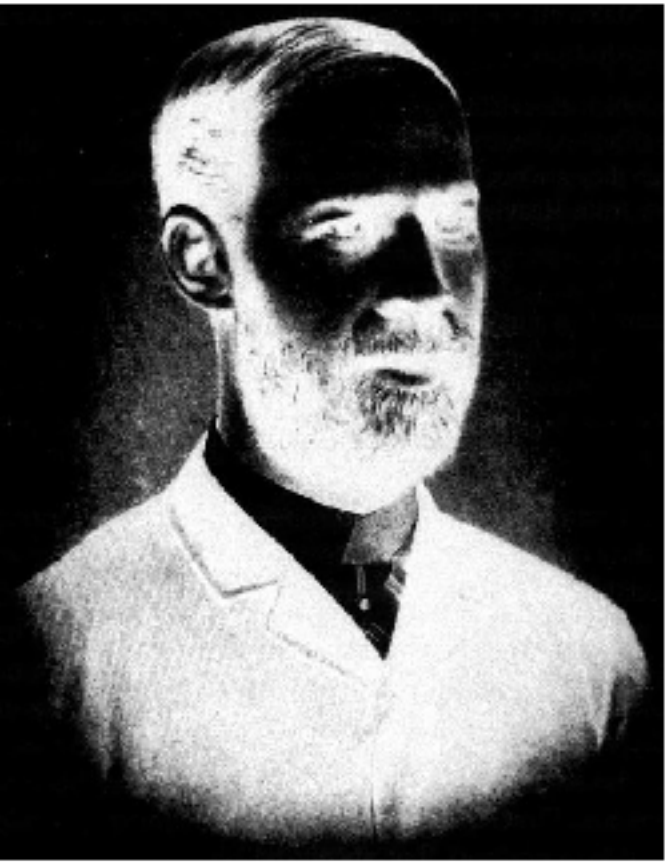
1831-1879

Brilliant scientist working in Britain.

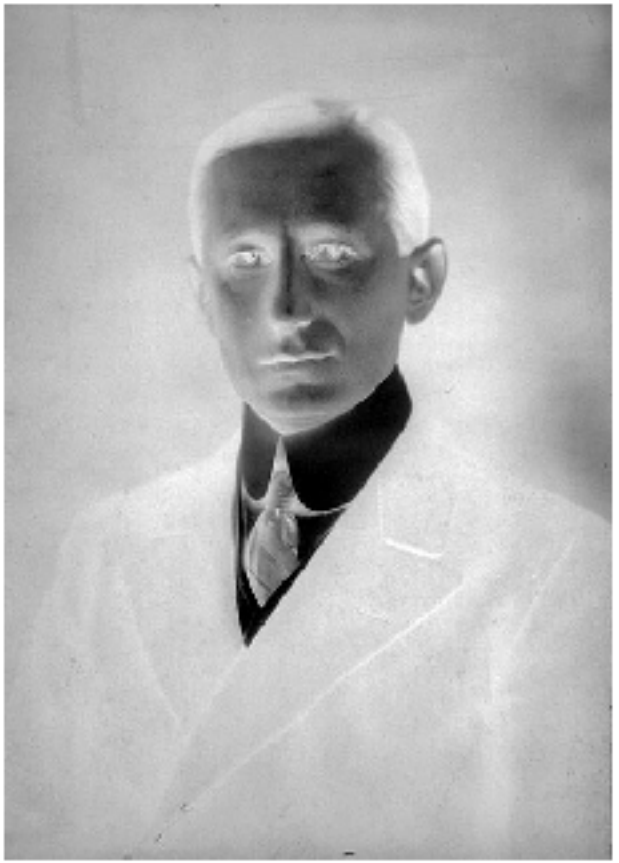
- United electricity and magnetism into a single "force"
- Developed a theory of large numbers of particles
- Made the first true color photograph

Published in 1864 "A Dynamical Theory of the Electromagnetic Field."

