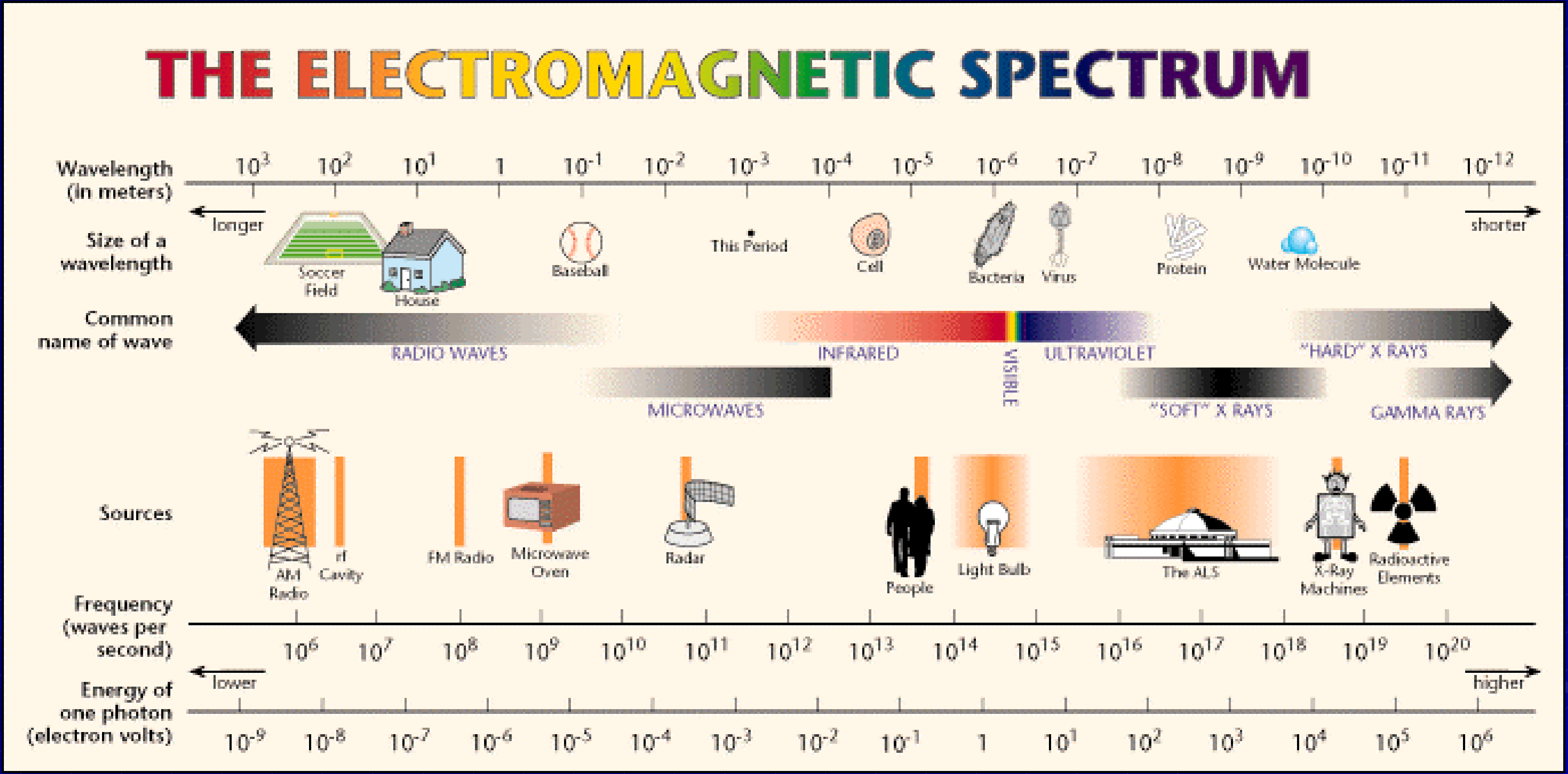
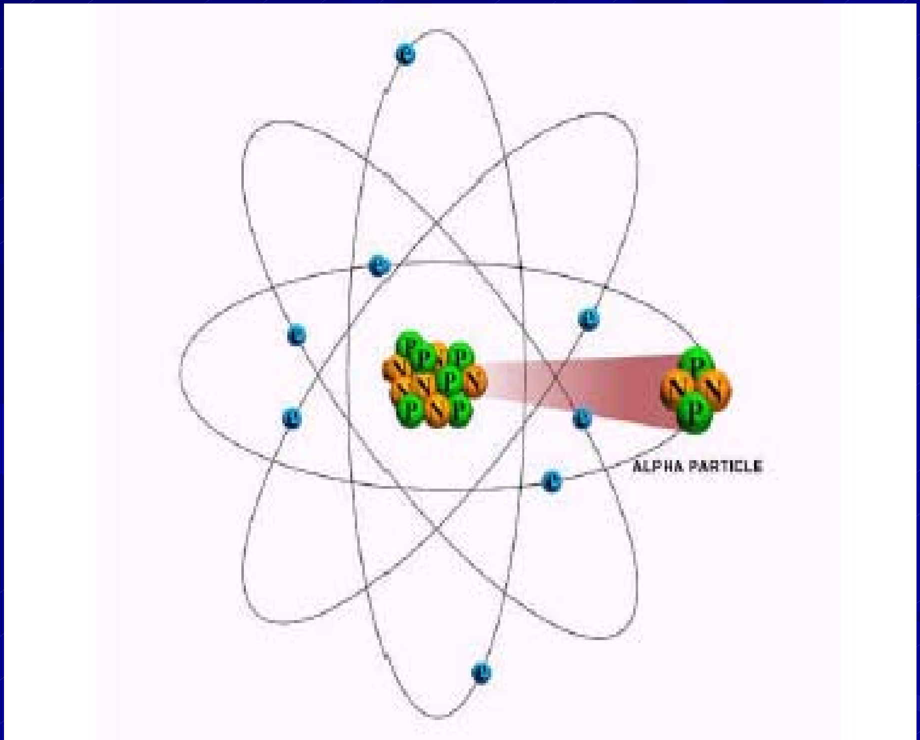
What Is Ionizing Radiation ?

