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Radiation MADNESS!
Part 1: Understanding Radiation

Supplementary Material for
CFB3333/PHY3333/KNW2333

Professors John Cotton, Randy Scalise,
and Stephen Sekula

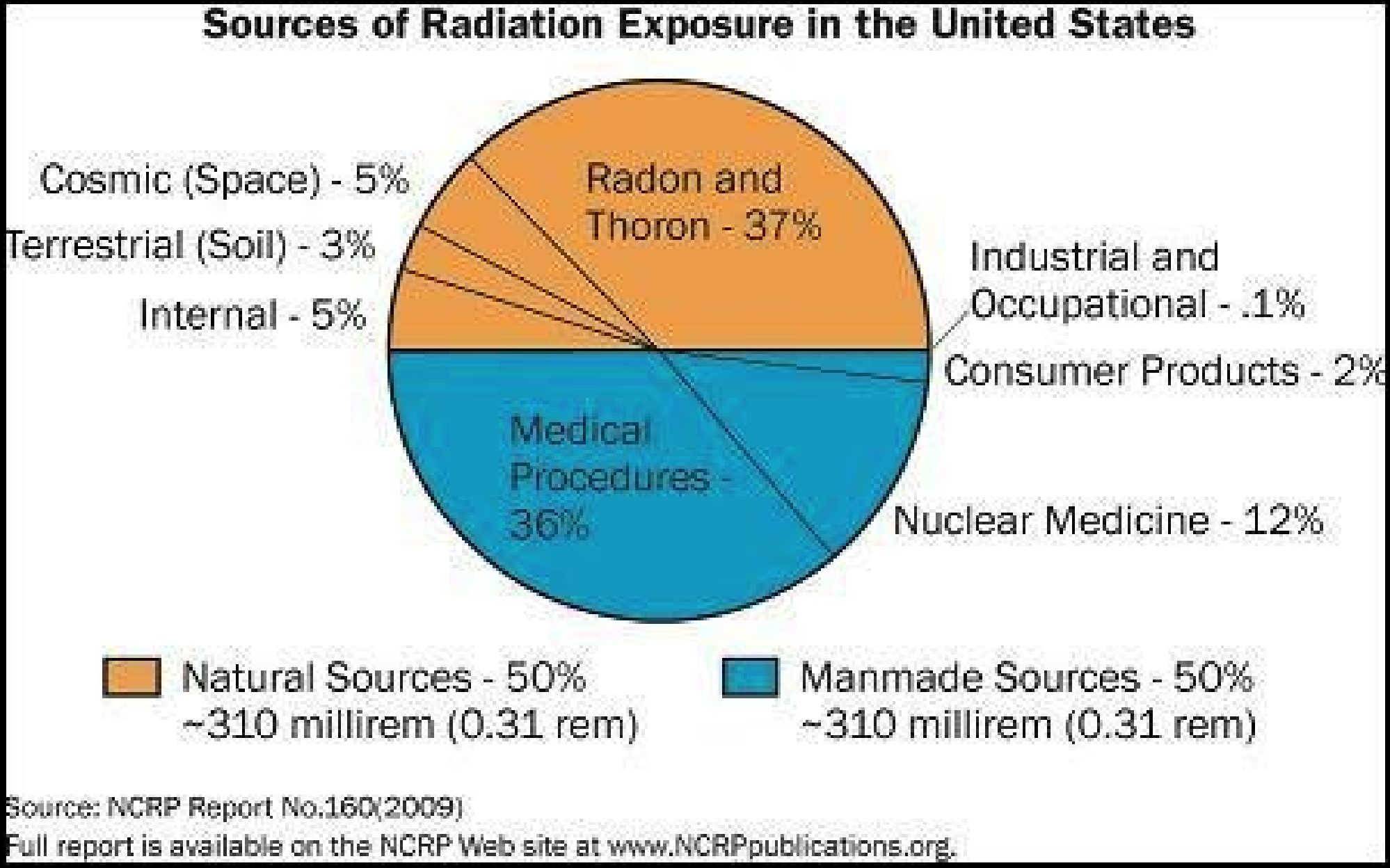
HAVE YOU EVER BEEN EXPOSED TO RADIATION?

(better yet: 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.

Some Numbers

- You are radioactive! (sort of)
  - just sitting next to someone for a few hours is a dose of radiation equivalent to about 0.05 micro-Sv (0.0000005 Sv)
- Eating a banana gives you a “dose” of radiation
  - about 0.1 micro-Sv
  - known as a “Banana Equivalent Dose” or BED
    - http://en.wikipedia.org/wiki/Banana_equivalent_dose
- So, sitting next to someone for a few hours is worth 0.5 BEDs.

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WHO IS MOST EXPOSED TO RADIATION?

(Class: any guesses?)

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)

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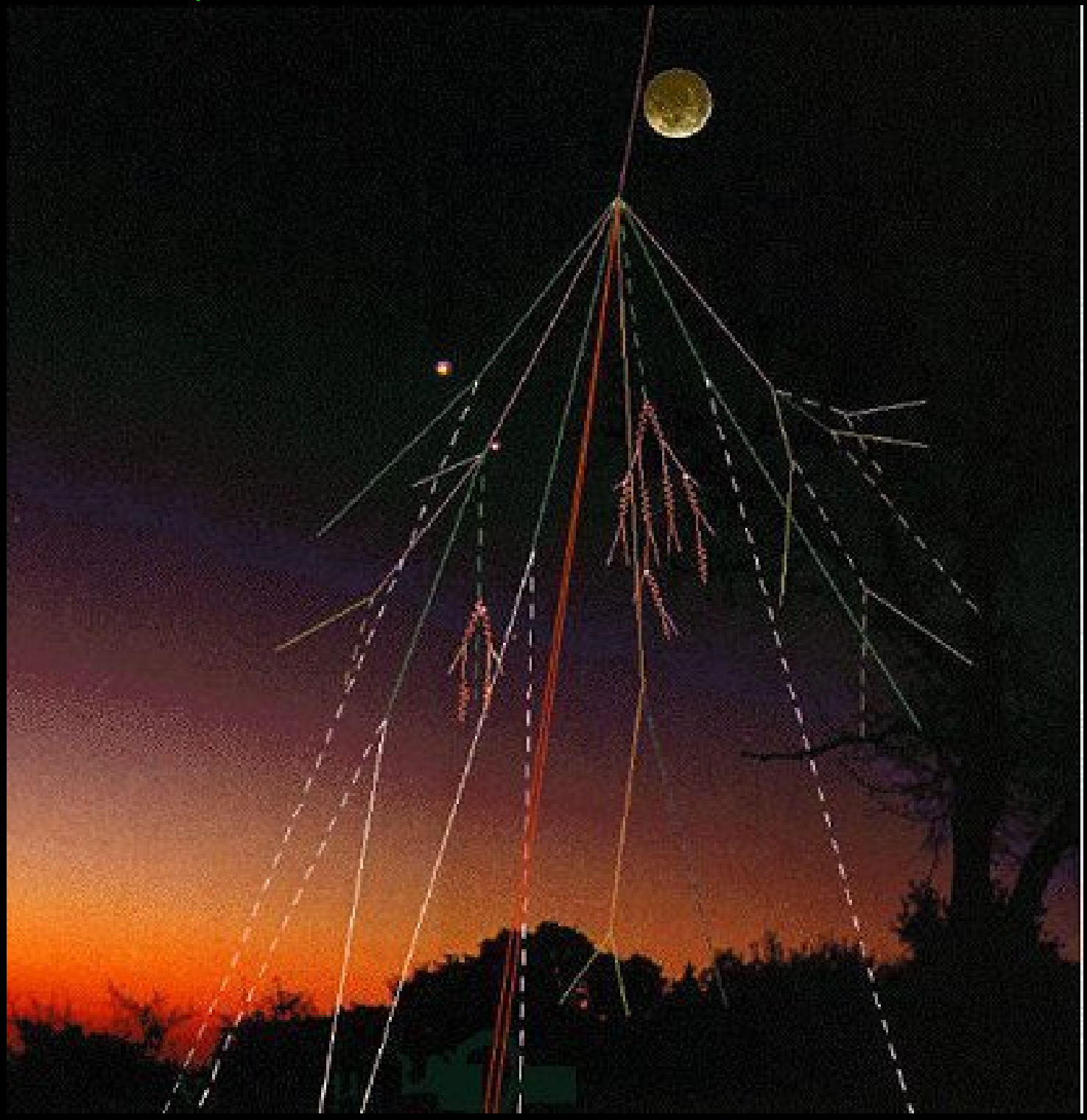

A BRIEF HISTORY OF OUR UNDERSTANDING OF RADIATION

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."