Electromagnetic Radiation



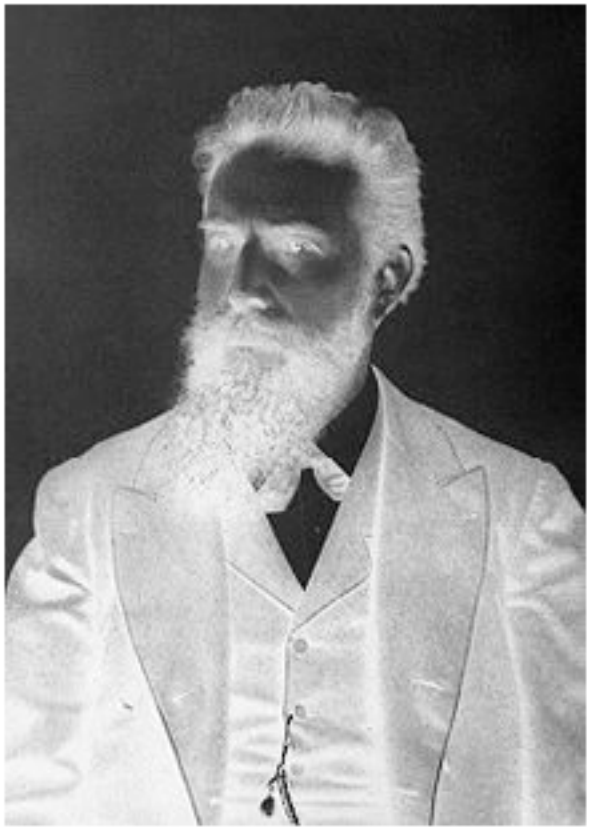
Heinrich Hertz
(1857-1894)
First to satisfactorily demonstrate the existence of electromagnetic waves



Guglielmo Marconi
(1874-1937)
Italian inventor who developed the radio telegraph system (first demonstrated in 1894)

Robert Hyer
(1860-1929)
Physicist, Founder and First President of SMU
First American to communicate using EM waves (1894)

A New Kind of Radiation



William Roentgen
(1845-1923)
Was experimenting with electromagnetic radiation using vacuum tube equipment. Discovered x-rays being emitted from the equipment.

Roentgen's first medical x-ray image.

Henri Bequerel
(1852-1908)
Discovered that uranium salts emitted x-rays without any external input of energy.

A New Kind of Radiation

Ernest Rutherford
(1871-1937)
Discovered alpha, beta, and gamma radiation. He also recognized that natural radioactivity answered an old puzzle raised by Lord Kelvin: the age of the Earth.

Marie Curie
(1867-1934)
Discovered that only certain elements are able to emit radiation, discovered radium and polonium, and coined the term "radioactivity".