Electromagnetic Spectrum



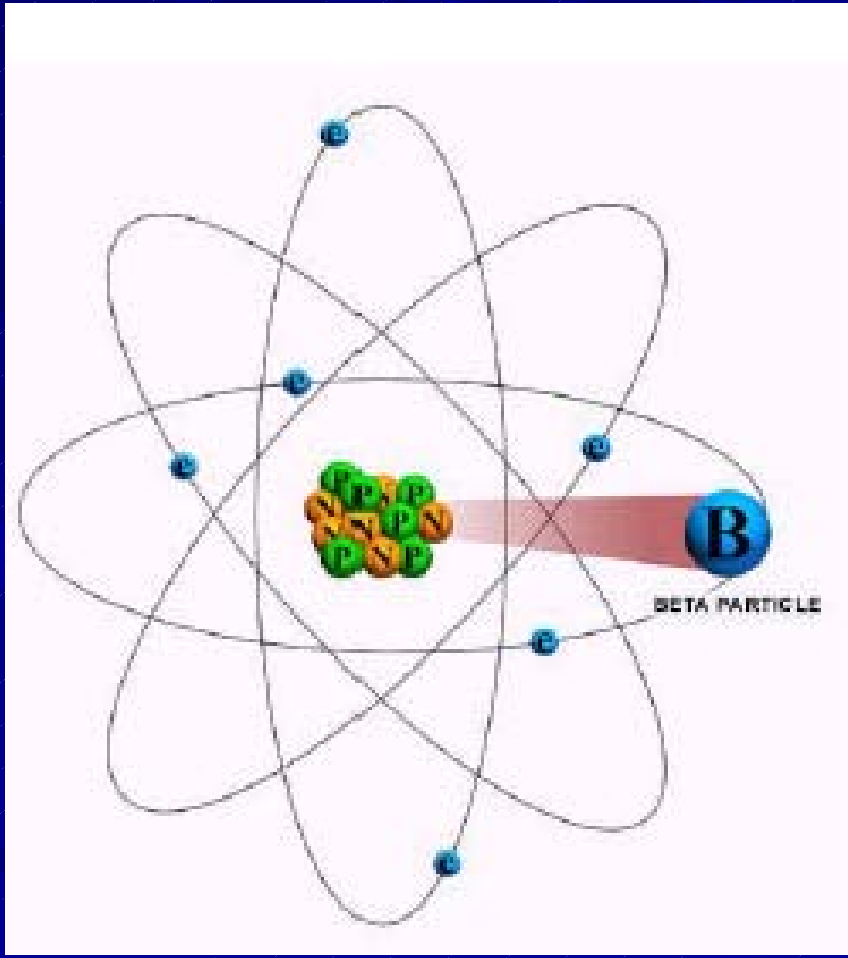
Alpha Particle (α)