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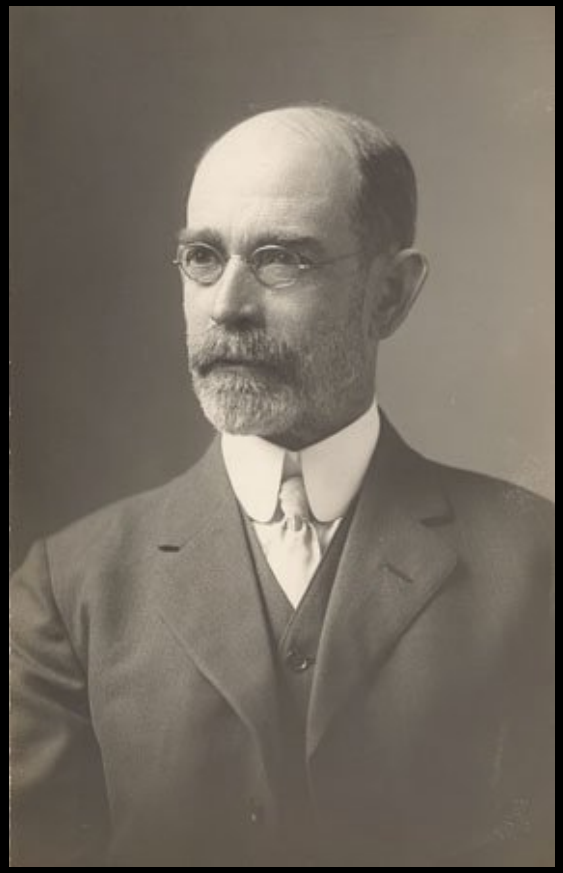
Electromagnetic Radiation

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)

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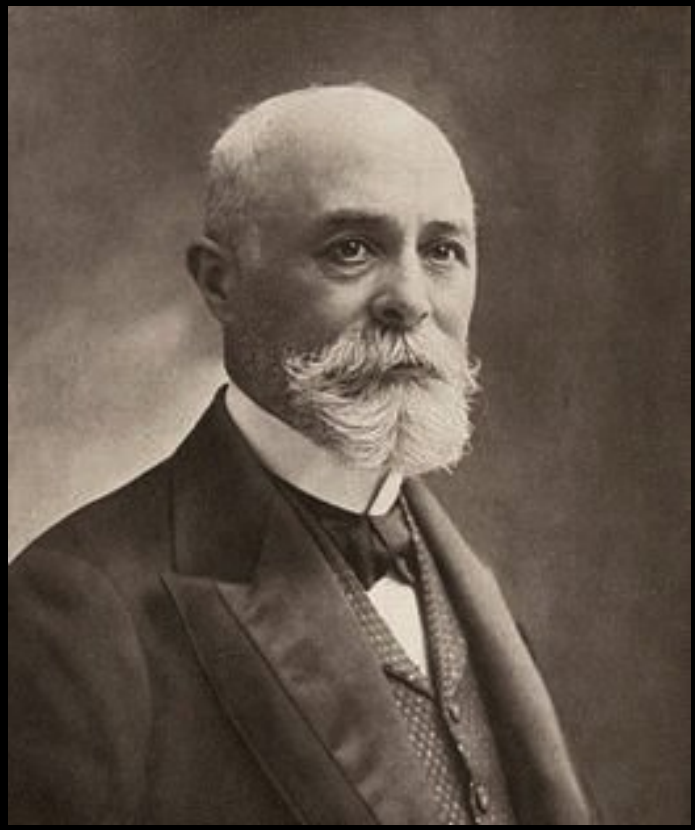
A New Kind of Radiation

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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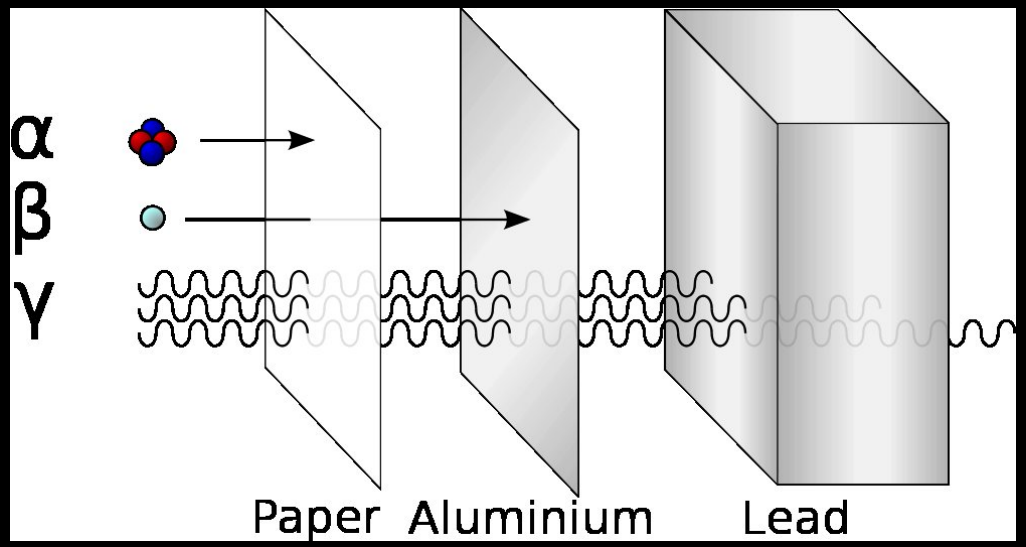
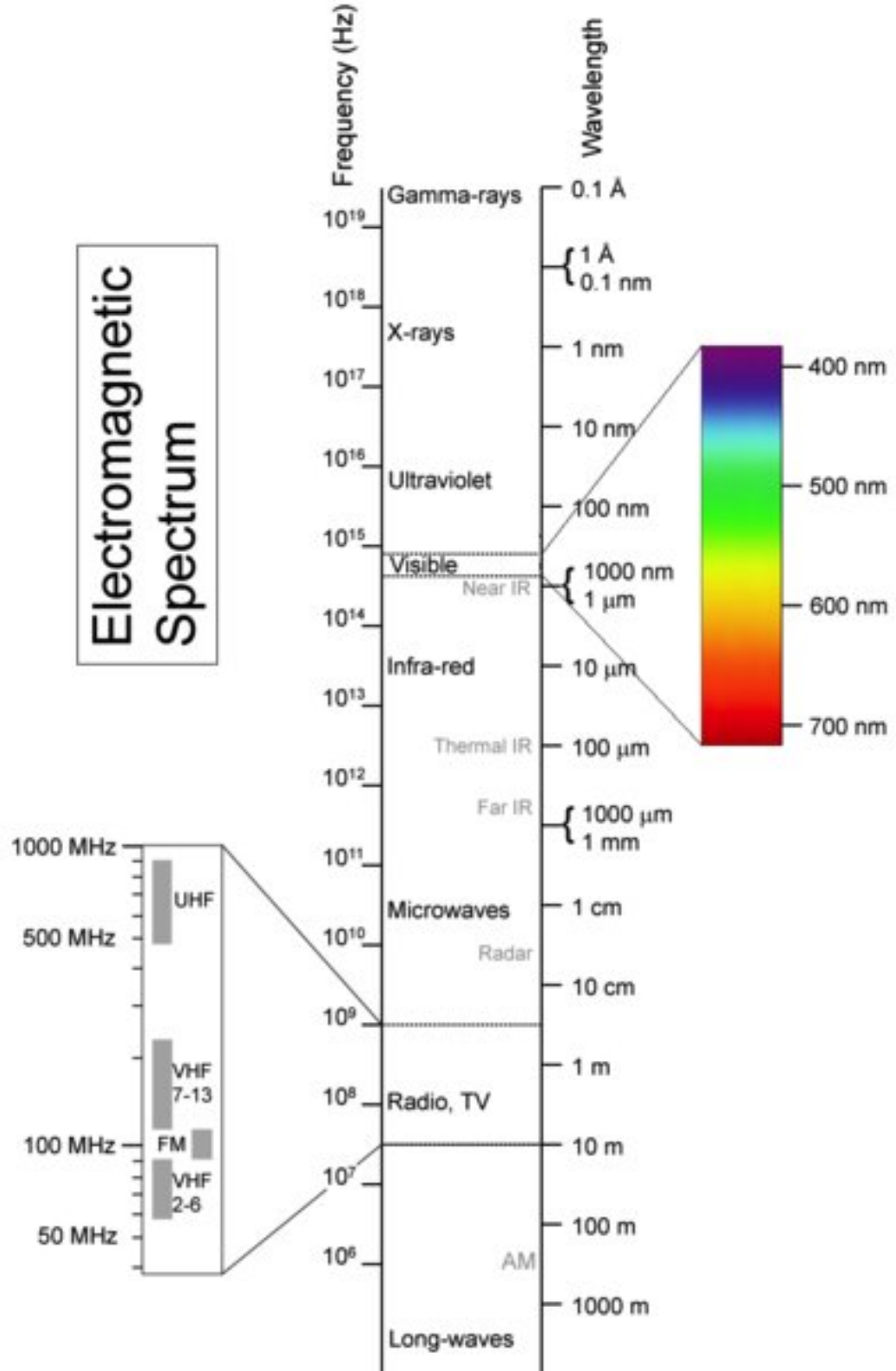


Particle Radiation

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.