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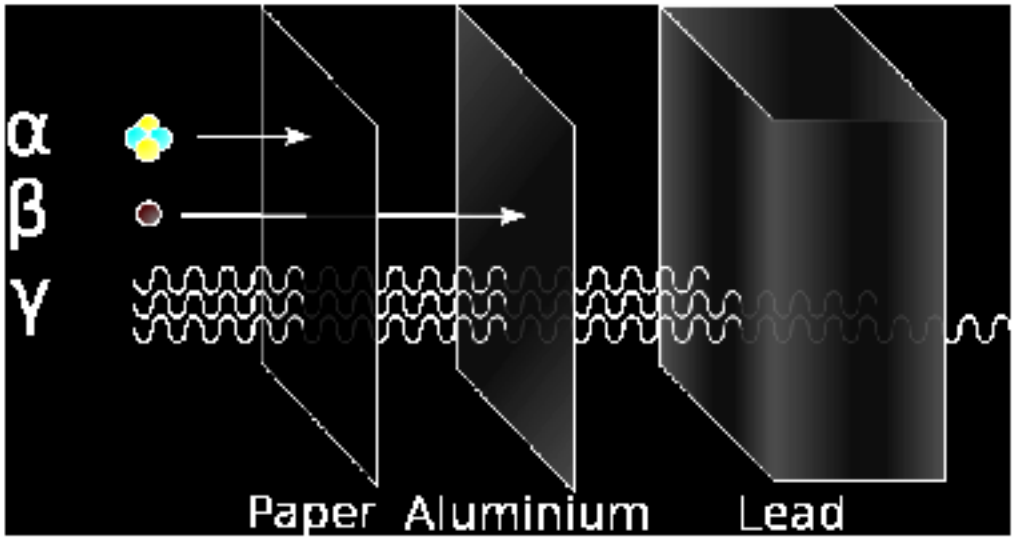
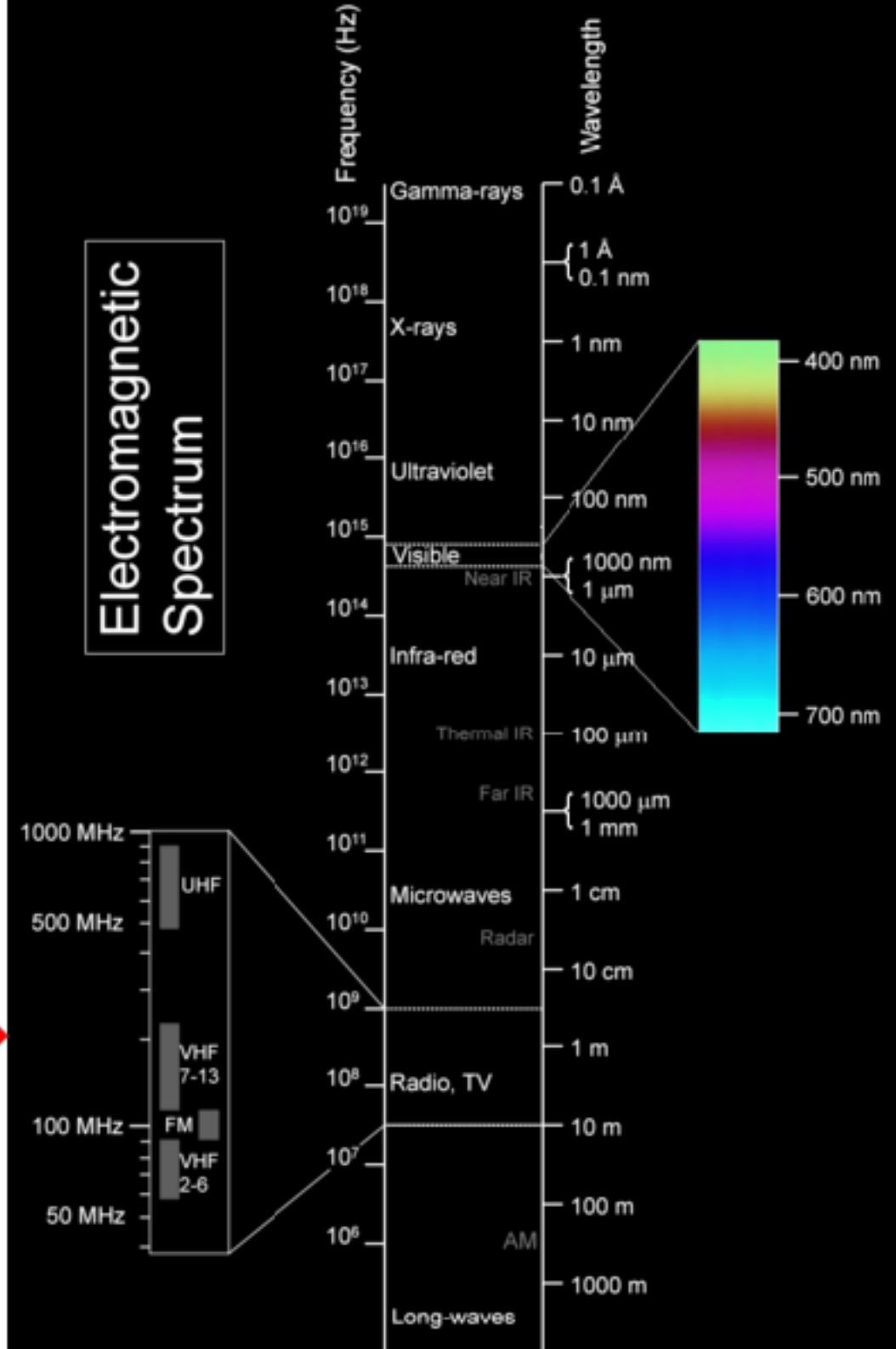


Particle Radiation

Electromagnetic Radiation



Two Kinds of Radiation: Ionizing and Non-Ionizing

- Ionizing Radiation
  - has enough energy to remove electrons from atoms ("ionization") - atoms are quantum systems, and if you don't put in enough energy you CANNOT remove an electron.
- Non-ionizing Radiation
  - cannot remove an electron from an atom
  - might be capable of causing an atom to vibrate, rotate, or to briefly excite an electron to a higher atomic orbit; but it cannot change the properties of the atom.

Quantum Physics and Radiation

- Quantum Physics relates the properties of particles:
  - Energy
  - Momentum
- to those of waves (like radiation)
  - wavelength
  - frequency
- Quantum physics unites the wave and particle views of nature and lets us easily relate the wavelength of radiation directly to its energy

Getting the Energy

- If you know the frequency of radiation, f, you can calculate the energy transmitted by the electromagnetic radiation, E, as follows:

$$E = h\,f$$

where h = 4.136 x 10^{-15} eV•s (eV = "electron Volt", the energy gained by a single electron when accelerated through a 1V potential difference)

Can Mobile Phones Cause Cancer?

