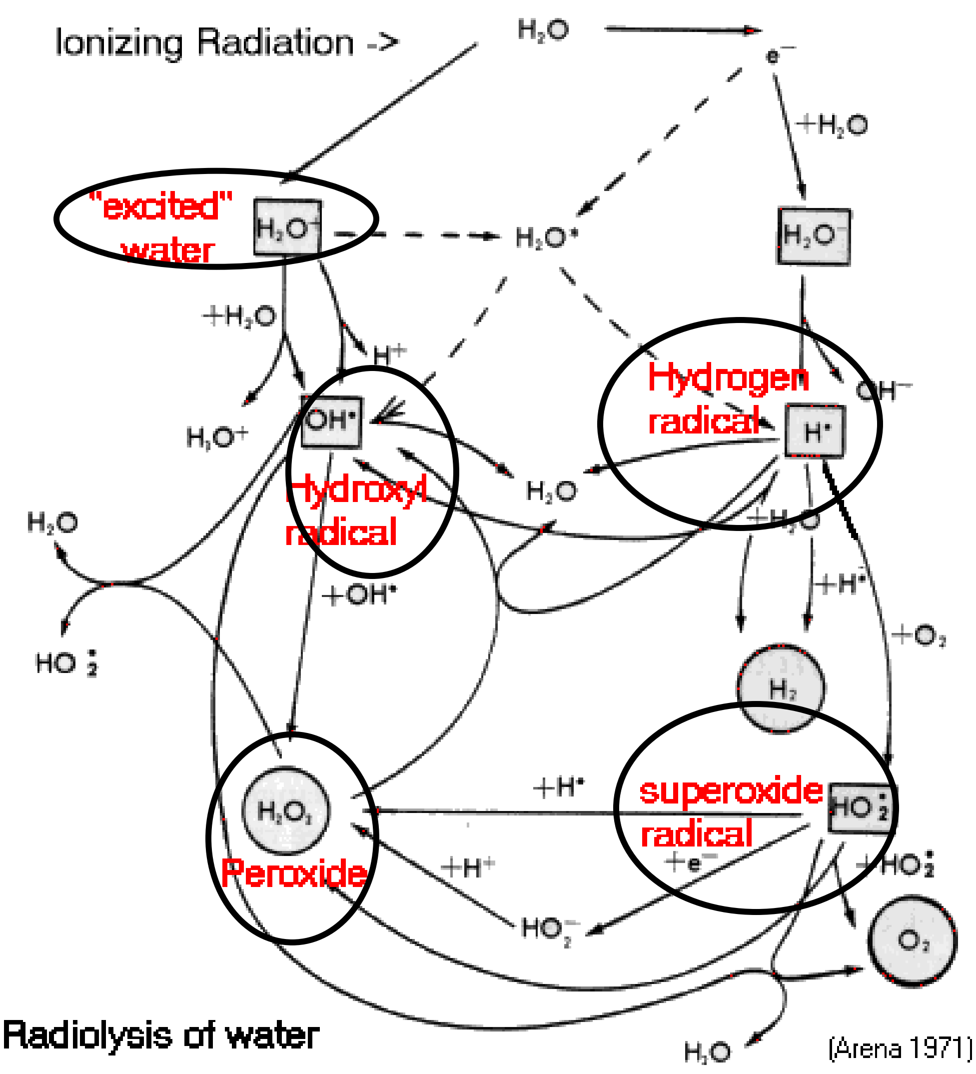
RDCH 702 Lecture 7: Radiation Reactions: Dosimetry and Hot Atom Chemistry

- **Readings:**
  - **Reading: Modern Nuclear Chemistry, Chap. 17; Nuclear and Radiochemistry, Chap. 6, Chap 11.C.**
- **Interaction of radiation with matter**
  - **Neutron, positive ions, electrons, photons**
- **Dosimetry**
- **Radiation Protection**
- **Hot Atom Chemistry**

Effect in biological systems
Radicals are formed by the interaction of radiation with water

Radicals drive reactions



Radiolysis of water

(Arena 1971)