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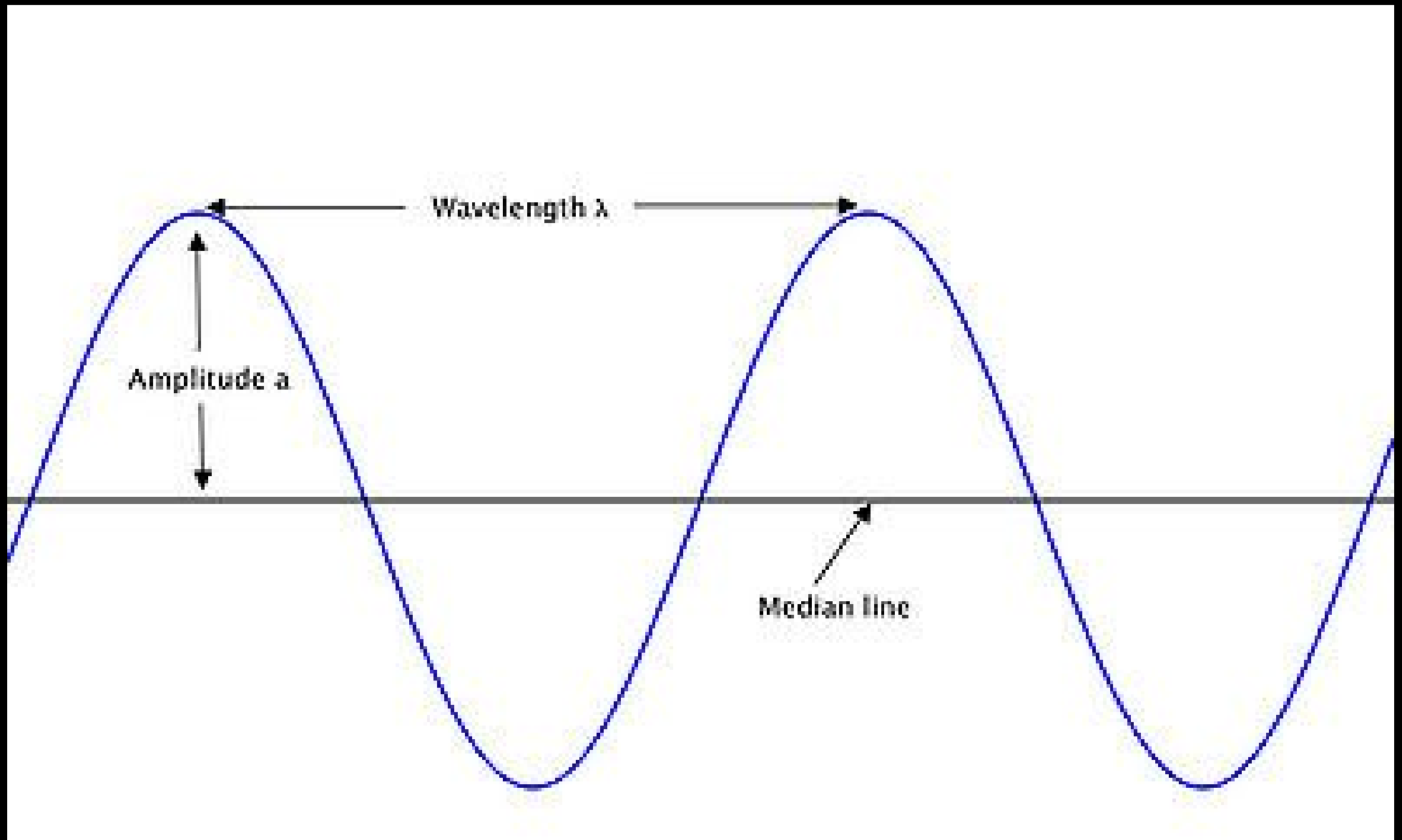

The “frequency” tells you how often the same location on a wave passes a common point (in units of 1/s, or “per second” . . . also called “Hertz”)

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

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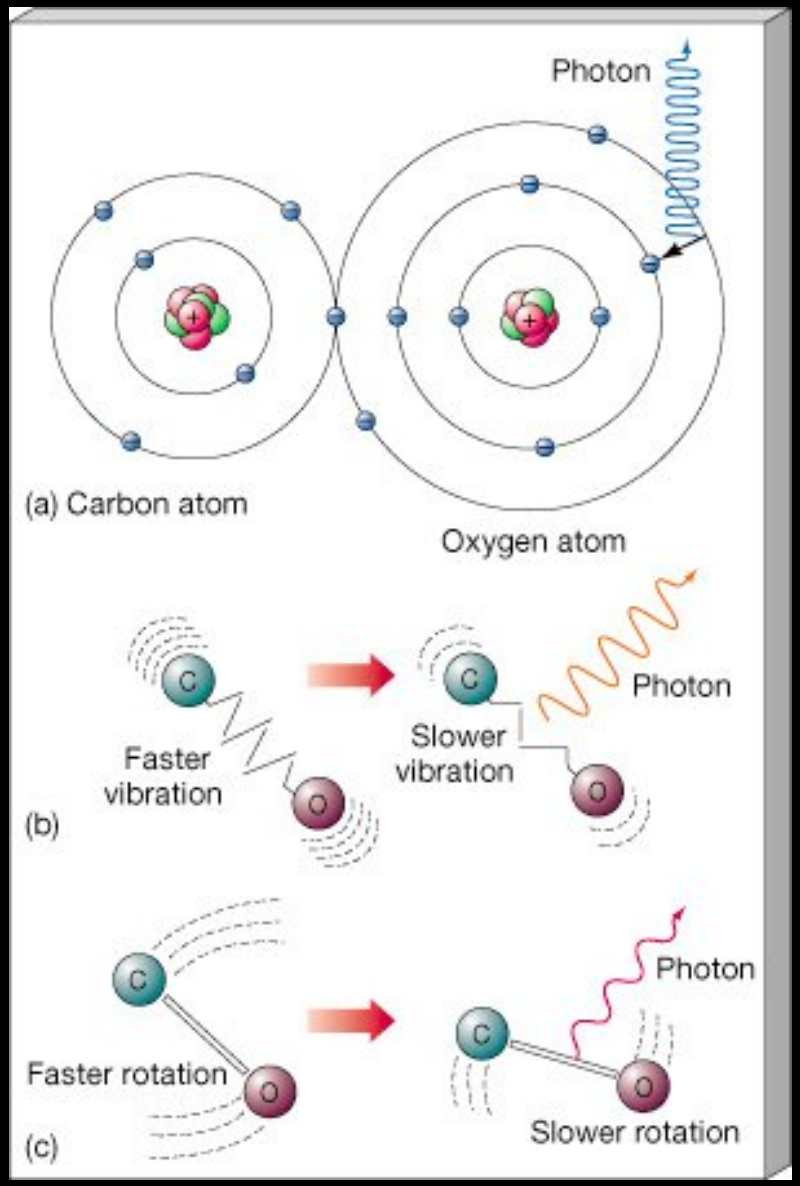
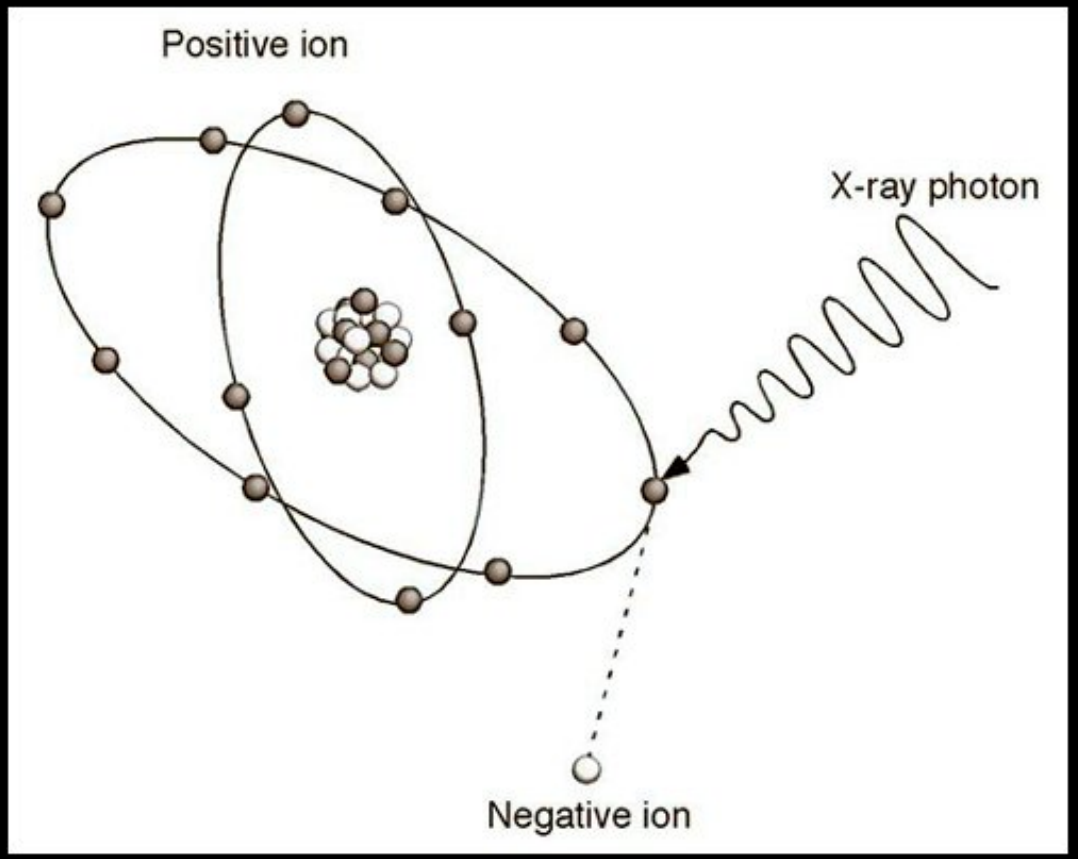
Differences between non-ionizing and ionizing radiation on atoms