Alpha decay, the emission of an alpha particle (a helium nucleus), only occurs in very heavy elements such as uranium, thorium and radium. The reason alpha decay occurs is because the nucleus of the atom is unstable. In an attempt to reduce the instability, an alpha particle is emitted. The alpha particles are in constant collision with an energy barrier in the nucleus and because of their energy and mass, there exists a nonzero probability of transmission. That is, an alpha particle (helium nucleus) will tunnel out of the nucleus of the heavy element.



Beta Particle (β)

- **Beta decay** occurs when the neutron to proton ratio is too great in the nucleus and causes instability. In basic beta decay, a neutron is turned into a proton and an electron. The electron is then emitted.
- There is also **positron emission** when the neutron to proton ratio is too small. A proton turns into a neutron and a positron and the positron is emitted. A positron is basically a positively charged electron.

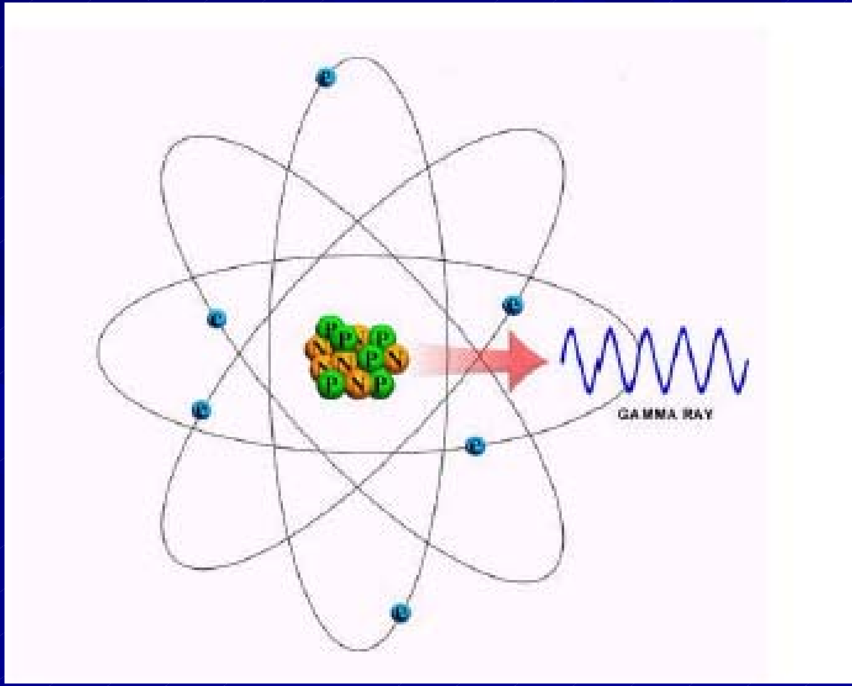


Gamma Ray (γ)