Interaction of Radiation with Matter

- Interaction of radiation with matter leads to:
  - dissociation of molecules
  - excitation of atoms or molecules
  - ionization of atoms or molecules
- Ionization is easily measured
  - used for detection
- In air about 35 eV of energy are dissipated for each ion pair formed
- Other gases
- Xe: 21.9 eV, He: 43 eV, NH3: 39 eV (IP = 10.8 eV), Ge: 2.9 eV
  - Radiation detected by interaction with matter
  - Interactions ultimately have the same effect
    - → (35 ev/ion pair formation)
  - Measure total number of ions produced to determine energy

Energy Loss Overview

1. At sufficiently high energy ion is bare and energy loss is through electronic excitation and ionization of stopping material
2. At velocities comparable to the K-shell electron, ion begins to pick up electrons, stopping is still electronic
3. At velocities comparable to valence electrons elastic collisions account for energy loss
   - nuclear stopping

- No sharp difference point between methods 2 and 3
  - elastic and inelastic collisions

Positive Ions

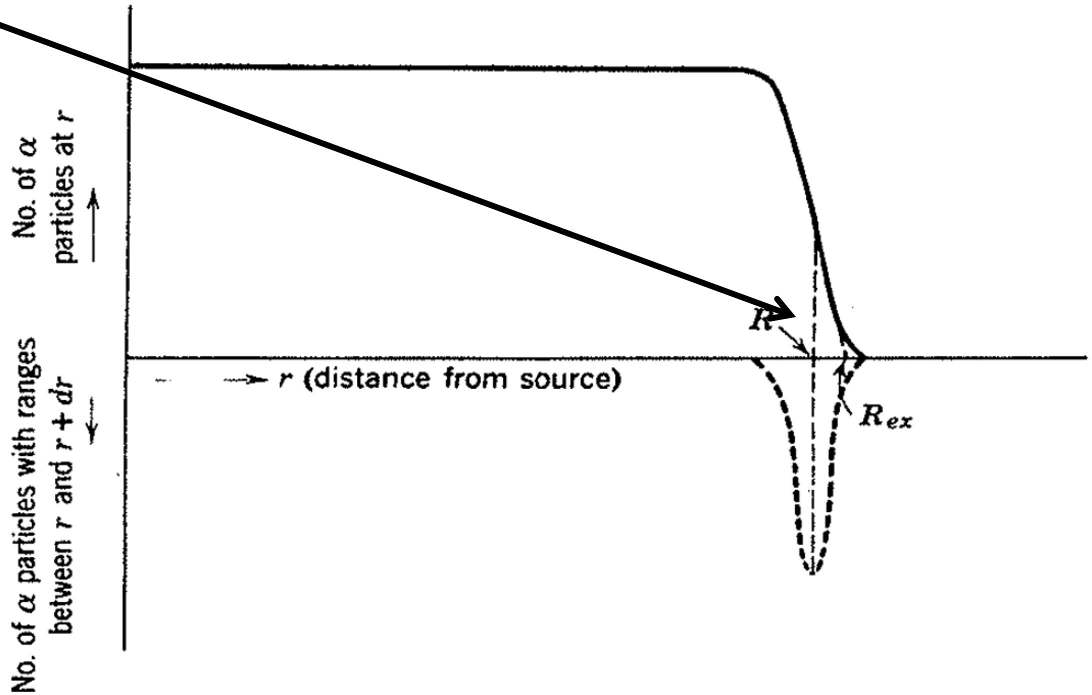
Interaction with matter

- **Neutrons**
  - **Very little interaction with electron, primary ionization is negligible**
  - **Interaction confined to nuclear effect**
    - → **scattering (elastic and inelastic)**
    - → **reactions (n,γ), (n,p), (n,α), (n,2n)**
    - → **fission**

- **Processes for energy loss**
  - **Chiefly by interactions with electrons**
- **Maximum velocity (v) imparted to electron is 2v**
  - $K_E = 0.5mv^2$; $v = (K_E/0.5m)^2$
    - → **Consider maximum energy from 6 MeV alpha to electron**
    - → **Average energy from ions to electrons is 100-200 eV**
      - * **Secondary ionization**
- **Electronic stopping**
  - **inelastic collisions between bound electrons and ion**
    - → **Excitation of atomic electrons**
- **Nuclear stopping**
  - **velocity of ion close to velocity of valence electrons**
  - **elastic collisions dominate**
- **Velocity of the ion comparable to K shell electron, ion begins to pick up electrons**
  - **Ions passing through matter**
    - → **stripped of all orbital electrons whose orbital velocity is less than ion velocity**