- What causes cancer?
  - genetic mutations in cells lead to runaway growth of the cells, unchecked by natural mechanisms for disposing of such problem cells – this is the essence of cancer (tumors, etc.)
  - what causes genetic mutations? Chemical bonds must be broken during DNA replication, which leads to mutations in genes during copying – specifically, *irreparable* damage
    - mutations happen all the time; it's the bad, runaway ones that can lead to cancers
- How much energy is needed to break chemical bonds?
  - the weakest bonds are hydrogen bonds, and can require as little as a few eV to be broken . . . requires IONIZING radiation
  - so . . . how does this compare to mobile phone radiation?

Aside:

in quantum physics, more radiation is not the same as more energy from radiation

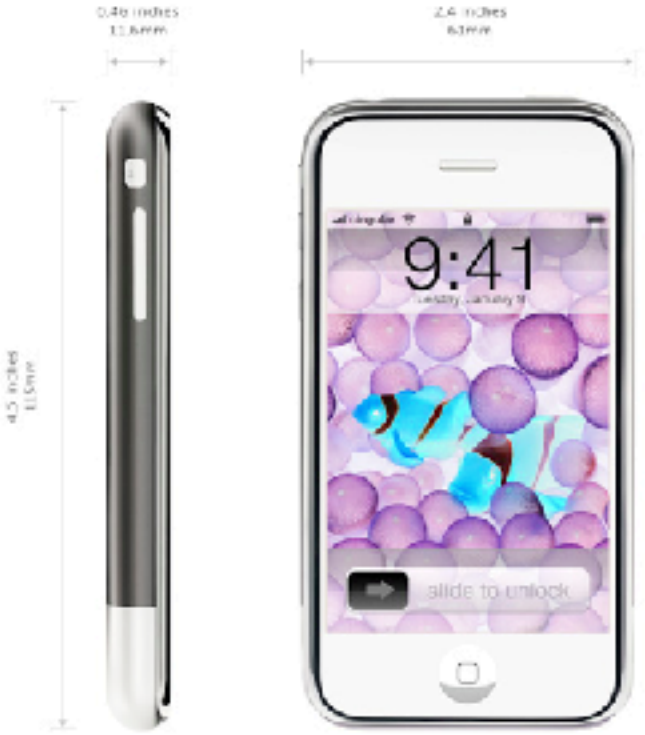
- Demonstrate with the photoelectric effect

So . . . can mobile phones cause cancer?

Mobile phone radiation is restricted by the FCC to a range of bands:

- GSM: 380.2 – 1909.8 MHz

What energy is transported by the electromagnetic waves in this radiation?

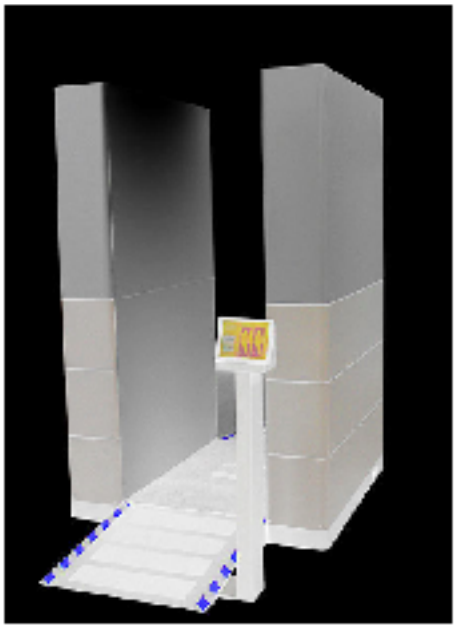


$E = hf = [1.6, 79.0] \times 10^{-5}$ eV

That's 0.000016-0.0000790 eV . . . compared to the ~few eV needed to break the weakest chemical bonds.

Mobile phones cannot cause cancer.

Aside: Airport Full Body Scanners



There are currently two kinds:

- Millimeter-wave: uses non-ioninizing radiation, MICROWAVES. Microwaves are defined as any electromagnetic wave with a wavelength between a millimeter, 0.001m), up to a 300cm (0.3m).

- X-ray backscatter: uses a low dose of x-rays (ionizing radiation). The possible dangers of this is a very active area of biophysics research, but the current evidence INDEPENDENT of the companies that made them is that they are safe IF they are operating within normal design parameters. However, TSA personnel are NOT trained radiation safety officers or engineers, and cannot know if the machine is operating correctly.

But . . . but . . . but . . . microwaves can cook food!

- Microwave energy frequencies:
  - around 2.45 GHz – about 25% higher in frequency (and energy) than the highest-frequency mobile phone radiation.
    - how much energy can be imparted from microwave oven radiation to an atom in your food?
    - $E = hf = 1 \times 10^{-5}$ eV
  - so . . . how does a microwave oven cook food?
    - fats, water, etc. in food posses varying degrees of what are called “electric dipoles” which cause them to respond to electromagnetic waves by moving around. This causes heating when sufficient power is present in the wave.