Ionizing Radiation – alters chemistry by ejecting electrons

Non-Ionizing Radiation – heats, but does not alter chemistry

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)

Comparing EM radiation and energy

SOURCE	WAVELENGTH (m)	FREQUENCY (1/s)	ENERGY (eV)
Mobile Phone	0.151-0.789	(380.2-1989.8) $\times 10^{6}$	(1.6-8.2) $\times 10^{-6}$
Infrared Light (heat)	(10-1000)$\times 10^{-6}$	(300-30,000) $\times 10^{9}$	(0.0012-0.12)
Red Light	700×10^{-9}	4.3×10^{14}	1.8
Blue Light	450×10^{-9}	6.6×10^{14}	2.8
Violet	380×10^{-9}	7.9×10^{14}	3.3
Ultraviolet	~200×10^{-9}	~15×10^{14}	6.2
X-ray	~10×10^{-9}	300×10^{14}	124

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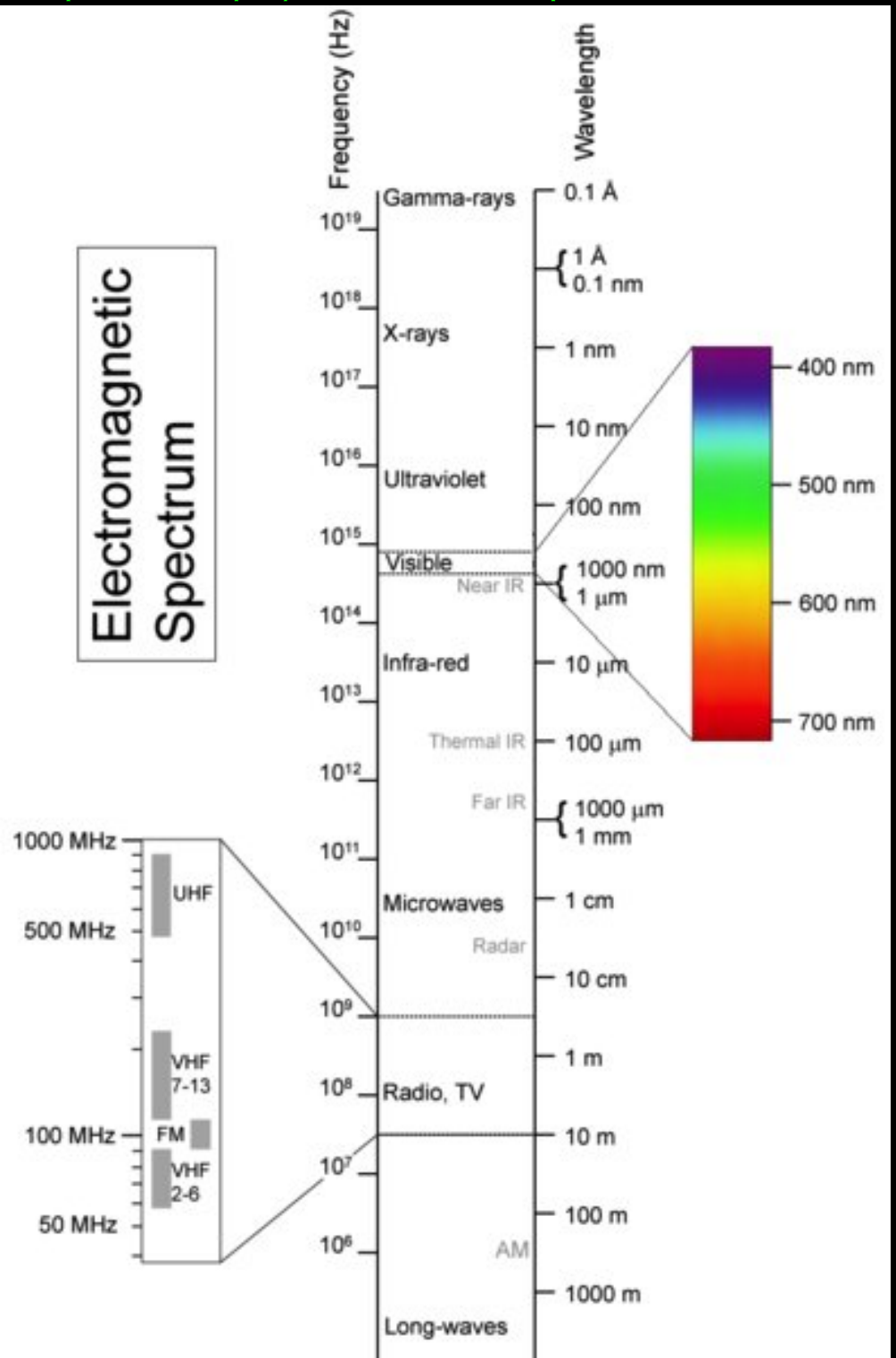
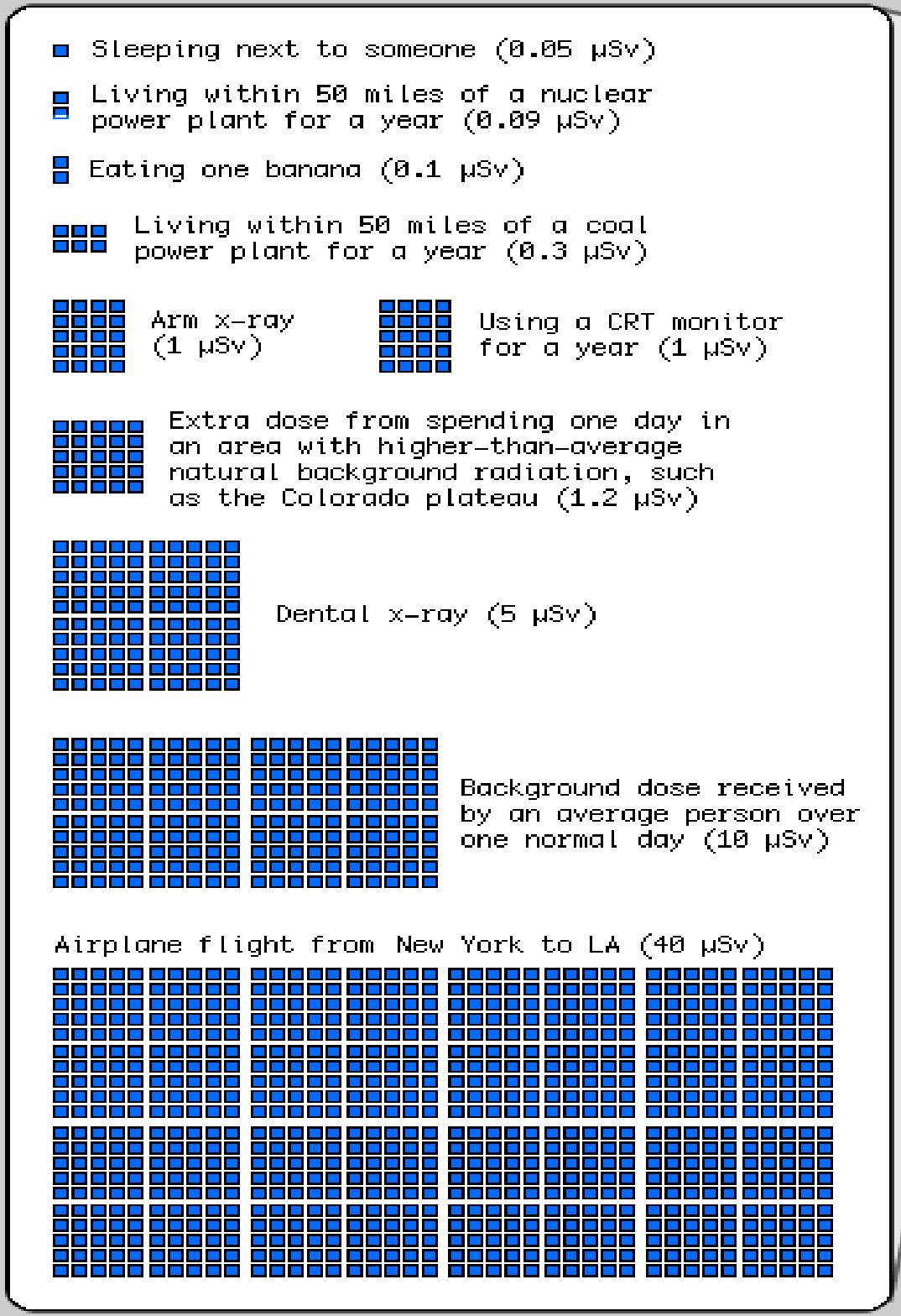


So . . . when does electromagnetic radiation become biologically dangerous?