Range

- Due to large mass of positive ion compared to electron
- distances that positive ions travel in matter are in narrow limits
  - Particle and energy dependent
  - Defined as range
- Large mass drives behavior
  - Fractional energy loss per collision is small
    - → large number of collisions required to stop ion
  - Deflection of ion in each collision is small
- Straggling is fluctuations in average energy loss and projected path
  - order of a few percent



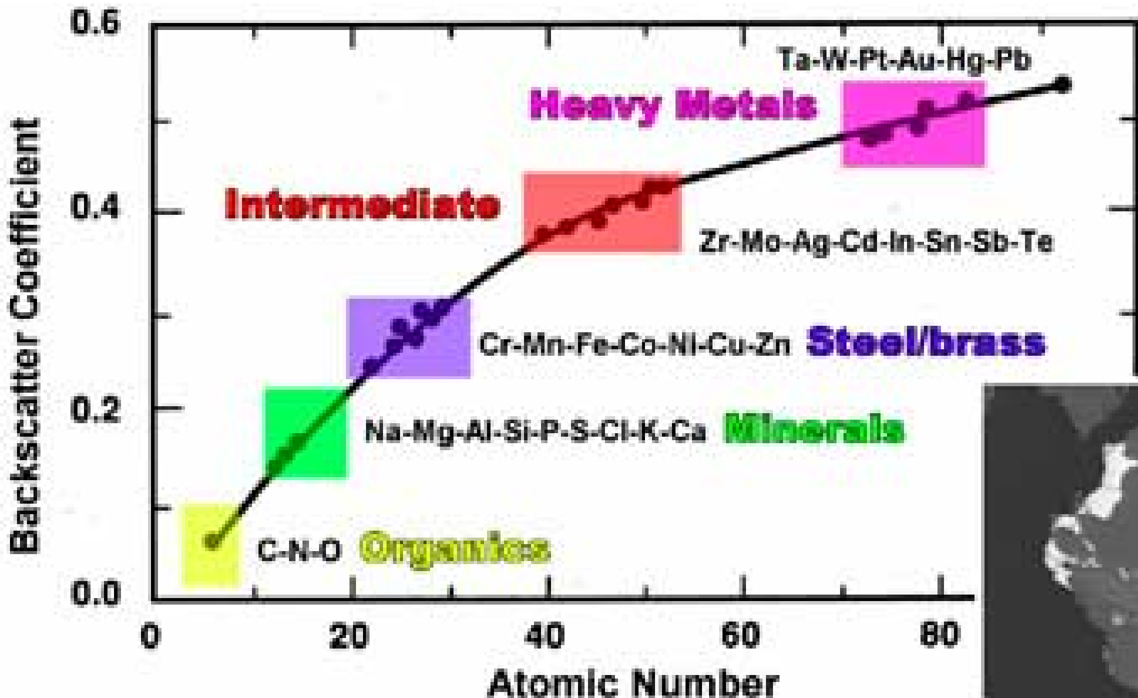
Number of ions from a point source fn(distance)

Electrons

- Energy loss
  - similar to that of positive ions
  - average ion pair formation about 35 eV in air
  - 70-80% of ionization is secondary
- Electron has less mass than positive ions
  - For the same energy, higher velocity
  - Lower stopping power
- Maximum at 146 eV (5950 ion pairs per mg/cm^2)
- In air ionization stops around 12.5 eV
- Electron can lose a large fraction of energy in one collision
- Straggling is more pronounced
- Energy loss through electron interaction, nuclear scattering

Electron Backscattering

- Significant fraction of electrons may be reflected from scattering
- Reflected intensity increases with increasing thickness of reflector
  - Saturation can be achieved
- Ratio of measured activity beta source with reflector to that without reflector is back-scattering factor
- Factor varies with material
  - Used to determine Z of material