Power!

- So is your mobile phone cooking your brain?
  - Microwave Oven power: typically 700W (a Watt is a unit of energy transmitted per second)
  - Mobile phone power: typically a few watts – a few hundred times smaller than a microwave oven
- Does cooking (thermal heating) cause cancer?
  - You get more heating in your head from sitting outside on a hot day.
  - The blood in the body effectively moves excess heat away from the brain. You get more heat in your head on a hot day than you do from a mobile phone.

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The Danish Cohort Study

Cellular Telephone Use and Cancer Risk: Update of a Nationwide Danish Cohort

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Abstract

Background: The widespread use of cellular telephones has heightened concerns about possible adverse health effects. The objective of this study was to investigate cancer risk among Danish cellular telephone users who were followed for up to 21 years. *Methods:* This study is an extended follow-up of a large nationwide cohort of 420 095 persons whose first cellular telephone subscription was between 1982 and 1995 and who were followed through 2002 for cancer incidence. Standardized incidence ratios (SIRs) were calculated by dividing the number of observed cancer cases in the cohort by the number expected in the Danish population. *Results:* A total of 14 249 cancers were observed (SIR = 0.95; 95% confidence interval [CI] = 0.93 to 0.97) for men and women combined. Cellular telephone use was not associated with increased risk for brain tumors (SIR = 0.97), acoustic neuromas (SIR = 0.73), salivary gland tumors (SIR = 0.77), eye tumors (SIR = 0.95), or leukemias (SIR = 1.00). Among long-term subscribers of 10 years or more, cellular telephone use was not associated with increased risk for brain tumors (SIR = 0.66, 95% CI = 0.44 to 0.95), and there was no trend with time since first subscription. The risk for smoking-related cancers was decreased among men (SIR = 0.88, 95% CI = 0.86 to 0.91) but increased among women (SIR = 1.11, 95% CI = 1.02 to 1.21). Additional data on income and smoking prevalence, primarily among men, indicated that cellular telephone users who started subscriptions in the mid-1980s appeared to have a higher income and to smoke less than the general population. *Conclusions:* We found no evidence for an association between tumor risk and cellular telephone use among either short-term or long-term users. Moreover, the narrow confidence intervals provide evidence that any large association of risk of cancer and cellular telephone use can be excluded.

The Danish Cohort Study

- Denmark's national health care system allows them to collect and analyze vast amounts of health data
  - health data was linked to mobile phone subscriber data
- The study (2006) included data from over 420,000 individuals spanning 20 years
  - updated in 2011 (http://www.bmj.com/content/343/bmj.d6387)
  - found no evidence for a relationship between various head or nervous system tumors and use of mobile phones over two decades

The INTERPHONE Study

- Published in the International Journal of Epidemiology.
  - "Brain tumour risk in relation to mobile telephone use: results of the INTERPHONE international case–control study." Int. J. Epidemiol. (2010) 39 (3): 675-694.)
  - interview-based case-control study spanning 13 countries, with a common protocol used in each country
  - also found no evidence for a relationship between brain or nervous system tumors