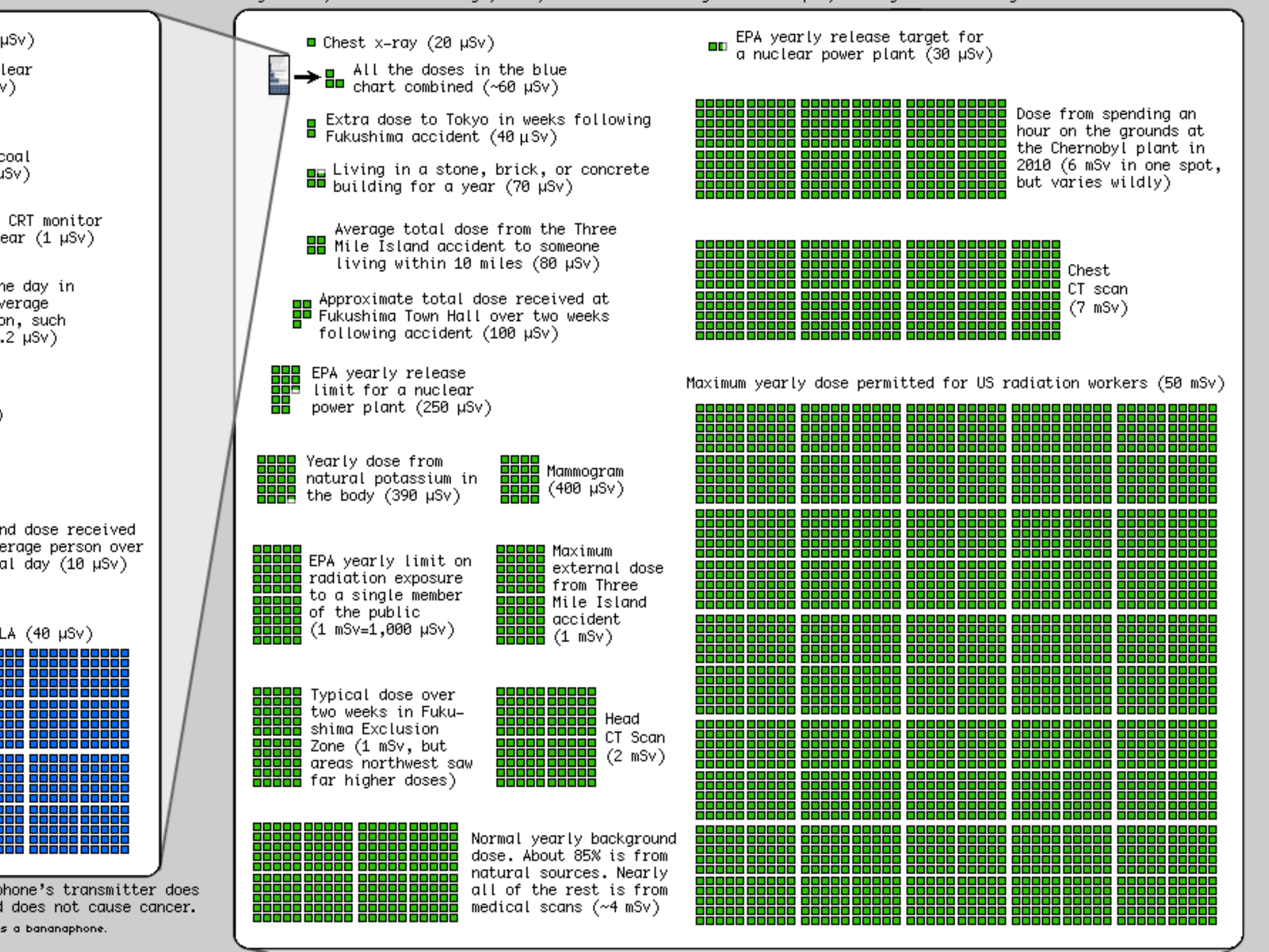
- When the energy of the radiation becomes comparable to a ~few eV (about 4 eV)
- All the radiation we've talked about so far (microwave) has wavelengths LONGER than visible light (lower frequency, less energy)
- Visible light:
  - red: ~1.8 eV
  - green: ~2.5 eV
  - violet: ~3.2 eV
- Ultraviolet light: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

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

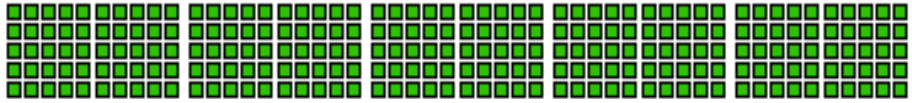


Source of this chart:
http://xkcd.com/radiation/

(the authors of this excellent chart cite their sources for the numbers at the bottom of the chart. See the link for details)


Chest x-ray (20 µSv)
All the doses in the blue chart combined (~60 µSv)
Extra dose to Tokyo in weeks 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 (80 µSv)
Approximate total dose received at Fukushima Town Hall over two weeks following accident (100 µSv)
EPA yearly release limit for a nuclear power plant (250 µSv)
Yearly dose from natural potassium in the body (390 µSv)
Mammogram (400 µSv)
EPA yearly limit on radiation exposure to 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 Exclusion Zone (1 mSv, but areas northwest saw 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)
EPA yearly release target for a nuclear power plant (30 µSv)
Dose from spending an hour on the grounds at the Chernobyl plant in 2010 (6 mSv in one spot, but varies wildly)
Chest CT scan (7 mSv)
Maximum yearly dose permitted for US radiation workers (50 mSv)

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 north-west edge of the Fukushima exclusion zone (40 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 (~180 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 (100 mSv)

Dose limit for emergency workers in lifesaving operations (250 mSv)

Severe radiation poisoning, in some cases fatal (2000 mSv, 2 Sv)

Usually fatal radiation poisoning. Survival occasionally possible with prompt treatment (4 Sv)

Fatal dose, even with treatment (8 Sv)

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Radiation MADNESS!

Part 2: Can Mobile Phones Cause Cancer?

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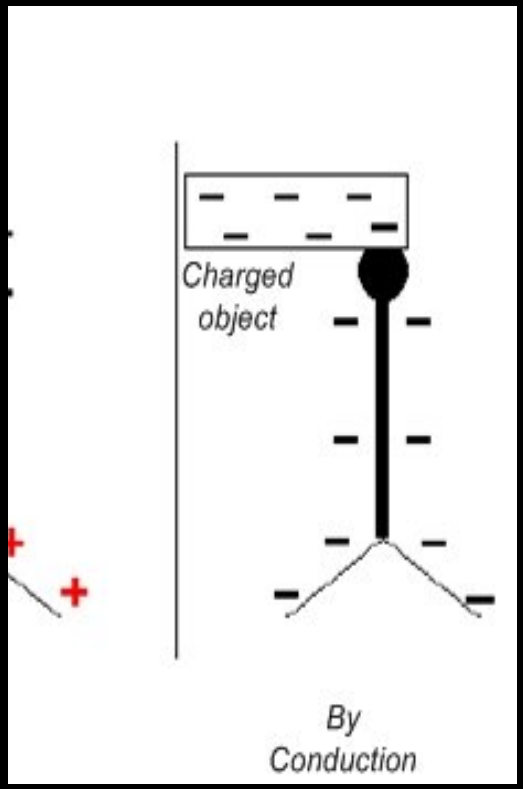
Demonstration: can mobile phone radiation ionize?

UV Sanitizing wand uses 253.7nm UV-C (about 4.9eV)



Energy required to remove loosely bound electrons from aluminum = 4 eV

What Causes Cancer?

- What causes cancer?
  - mutations to cells that lead to uncontrolled growths (e.g. tumors)
- What causes mutations? Damage to DNA:
  - alternations to molecules can make “free radicals”
  - radiation can directly damage DNA
- 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

Some origins of the claim

- David Reynard on Larry King Live in 1993
  - claimed his wife's cancer was caused by her cell phone usage.

    "Most people first heard about a possible cell phone/cancer connection when David Raynard, whose wife had died of brain cancer, was a guest on the television show Larry King Live. Raynard was suing the cell phone industry, insisting that his wife's cancer had been caused by a cell phone. "She held it against her head, and she talked on it all the time," he explained. It was January 23, 1993; from that day on, it seemed that every media story dealing with cell phones brought up the cancer issue. "
    – JNCI J Natl Cancer Inst (2001) 93 (3): 166-167. doi: 10.1093/jnci/93.3.166
- Poor science reporting after the claim circulated
  - http://www.cnn.com/2008/HEALTH/07/31/ep.cell.phones.cancer/index.html

Some origins of the claim [cont.]

- Example of bad science reporting:
  - http://www.cnn.com/2008/HEALTH/07/31/ep.cell.phones.cancer/index.html
  - “5 tips to limit your cell phone risk” (CNN, July 31, 2008)
  - Quotes Dr. Devra Davis, DIrector of the University of Pittsburgh’s Center for Environmental Oncology (until 2009):
    - "I hope you’re talking to me on a speakerphone," Devra Davis barks at me when I call her on my cell phone. "You’d better not be holding that phone up to your head."
    - And heaven forbid anyone should carry a cell phone in a pocket or clipped to a belt. "You’re just roasting your bone marrow," Davis said.