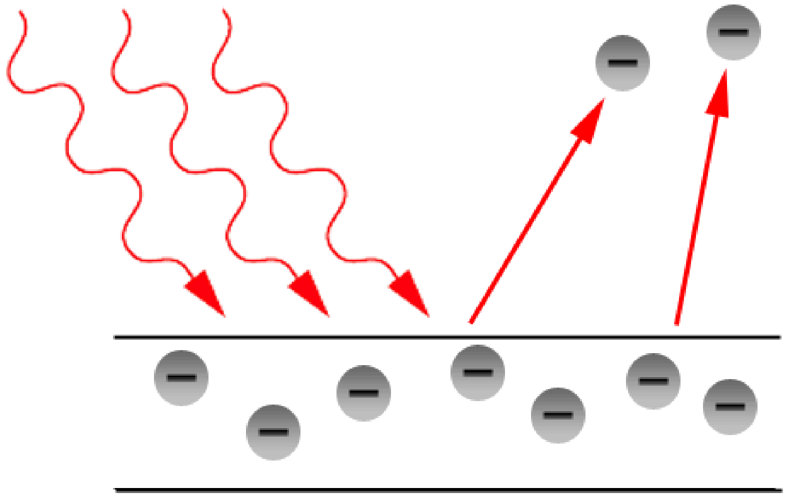


Photons

- **Lose most energy in a few interaction or a single interaction**
- **Need more material for interaction than electron**
- **Average specific ionization is less than electron (10%)**
- **Average energy loss per ion pair formation in air is 35 eV**

Photoelectric effect

- **photon with energy hv ejects bound electron and imparts energy hv-εb to electron**
  - **εb is electron binding energy**
- **Mostly K-shell, some L-shell (about 20%)**
- **Proportional to Z^5 of absorber**
- **For 5% photoelectric effect, γ energy needed for different Z**
  - **Al- 0.15 MeV**
  - **Cu-0.4 MeV**
  - **Sn-1.2 MeV**
  - **Pb-4.7 MeV**



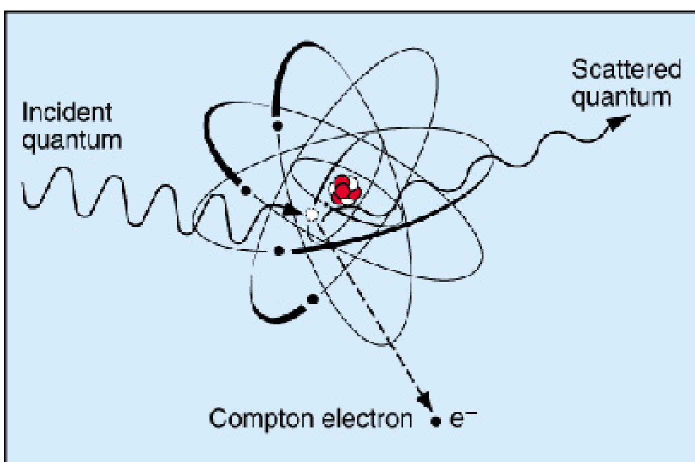
Compton Effect

- Photon loss part of energy to electron
- Photon is scattered
- Minimum for scattered photon is