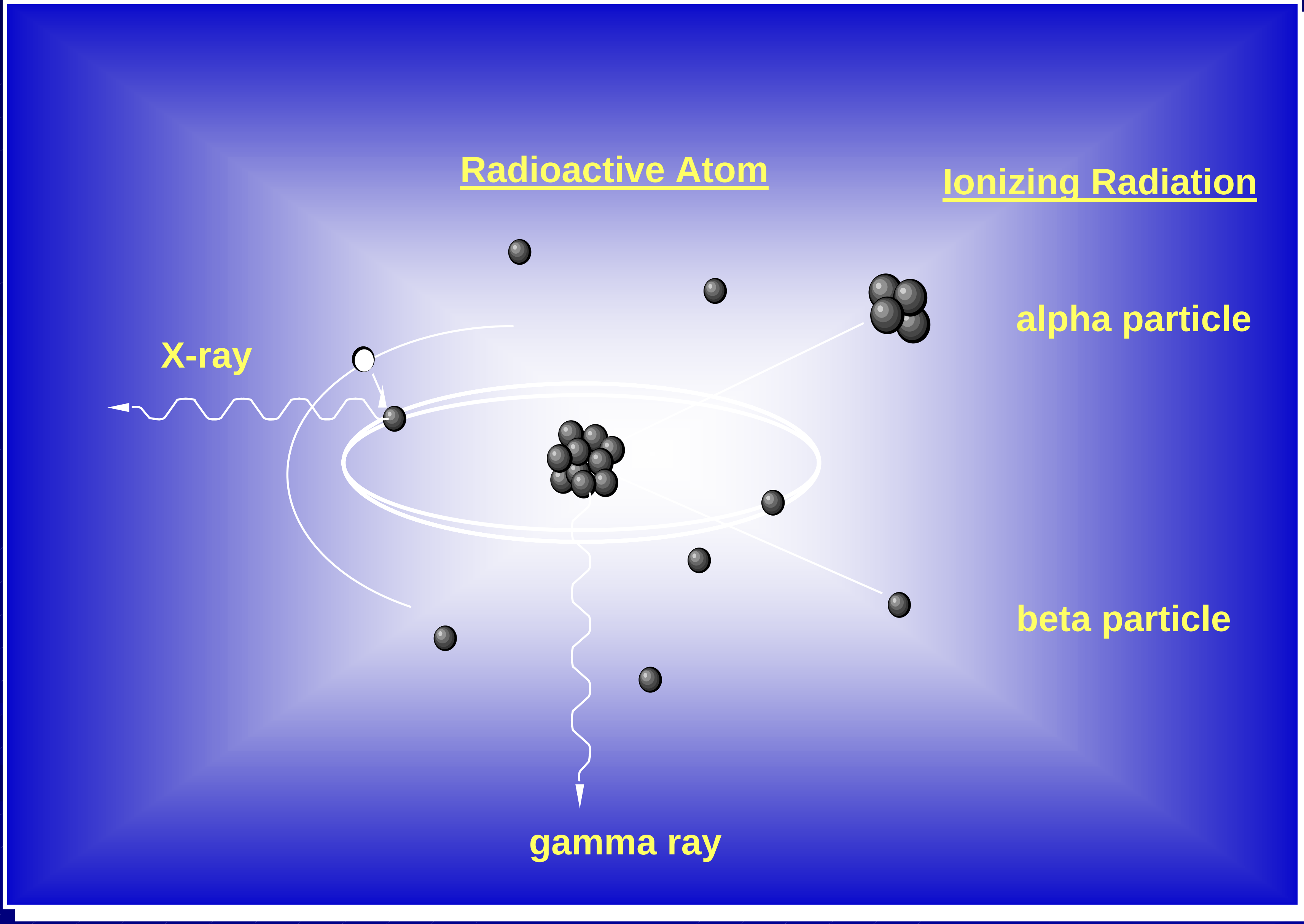
- After a decay reaction, the nucleus is often in an "excited" state. This means that the decay has produced a nucleus which still has excess energy to get rid of. Rather than emitting another beta or alpha particle, this energy is lost by emitting a pulse of electromagnetic radiation called a gamma ray. The gamma ray is identical in nature to light or microwaves, but of very high energy. Like all forms of electromagnetic radiation, the gamma ray has no mass and no charge.