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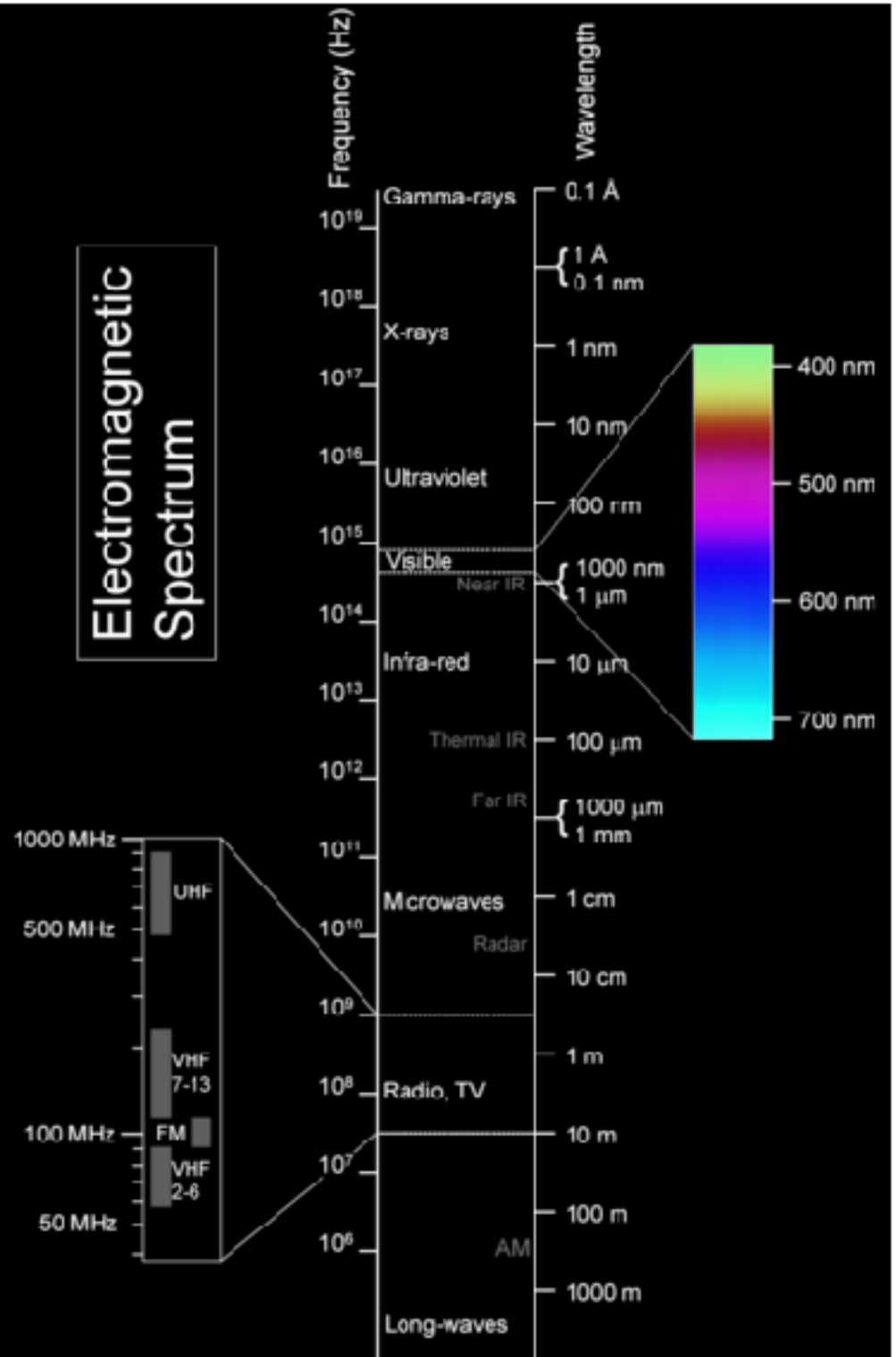


So . . . when does electromagnetic radiation become biologically dangerous?

- When the WAVELENGTH (FREQUENCY) of the radiation becomes comparable to a ~few eV (about 4 eV)
- All the radiation we've talked about so far (microwave) has wavelengths LONGER than visible light (lower frequency, less energy)
- Visible light:
  - red: ~1.8 eV
  - green: ~2.5 eV
  - violet: ~3.2 eV
- Ultraviolet light:
  - UVA: ~3.9 eV
  - UVB: ~4.4 eV

Ultraviolet light is where you want to start putting something between you and the radiation.

Radiation Dose Chart

http://xkcd.com/radiation/

This is a chart of the ionizing radiation dose a person can absorb from various sources. The unit for absorbed dose is "sievert" (Sv), and measures the effect a dose of radiation will have on the cells of the body. One sievert (all at once) will make you sick, and too many will kill you, but we safely absorb small amounts of natural radiation daily. Note: The same number of sieverts absorbed in a shorter time will generally cause more damage, but your cumulative long-term dose stays. Big dose in things like cancer risk.