$$(E'_{\gamma})_{min} = \frac{E_o}{2} \frac{1}{1 + \frac{E_o}{2E_{\gamma}}}$$

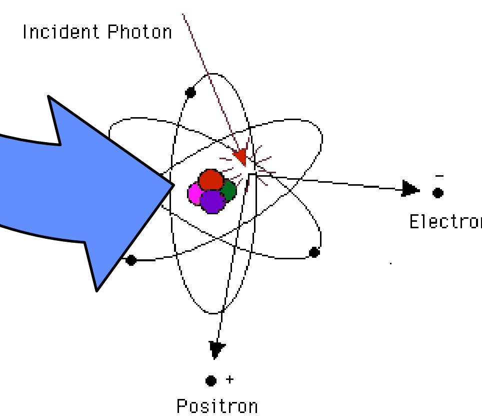
E_o= electron rest energy

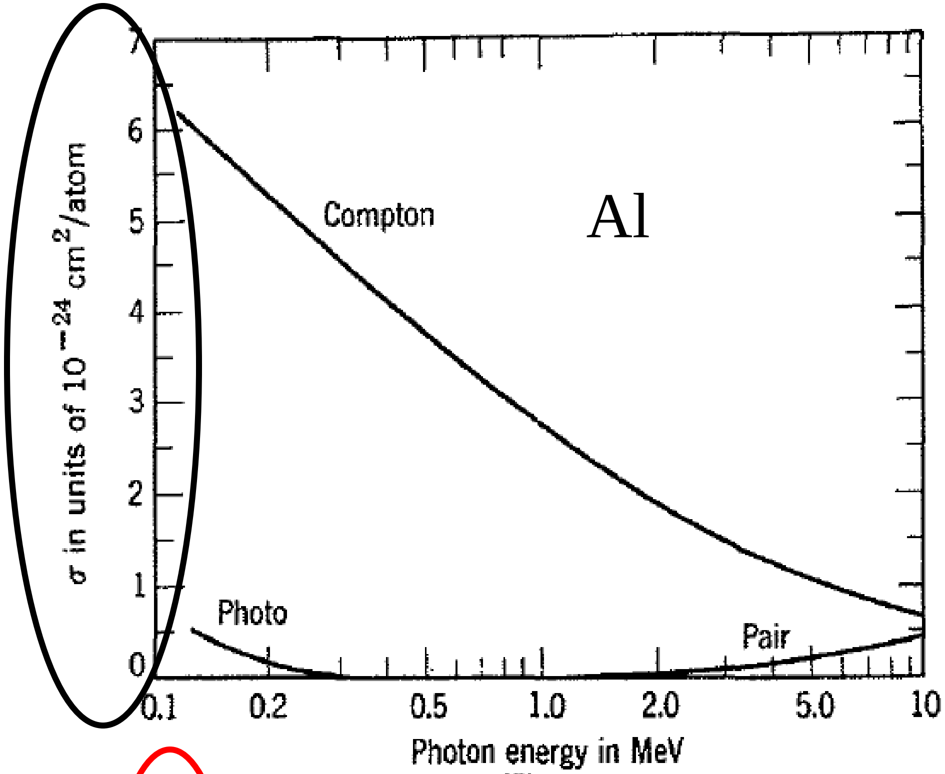
Back scattering peak can be seen on spectra