More: Dr. Davis mis-interprets and cherry-picks the INTERPHONE study and ignores the Danish Cohort Study:
http://www.huffingtonpost.com/devra-davis-phd/cell-phones-and-brain-can_b_585992.html

Who is Devra Davis?

- Degrees and research experience:
  - Ph.D. in "Science Studies" from the University of Chicago
  - Masters of Public Health from Johns Hopkins University
  - Post-doctoral positions at National Cancer Institute
  - " . . . held post-doctoral positions with the National Science Foundation in the history, sociology and philosophy of science at Catholic University in 1971 and with World Man Fund and Lorenz K. Y Ng, MD at National Institutes of Health in 1975–76" (http://en.wikipedia.org/wiki/Devra_Davis)
- Medical and patient experience
  - zero
- Peer-reviewed publications on mobile phone radiation, or the link between mobile phones and cancer?
  - zero

http://www.epidemiology.pitt.edu/davis.asp

Do cancers increase in rate in correlation with mobile phone usage?

Some numbers

- Lymphomas
  - http://seer.cancer.gov/statfacts/html/lymph.html
  - Lymphomas increased in the US by +4.0% from 1975-1991, but only by +0.4% from 1991-2009
  - Mobile phone usage in the US (see next slide)

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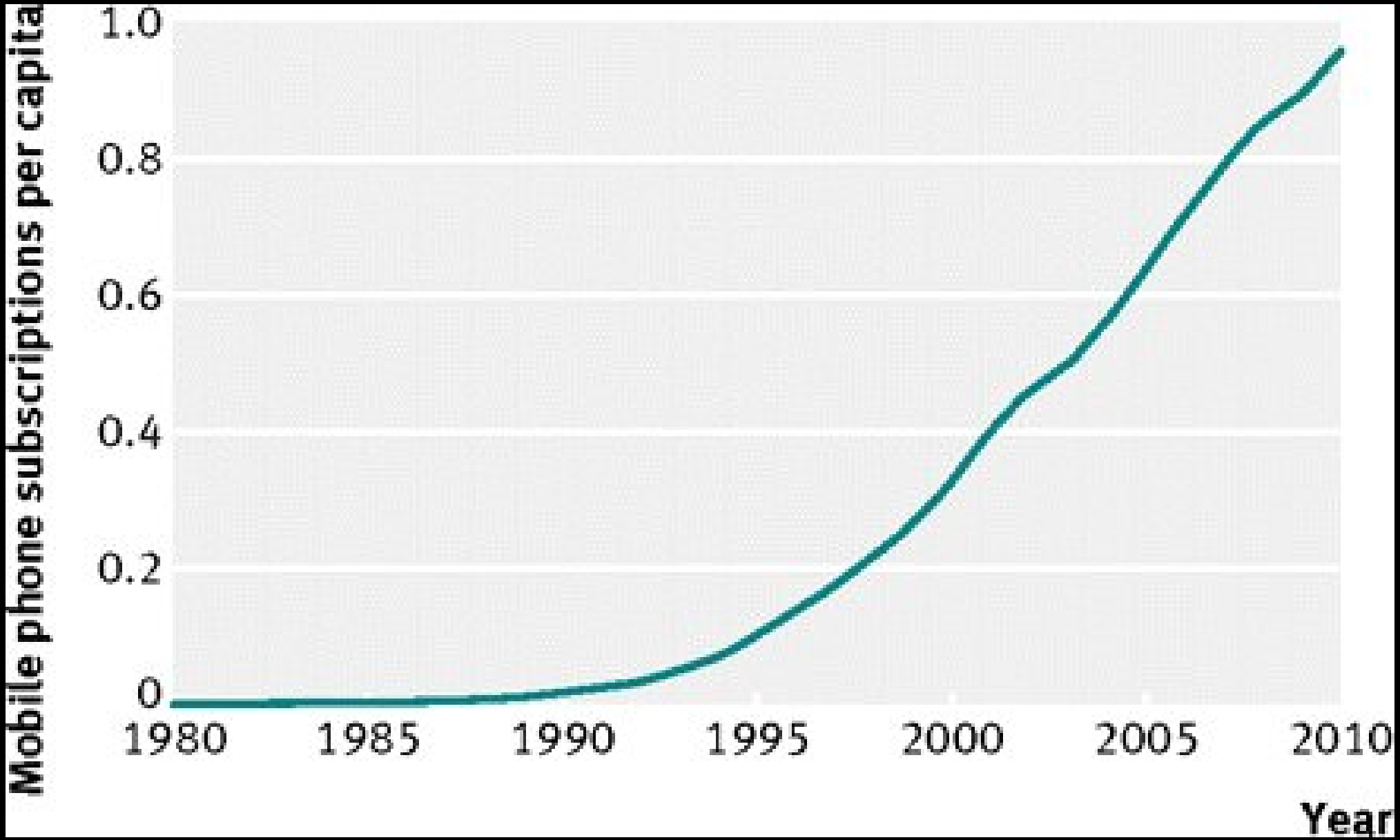
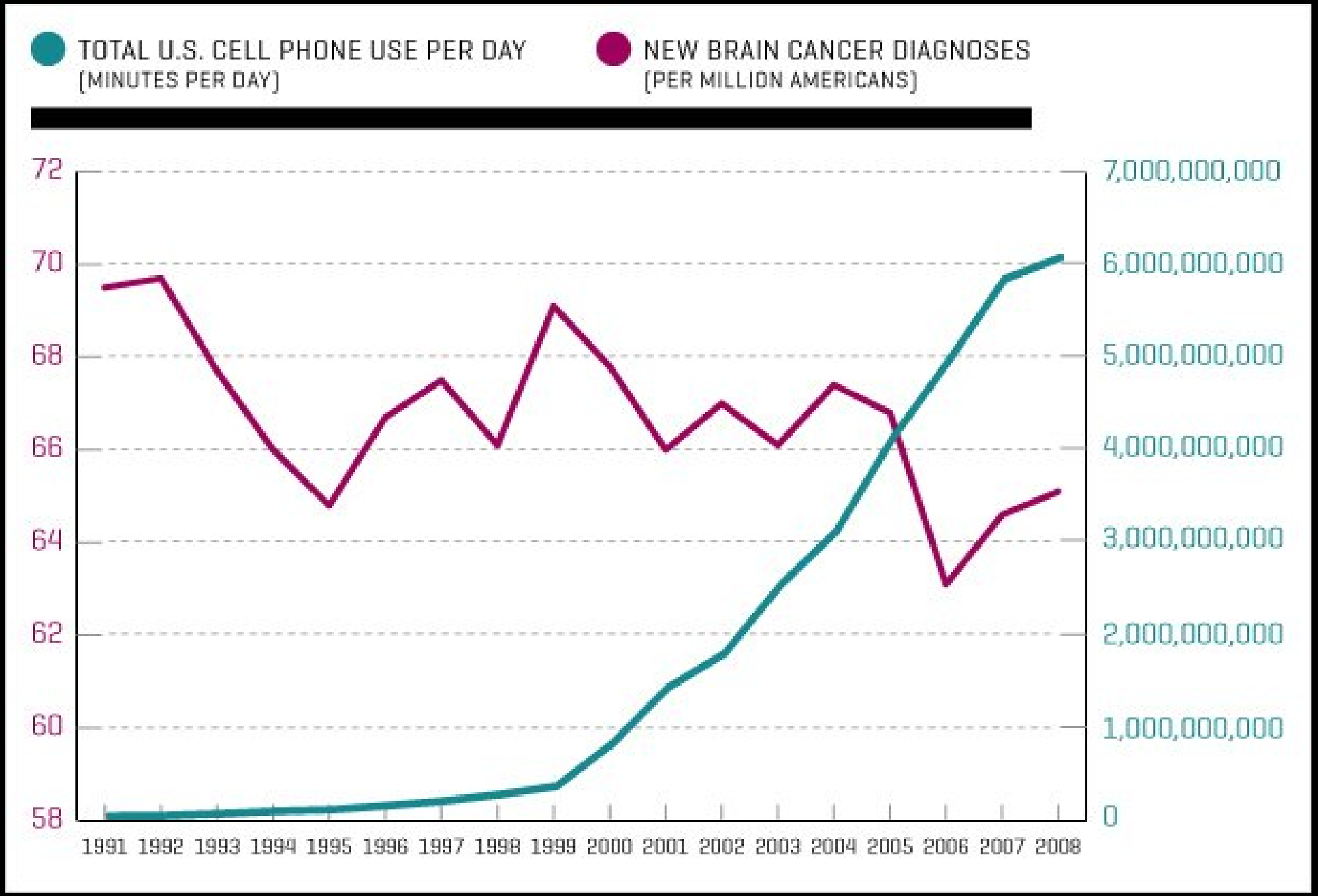


Mobile phone subscriptions per capita in the US, by year

http://www.bmj.com/content/344/bmj.e1147



Graph by CNN ("Good news, mobile phone users," Scott Wooley), July 28, 2011, but the data comes from the National Cancer Institute and the mobile phone industry. I verified the NCI numbers.