  Gamma rays interact with material by colliding with the electrons in the shells of atoms. They lose their energy slowly in material, being able to travel significant distances before stopping. Depending on their initial energy, gamma rays can travel from 1 to hundreds of meters in air and can easily go right through people.

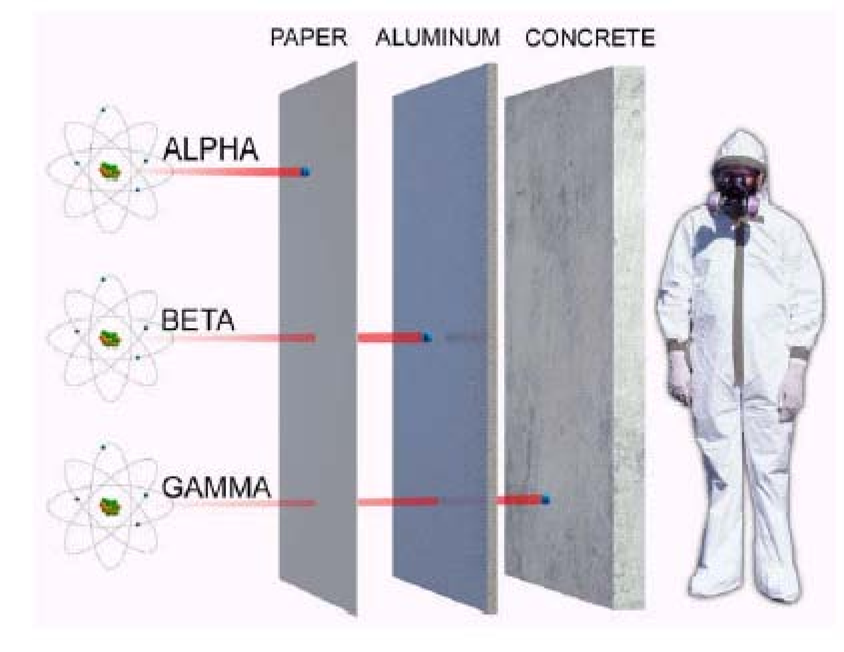
  It is important to note that most alpha and beta emitters also emit gamma rays as part of their decay process. There is no such thing as a "pure" gamma emitter.