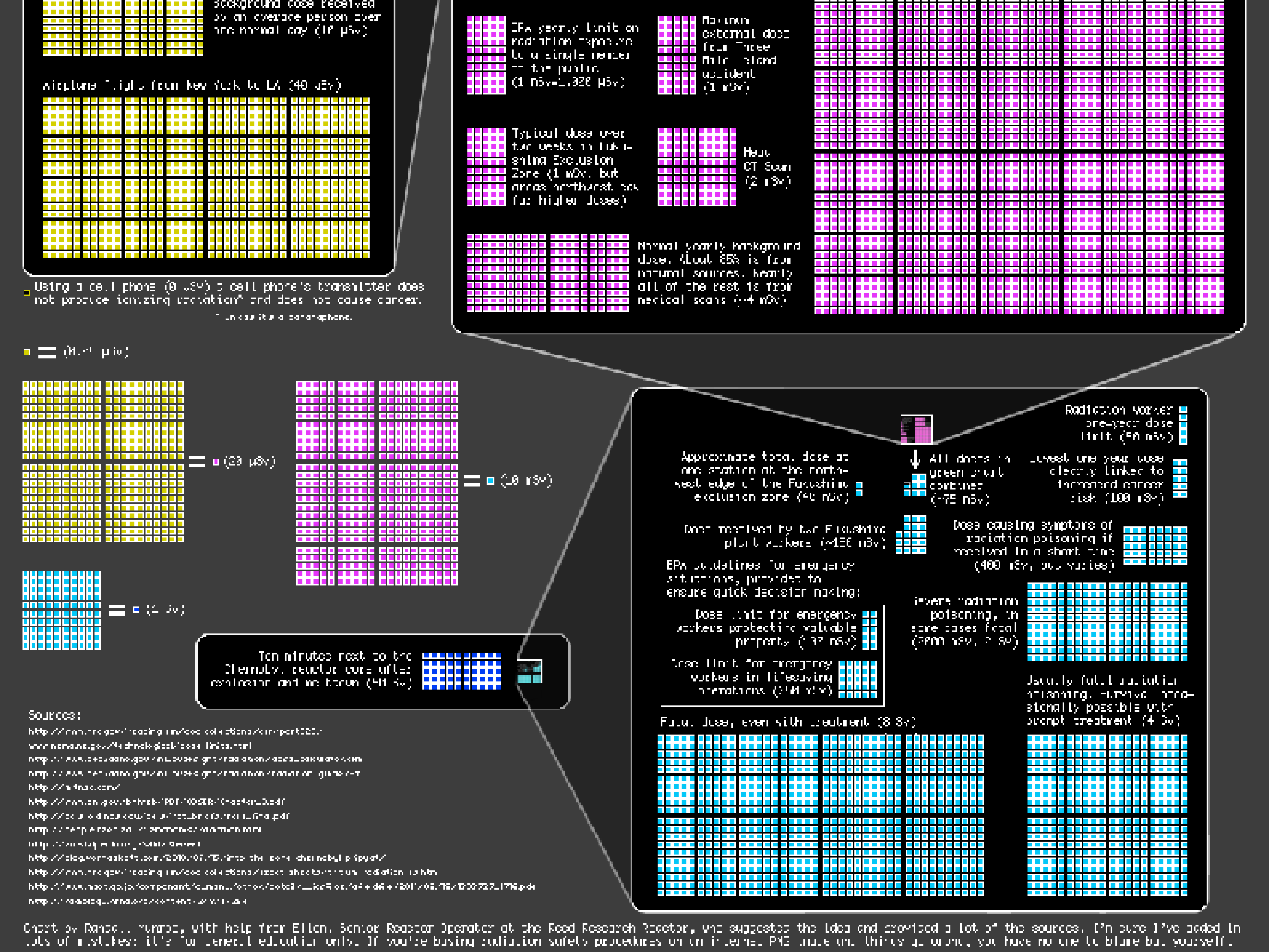
- Sleeping next to someone (0.04 µSv)
- Living within 50 miles of a nuclear power plant for a year (0.009 µSv)
- Eating one banana (0.1 µSv)
- Living within 50 miles of a coal power plant for a year (0.3 µSv)
- Arm x-ray (1 µSv)
- Using a CRT monitor for a year (1 µSv)
- Extra dose from spending one day in an area with higher than average natural background radiation, such as the Colorado plateau (2.5 µSv)
- Dental x-ray (5 µSv)
- Background dose received by an average person over one natural day (10 µSv)
- Airplane flight from New York to LA (40 µSv)
- Using a cell phone (0 µSv)—a cell phone's transmitter does not produce ionizing radiation[*] and thus can cause cancer.

[*] Unless it's a microwave

- = (0.25 µSv)

- Cheek x-ray (20 µSv)
- All the doses in the blue rectangle combined (~99 µSv)
- Extra dose to Tokyo in Arcto following Fukushima accident (40 µSv)
- Living in a stone, brick, or concrete building for a year (70 µSv)
- Average total dose from the three Mile Island accident to someone living within 10 miles (100 µSv)
- Approximate total dose received at Pripyat Town hall over two weeks following accident (170 µSv)
- CT4 pearls release limit for a year for power plant (250 µSv)
- Yearly dose from natural potassium in the body (390 µSv)
- Mammogram (400 µSv)
- EPA yearly limit on evacuation exposure for a single member of the public (1 mSv=1,000 µSv)
- Maximum external dose from three Mile Island accident (1 mSv)
- Typical dose over two weeks in Fukushima Evacuation Zone (1 mSv, but areas northwest are for higher doses)
- Head CT scan (2 mSv)
- Natural yearly background dose. About 1/3 is from natural sources, nearly all of the rest is from medical scans (~1 mSv)
- EPA yearly release limit for a nuclear power plant (1 mSv)
- Dose from spending an hour on the grounds at the Chernobyl plant in 2010 (5 mSv in one spot, but varies wildly)
- Chest CT scan (7 mSv)
- Maximum yearly dose permitted for US radiation workers (50 mSv)