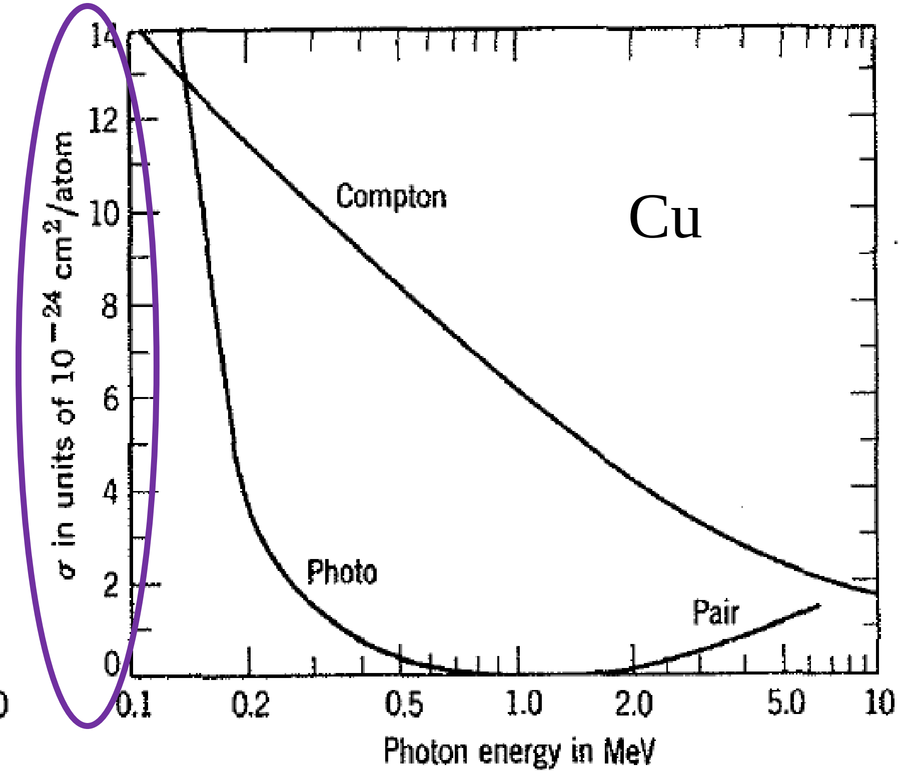


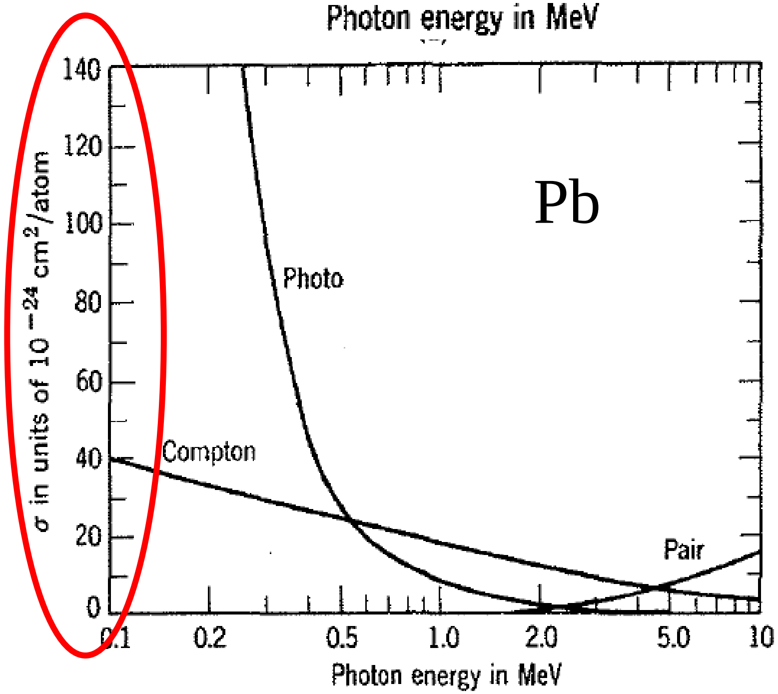
Pair Production

- Production of $ß^+$ and $ß^-$
- Proportional to energy (log E about 4 MeV) and Z^2
- More common at high energy
- 511 keV from positron-electron annihilation









Energy Dependence
Effects with different materials

Radicals are formed by the interaction of radiation with water

Radicals drive reactions

Dosimetry

- Quantitative relation between specific measurement in a radiation field and chemical and/or biological changes
  - dose effect relationship
  - caused by production of ionized molecules, atoms, secondary electrons
  - chemical changes, biological effects

Radiation Dose Units

- Absorbed Dose
  - energy absorbed per unit mass of target for any kind of ionizing energy
  - Gray (Gy) = 1J/kg
  - in US; rad = 100 erg/g
  - 1J/kg = 10^7 erg/10^3 g = 10^4 erg/g

    → 100 rad=1 Gy
- Absorbed dose is referred to as dose
- Treated as point function, having a value at every position in an irradiated object

1 eV = 1.60E-19 J

1 charge pair separation =1.60E-19 C

Dose Equivalent

- **Absorbed dose needed to achieve biological effect is different for different types of radiation**
  - **Difference due to high versus low linear energy transfer (LET)**
  - **Dose equivalent compensates for this difference**
  - **H (dose equivalent) = QD**
  - **Q is dimensionless, has some different values**
  - **Q=fn(particle, energy); 1≤Q≤20**
    - **→ Q from NCRP Report 116**
  - **uses LET (L) in keV/µm in water**

Radiation	QF
X and γ rays	1
Electrons and Positrons	1
Neutrons, E < 10 keV	3
Neutrons, E > 10 keV	10
Protons	1-10
Alpha Particles	1-20
Heavy Ions	20