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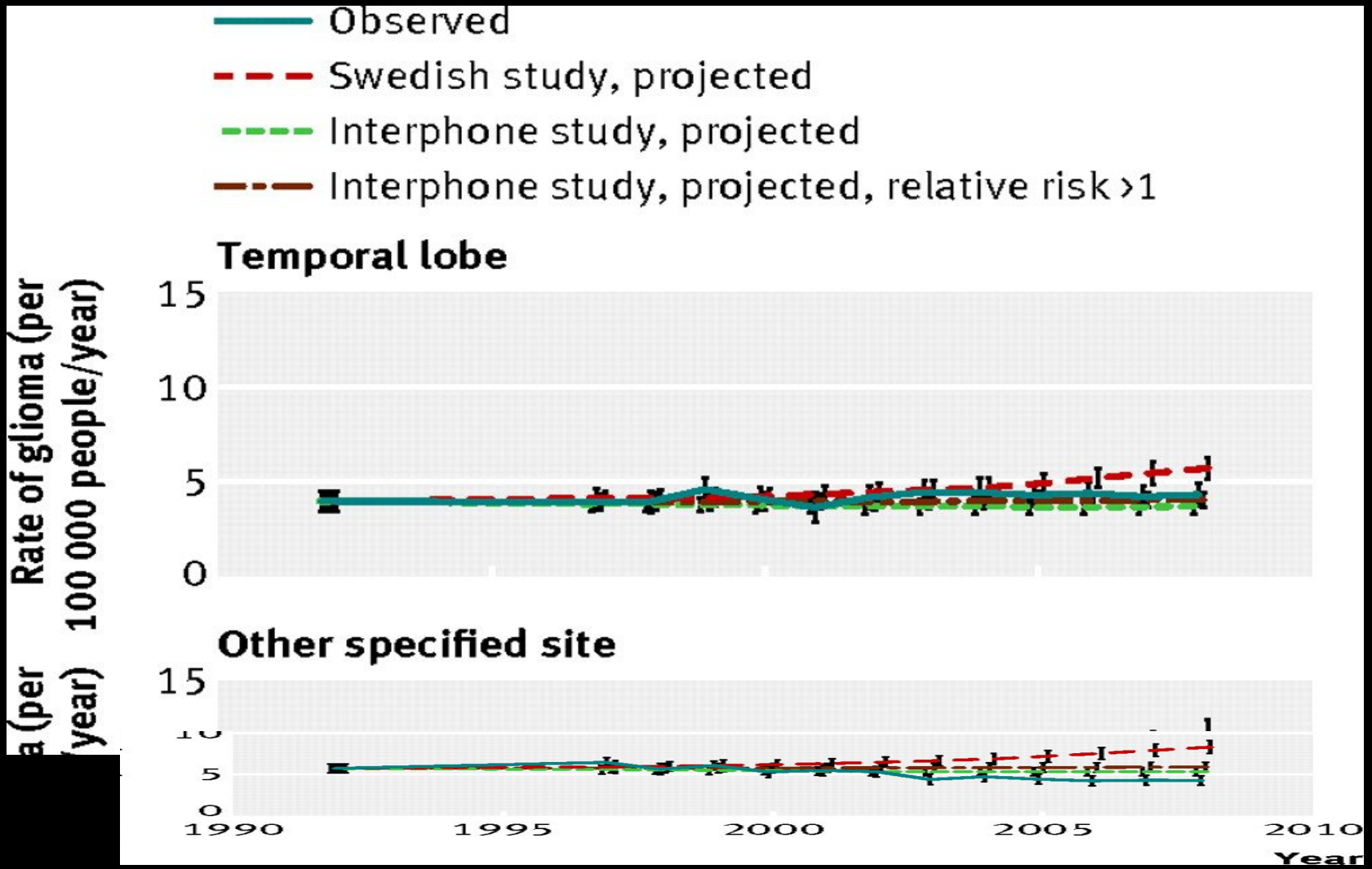

Observed and projected rates (95% CL) of malignant glioma in non-Hispanic white people, by tumor location, using the relative risks, periods of latency, and cumulative hours of phone use from the Swedish study and Interphone study.

(coming up on those other studies in a moment)

Are there any scientific claims of a link?

Repacholi et al

- Repacholi, M., Basten, A., Gebski, V., Noonan, D., Finni, J. and Harris, A.W. (1997) Lymphomas in Eμ-Pim1 transgenic mice exposed to pulsed 900 MHz electromagnetic fields. Radiat. Res., 147: 631–640.
- Used 201 genetically modified mice that are more prone to spontaneously develop lymphoma
  - 100 in the control group (received "sham radiation")
  - 101 in the group exposed to radio frequency EM radiation
  - the odds of developing lymphoma after 1 year were 2.4 times higher in the exposed group over control

Attempts to reproduce Repacholi et al.

- Independent studies used larger populations, more exposure, more groups, and mice that were and were not genetically modified.
- Other studies followed up and could not repeat the positive result:
  - Tammy D. Utteridge, Val Gebski, John W. Finnie, Barrie Vernon-Roberts, and Tim R. Kuchel (2002) Long-Term Exposure of Eμ-Pim1 Transgenic Mice to 898.4 MHz Microwaves does not Increase Lymphoma Incidence. Radiation Research: September 2002, Vol. 158, No. 3, pp. 357-364.
  - No effects of GSM-modulated 900 MHz electromagnetic fields on survival rate and spontaneous development of lymphoma in female AKR/J mice. Angela M Sommer, Joachim Streckert, Andreas K Bitz, Volkert W Hansen and Alexander Lerchl. BMC Cancer 2004, 4:77 doi:10.1186/1471-2407-4-77. 11 November 2004

The Details: Can/Do Mobile Phones Cause Cancer?

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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?

$E = hf = [1.6, 7.9]x10^{-6}$ eV

Millionths of an electron-Volt . . . compared to the ~few eV needed to break the weakest chemical bonds.

Mobile phones cannot cause cancer.

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. (solar power = ~250 W/m^2)
  - Blood flow regulates body temperature, removing excess heat from your head.

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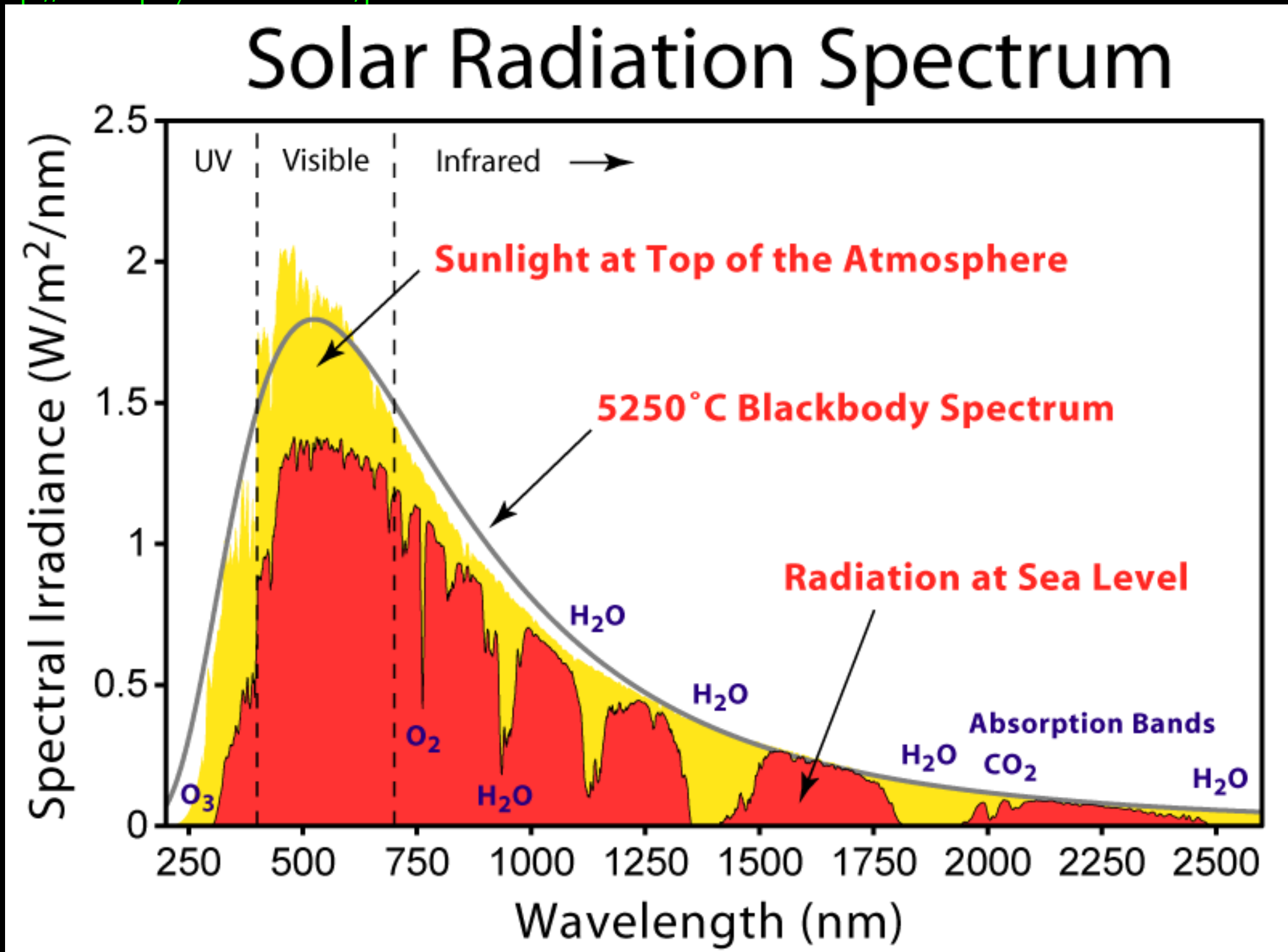