Radiation sources
Exposure dose



Airplane flight from New York to LA (40 μSv)
Using a cell phone (0 μSv): a cell phone's transmitter does not produce ionizing radiation* and does not cause cancer.
EPA yearly limit on radiation exposure to a single person of the public (1 mSv=1,000 μSv)
Maximum external dose from Three Mile Island accident (1 mSv)
Typical dose over two weeks in Fukushima Exclusion Zone (1 mSv, but areas northwest see far higher doses)
Head CT Scan (2 mSv)
Normal yearly background dose. About 85% is from natural sources. Nearly all of the rest is from medical scans (~4 mSv)
Radiation worker one-year dose limit (50 mSv)
Approximate total dose at one station at the northwest edge of the Fukushima exclusion zone (45 mSv)
All doses in green chart combined (~75 mSv)
Lowest one-year dose clearly linked to increased cancer risk (100 mSv)
Dose received by two Fukushima plant workers (~150 mSv)
Dose causing symptoms of radiation poisoning if received in a short time (400 mSv, but varies)
EPA guidelines for emergency situations, provided to ensure quick decision making:
Dose limit for emergency workers protecting valuable property
Dose limit for emergency workers in lifesaving operations
Severe radiation poisoning, in some cases fatal
Fatal dose, even with treatment (8 Sv)
Usually fatal radiation poisoning. Survival occasionally possible with prompt treatment (4 Sv)
Ten minutes next to the Chernobyl reactor core after explosion and meltdown
Sources:
Chart by Randall Munroe, with help from Ellen, Senior Reactor Operator at the Reed Research Reactor

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Health Risk	Est. life expectancy lost
Smoking 20 cigs a day	6 years
Overweight (15%)	2 years
Alcohol (US Ave)	1 year
All Accidents	207 days
All Natural Hazards	7 days
Occupational dose (300 mrem/yr)	15 days
Occupational dose (1 rem/yr)	51 days

You can also use the same approach to looking at risks on the job:

Industry type	Est. life expectancy lost
All Industries	60 days
Agriculture	320 days
Construction	227 days
Mining and quarrying	167 days
Manufacturing	40 days
Occupational dose (300 mrem/yr)	15 days
Occupational dose (1 rem/yr)	51 days

These are estimates taken from the NRC Draft guide DG-8012 and were adapted from B.L Cohen and I.S. Lee, "Catalogue of Risks Extended and Updates", *Health Physics*, Vol. 61, September 1991.

See also: http://www.umich.edu/~radinfo/introduction/risk.htm

Take-away Messages

- Radiation is everywhere. In fact, biological diversity is possible, in part, because of radiation's random mutagenic effects on DNA which can lead to beneficial mutations.
- Non-ionizing radiation can, in large amounts, cause heating or other mechanical effects, but is otherwise completely harmless to us at typical levels
- Irreversible biological damage can only occur in the presence of significant amounts of ionizing radiation (electromagnetic radiation above the violet – UVA, UVB, x-rays, gamma rays; particle radiation can also do this, such as alpha and beta particles, cosmic rays, etc.)

Take-away Messages

- You have little to nothing to fear from everyday radiation. In terms of radiation:
  - Living within 50 miles of a nuclear power plant is safer than eating a banana
  - eating a banana is safer than living within 50 miles of a coal power plant
  - living within 50 miles of a coal power plant is safer than getting basic medical x-rays
  - getting basic medical x-rays is safer than taking a single long plane flight
  - taking a single long plane flight is safer than living in the Fuskushima exclusion zone in the two weeks after the reactor core meltdown
  - living in the Fuskushima exclusion zone in those two weeks is safer than intense medical imaging procedures (CT scans)
  - Intense medical imaging procedures is safer than being a trained radiation worker receiving their maximum occupational dose in a year
  - Being a trained radiation worker receiving their maximum occupational dose in a year is safer than adding up all the other doses with this one in a single year.
  - Adding up all the previous doses in a year is safer than the lowest single radiation dose in a year known to cause cancer.
  - Mobile phones aren't even on the list. Unless it's a banana phone.