Radioactive Atom



Relative Stopping Power



Effects

Effects of Ionizing Radiation

1. Direct effect

    Ionization, excitation

2. Indirect effect

    Reactions of the species formed from the solvent with the solute

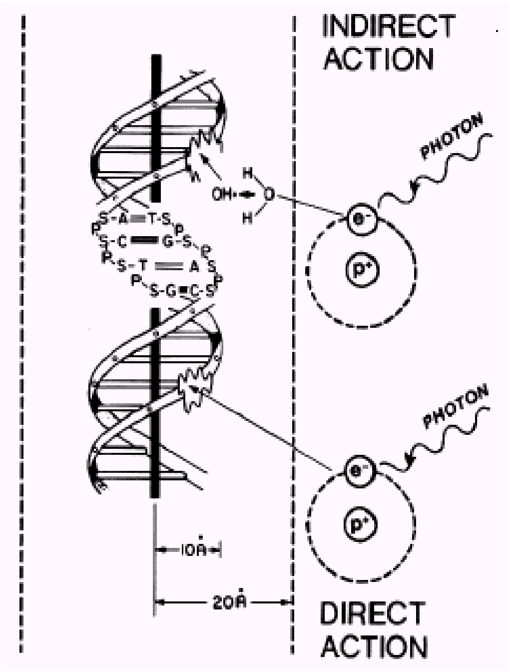
DNA damage

DNA damage is the result of direct and indirect effects of radiation

- All 4 bases subject to damage; ~9eV sufficient to break DNA backbone
- SSB correlates poorly with lethality
- DSB most important lesion

Damage / Gy of X-rays:

- 40 DSBs
- 150 DNA crosslinks
- 1,000 SSB
- 2,500 base damages

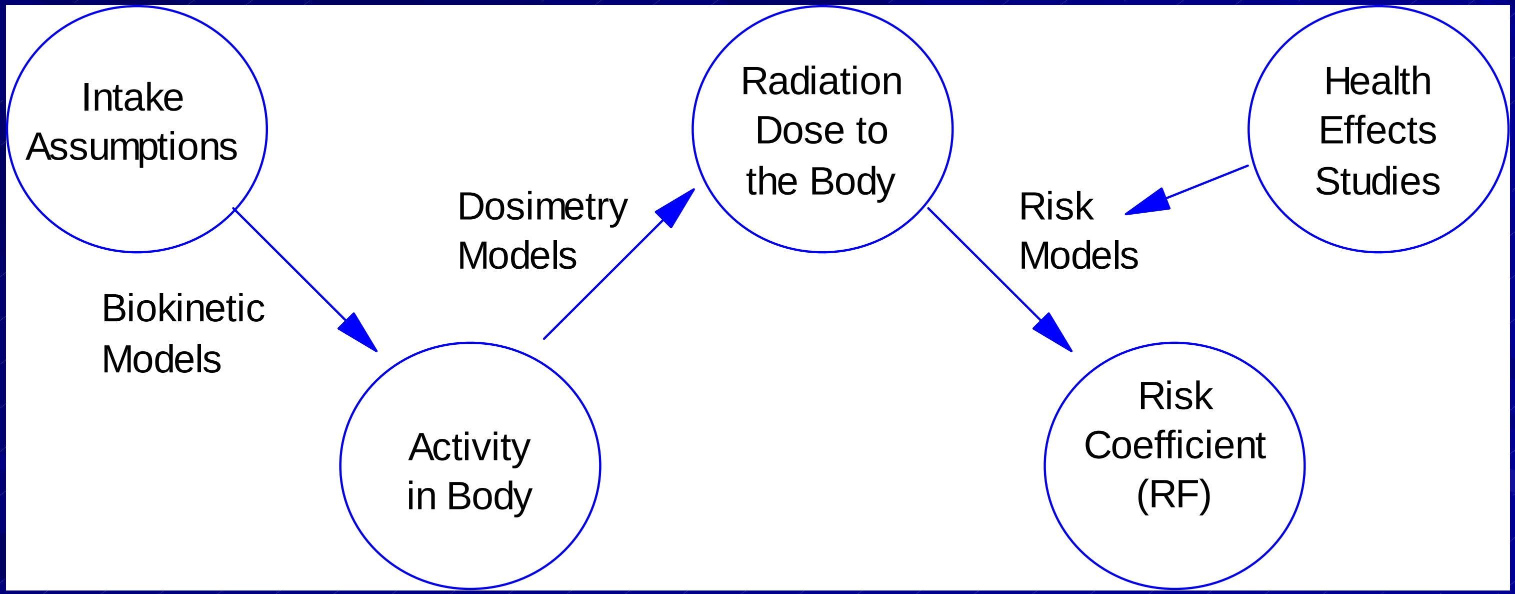


From: Hall, "Radiobiology for the Radiologist"