Big Data: long-duration population studies

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The Danish Cohort Study

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

Joachim Schüz, Rune Jacobsen, Jørgen H. Olsen, John D. Boice Jr, Joseph K. McLaughlin and Christoffer Johansen

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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 = 0.96), 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

"Use of mobile phones and risk of brain tumours: update of Danish cohort study." BMJ 2011;343:d6387

Danish Cohort: Conclusions

The authors updated the study in 2011 and drew the following conclusions:

"Results: 358,403 subscription holders accrued 3.8 million person years. In the follow-up period 1990-2007, there were 10,729 cases of tumours of the central nervous system. The risk of such tumours was close to unity for both men and women. When restricted to individuals with the longest mobile phone use—that is, 13 years of subscription—the incidence rate ratio was 1.03 (95% confidence interval 0.83 to 1.27) in men and 0.91 (0.41 to 2.04) in women. Among those with subscriptions of 10 years, ratios were 1.04 (0.85 to 1.26) in men and 1.04 (0.56 to 1.95) in women for glioma and 0.90 (0.57 to 1.42) in men and 0.93 (0.46 to 1.87) in women for meningioma. There was no indication of dose-response relation either by years since first subscription for a mobile phone or by anatomical location of the tumour—that is, in regions of the brain closest to where the handset is usually held to the head."

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

The INTERPHONE Study: Conclusions

- "Overall, no increase in risk of glioma or meningioma was observed with use of mobile phones. There were suggestions of an increased risk of glioma at the highest exposure levels, but biases and error prevent a causal interpretation. The possible effects of long-term heavy use of mobile phones require further investigation."
  – *INTERPHONE Study Group. Brain tumour risk in relation to mobile telephone use: results of the INTERPHONE international case-control study. Int J Epidemiol 2010 Jun; 39(3):675-94. Epub 2010 May 17*

The INTERPHONE Study: Conclusions

- "There was no increase in risk of acoustic neuroma with ever regular use of a mobile phone or for users who began regular use 10 years or more before the reference date. Elevated odds ratios observed at the highest level of cumulative call time could be due to chance, reporting bias or a causal effect. As acoustic neuroma is usually a slowly growing tumour, the interval between introduction of mobile phones and occurrence of the tumour might have been too short to observe an effect, if there is one."
  – INTERPHONE Study Group. Acoustic neuroma risk in relation to mobile telephone use: results of the INTERPHONE international case-control study. Cancer Epidemiol 2011 Oct; 35(5):453-64. Epub 2011 Aug 23.

Conclusions from the Evidence

- Is cancer from a mobile phone a physical possibility based on the known laws of physics?
  - No – cancers can result only from ionizing radiation, and mobile phones do not emit ionizing radiation (by a factor of a million below ionizing levels)
- Is cancer observed due to mobile phone use?
  - No – independent large population studies have found no link
  - There is also no convincing observed correlation with increased mobile phone use and cancers, like lymphomas or gliomas.

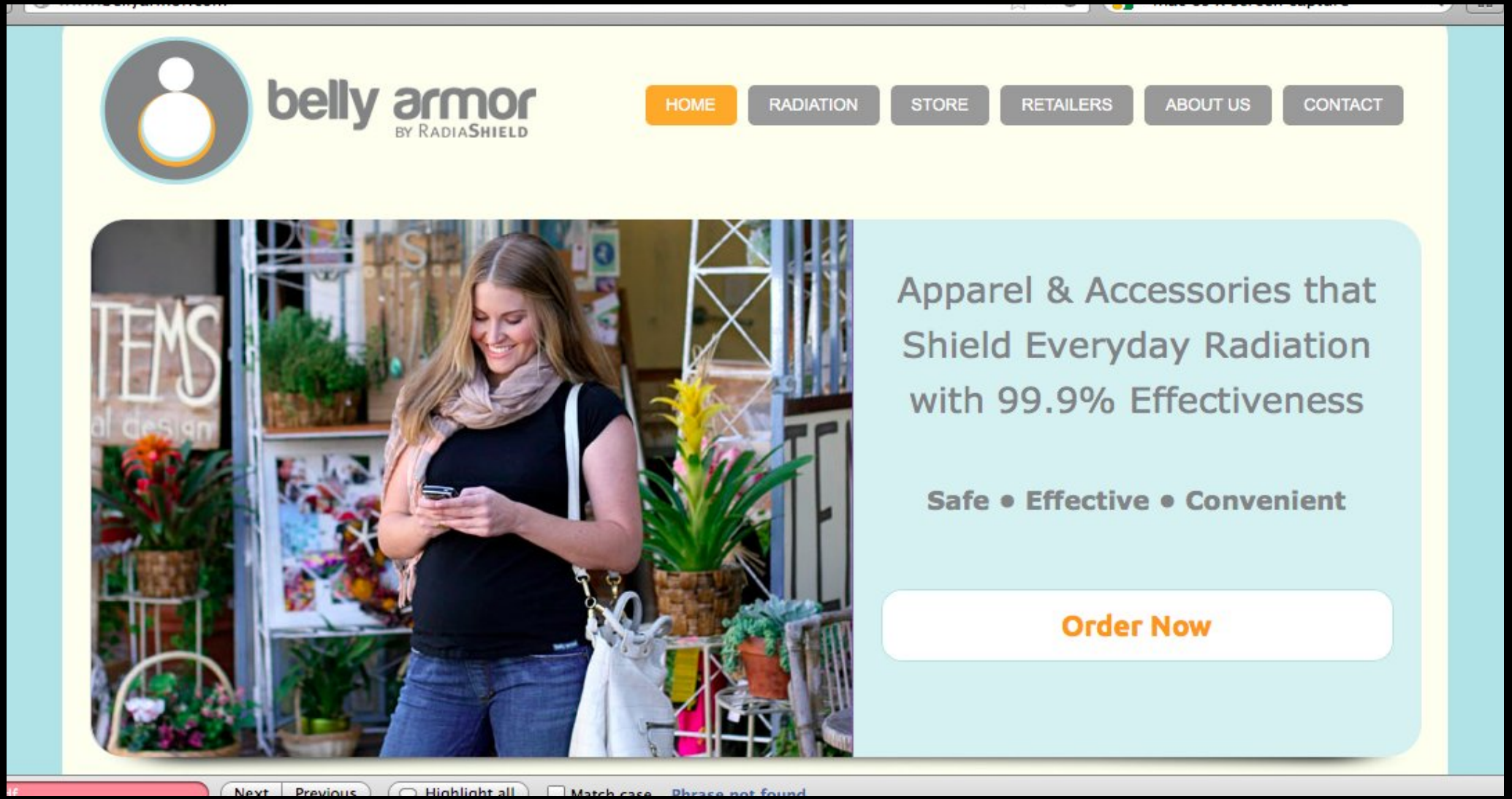
What's so bad about people wanting to believe that mobile phone radiation is bad for them?

Wasted Money: The Law

- Recently, the Italian Supreme Court ruled in favor of a man claiming his mobile phone caused his cancer
  - ignored evidence that was even partially funded by the mobile phone industry, such as Interphone
- This presumably opens the door to other cases in Italy
  - useful illustration of how legal truth (the ability to win an argument) is different from scientific truth (establishing knowledge of the natural world)

http://www.physics.smu.edu/pseudo

Wasted Money: Products



http://www.bellyarmor.com/

http://www.physics.smu.edu/pseudo

Wasted Money: Govt. Legislation

Uses cherry-picked results from INTERPHONE, ignores Danish Cohort, and misuses INTERPHONE conclusions.

Take-away Messages

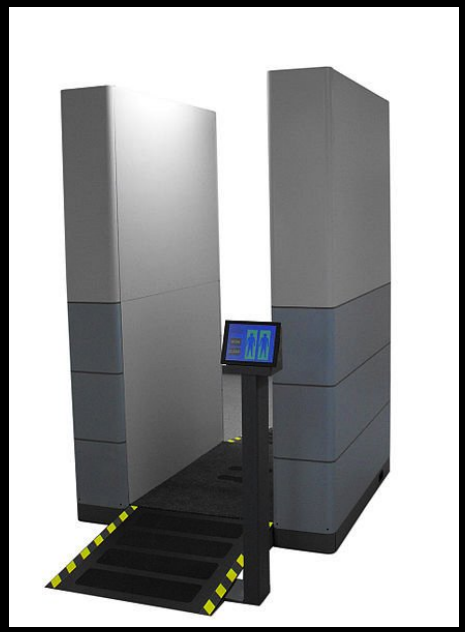
- Radiation is everywhere. In fact, biological diversity is possible, in part, because of radiation's random mutagenic effects on DNA which can lead to beneficial mutations.
- Non-ionizing radiation can, in large amounts, cause heating or other mechanical effects, but is otherwise completely harmless 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.)

http://www.physics.smu.edu/pseudo

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.

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.