Sequence

- Sequence of events by which ionizing radiation affects living systems
- Energy absorption (10**-17** sec)
- Ionization and excitation (10**-5** sec)
- Molecular changes (secs)
- Biochemical changes (secs - hrs)
- Physiologic & anatomic changes (min - hrs)
- Biological effects (hrs - yrs)
- Death of organism

EPA Radionuclide Risk Coefficients



Radioactivity vs. Dose

- Activity is disintegrations per second (dps)
  - Unit is picocurie (pCi) = 0.037 dps
  - Unique decay rates and half lives for each radionuclide
  - Depending on radionuclide, decay can be α or β, usually with one or more γ
  - Energy per decay is sum of particle and gamma energies
- Dose is energy deposited in a unit mass of a medium (e.g., per gram of tissue)
- Same activity of different radionuclides ≠ same dose (depends on energy per decay)

Converting Radiation Dose to Risk

- Dose assessments use effective dose (all tissues) for adult receptor
- Radionuclide slope factors are age-averaged -- calculate doses to each target organ or tissue, apply age- and gender-specific risk factors, and integrate over a lifetime
- External (uniform whole body) irradiation = 8×10^{-7} radiogenic cancers (incidence)/millirem
- For intakes, dose to risk conversion is radionuclide-dependent and varies between ~ 1×10^{-7} and 3×10^{-6} per millirem

Radiation Risk Assessments -

- Do not use body weight
- Do not use averaging time
- Are “best estimates” of age-averaged risk to the U.S. population, not upper 95th %
- Are derived from human epidemiology (dose response data extrapolated from atomic bomb survivors, U miners, etc.)
- Are based on linear, no-threshold model (LNT)

Health Basis for Radium MCL

- **1976 MCL**
  Ra-226 and Ra-228 = 5 pCi/L combined
  - Critical organ: Bone and soft tissues
  - Based on NAS-BEIR 1
  - Est. lifetime fatal cancer risk: 0.5 to 2.1 x 10^{-4}
  - Ra-226 and Ra-228 assumed to contribute equally to risk
  - Consistent with 1962 FRC recommendation, that the daily intake not exceed 20 pCi. Allowing 5 pCi per liter at a rate of 2 liters per day used up half of the recommended maximum intake.

Radium MCL (cont.)

- **1991 MCL**
  Ra-226 and Ra-228 = 20 pCi/L each
  - Critical organ: Bone, bone marrow, nasal sinuses (Ra-226)
  - Based on EPA's RADRISK calculations
  - Est. lifetime fatal cancer risk: 1 to 2 x 10^{-4}

Radium MCL (cont.)

Current Risk Estimates for Radium MCLs*

Isotope	1976 (pCi/L)	Current Risk Estimate	1991 (pCi/L)	Current Risk Estimate
Ra-226 alone	5	1×10^{-4}	20	3×10^{-4}
Ra-228 alone	5	3×10^{-4}	20	1×10^{-3}
Combined	5 (1/2 each)	2×10^{-4}	40	1×10^{-3}

*Lifetime excess cancers calculated using FGR-13 risk coefficients.

Health Basis for Alpha MCL

- **1976 MCL**
  Gross alpha = 15 pCi/L, including Ra-226, excluding uranium and radon
  – "Based on conservative assumption that if the radium concentration is 5 pCi/L and the balance of the alpha particle activity [10 pCi/L] is due to the next most radiotoxic alpha particle emitting chain, starting with lead-210 [i.e., Po-210], the total dose to bone would be equivalent to less than 6 pCi/L of radium-226."
  – Est. lifetime fatal cancer risk: 1 to 2 x 10^{-4} (or less)

Basis for Alpha MCL (cont.)

- **1991 MCL**
  Adjusted gross alpha = 15 pCi/L,
  excluding Ra-226, uranium and radon
  - Po-210 would be the most likely and most toxic alpha particle emitter in water, excluding Ra-226, uranium and Rn-222.
  - Lifetime consumption of 14 pCi/L Po-210 was estimated to yield a 1×10^{-4} fatal cancer risk
  - Est. lifetime fatal cancer risk: 1×10^{-4} (or less)

Basis for Alpha MCL (cont.)

Current Risk Estimates for Alpha MCLs*

Radionuclide	1976 = 1991 (pCi/L)	Current Risk Estimate
Po-210	15	1.4×10^{-3}
Ra-224	15	0.9×10^{-4}
Th-230	15	0.4×10^{-4}
Th-232	15	0.3×10^{-4}
Np-237	15	0.5×10^{-4}
Pu-239	15	1.4×10^{-4}

Statistic	Current Risk Estimate
Average	2×10^{-4}
Geo. mean	1×10^{-4}
Minimum	3×10^{-5}
Maximum	1×10^{-3}

*Lifetime excess cancers calculated using FGR-13 risk coefficients.

Health Basis for Beta MCL

- **1976 MCL**
  4 mrem/y total body or critical organ dose
  - Except for H-3 and Sr-90, derived activity concentrations each beta/photon emitter calculated using the168-hr MPCw values from NBS Handbook 69 (ICRP Publication 2 (1959)) adjusted by a factor for exposure of the general population
  - Sum-of-the-fractions method required for multiple, co-occurring beta/photon emitters
  - Est. lifetime fatal cancer risk: 5.6×10^{-5} (or less)

Basis for Beta MCL (cont.)

- **1991 MCL**
  4 mrem/y effective dose equivalent (ede)
  - Derived activity concentrations each beta/photon emitter calculated using EPA's RADRISK code (ICRP-30)
  - Sum-of-the-fractions method required for multiple, co-occurring beta/photon emitters
  - Est. lifetime fatal cancer risk: 1×10^{-4} (or less)

Basis for Beta MCL (cont.)

Current Risk Estimates for Beta/Photon MCLs*

Radionuclide	1976 (pCi/L)	Current Risk Estimate	1991 (pCi/L)	Current Risk Estimate
H-3	20,000	0.5 x 10-4	60,900	1.6 x 10-4
Co-60	100	0.8 x 10-4	218	1.7 x 10-4
Sr-90	8	0.2 x 10-4	42	1.2 x 10-4
Tc-99	900	1.3 x 10-4	3,790	5.3 x 10-4
I-129	1	0.1 x 10-4	21	1.6 x 10-4
Cs-137	200	3.1 x 10-4	119	1.8 x 10-4

*Lifetime excess cancers calculated using FGR-13 risk coefficients.

Basis for Beta MCL (cont.)

Current Risk Estimates for Beta/Photon MCLs*

Statistic	1976	1991
Average	1×10^{-4}	3×10^{-4}
Geometric mean	4×10^{-5}	3×10^{-4}
Minimum	1×10^{-6}	5×10^{-5}
Maximum	4×10^{-4}	2×10^{-3}

*Lifetime excess cancers calculated using FGR-13 risk coefficients.

Health Basis for Uranium MCL

- **1976 MCL**
  Not regulated
- **1991 MCL**
  20 micrograms/L (~30 pC/L)
  – based on chemical toxicity in kidney, assuming a 1000-fold uncertainty factor and Reference dose (RfD) based on short-term animal studies
  – 30 pCi/L equivalent to 20 micrograms/L assuming ratio of 1.3
  U-234:U-238 activity from NIRS database)
  – Est. lifetime fatal cancer risk: 1 x 10^{-4}

Basis for Uranium MCL (cont.)

Current Risk Estimates for Uranium MCL*

Radionuclide	1976 (pCi/L)	Current Risk Estimate	1991 (pCi/L)	Current Risk Estimate
Uranium	No limit set	---	30	$\sim 1 \times 10^{-4}$

*Lifetime excess cancers calculated using FGR-13 risk coefficients.