Q Dependence on LET

LET (L) (kev/µm in water)	Q
<10	1
10-100	0.32L-2.2
>100	300/L^0.5

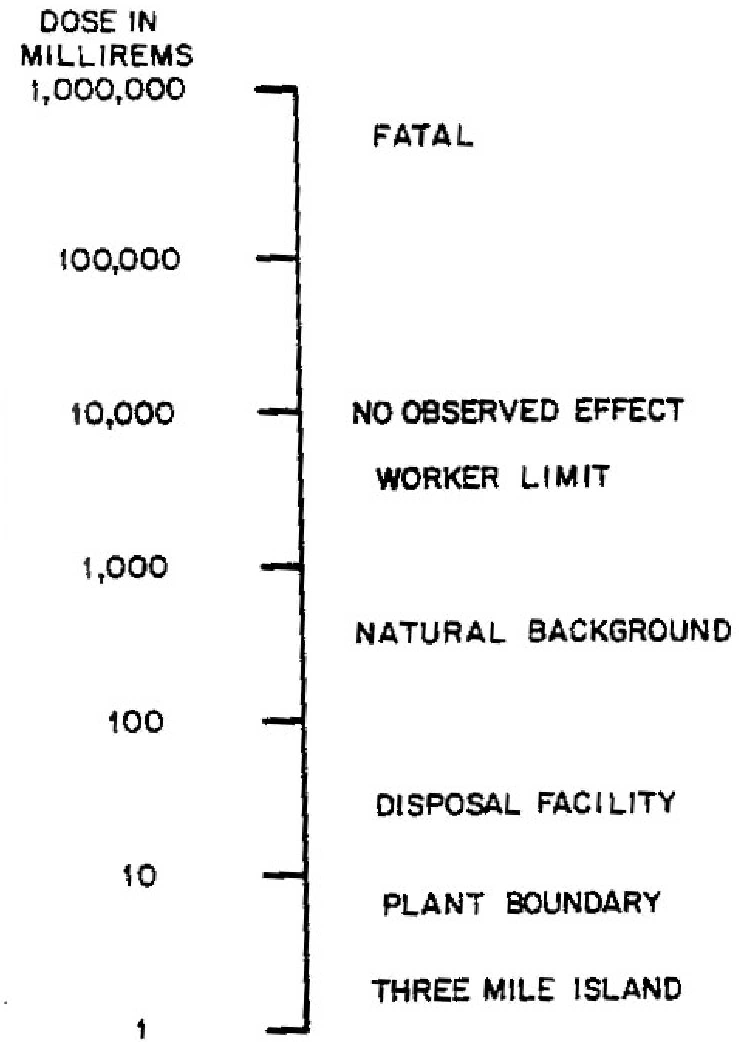
Dose Equivalent

- When dose in Gy, dose equivalent is Sv
- When dose in rad, dose equivalent is rem (roentgen-equivalent-man)
- 1 Gy = 100 rad, 1 Sv = 100 rem
- Particle type and energy should be explicitly considered

- Biological distribution can depend on isotope
  - I to thyroid
  - Sr, Ra to bone
  - Cs, H widely distributed
  - Metals go towards liver
  - Complexes can be released in kidneys
    - →pH change

Radiation Protection

- 6.24 mSv/y Typical background radiation to US public
  - Value updated
- 2.4 mSv/y Average dose to US nuclear industry employees. (0.01mSv/y to public)
- 350 mSv in lifetime Criterion for relocating people after Chernobyl
- 50 mSv annual worker dose limit
- 15 µSv to public from Three Mile Island in 50 mile radius
- 0.4 mSv from dental x-rays
- 1000 mSv as short term dose: causes (temporary) radiation sickness.
- 5000 mSv as short term dose: would kill about half those receiving it within a month.
- 10,000 mSv as short term dose: fatal within days



Dose Calculations

- **Alpha and Beta**
- **Absorbed dose: D = AE_{ave}x1.6E-13J/MeVx1E3g/kg**

=1.6E-10AE_{ave} (Gy/s)

A = conc. Bq/g,

E_{ave}= average energy

Calculated dose of 1.2 E5 Bq of ^{14}C in 50 g of tissue

ßmax of ^{14}C is 0.156 MeV

$E_{ave} \approx ß_{max}/3 \approx 0.052$ MeV

A = 1.2 E5 Bq/50g

D = 1.2 E5 Bq/50g x 0.052 MeV x 1.6E-10 = 20 nGy/s

What does this value mean?

Average background 6.24 mSv/year

2E-10 Sv/second= 0.2 nSv/s

More Dose Calculations

- **Photons**
- **μ/r is air energy absorption coefficient**

= 0.0027 m^2/kg for 60 keV to 2 MeV

D = 3.44E-17 CE/r^2 (Gy/s)

C in Bq, E in MeV and r, distance from source, in m

gamma energy needs to normalized to %

Dose from 10000 Bq ^{38}S at 0.1 m

95 % gamma yield 1.88 MeV

D= 3.44E-17 x 1E5 x 1.88*0.95 / 0.1^2

D = 6.14E-10 Gy/s

Need to consider average gamma energy

$$D = \frac{CE}{4\pi r^2}\frac{\mu}{\rho}$$

Probability Coefficients for Stochastic Effects

Detriment	Adult Workers (1E-2/Sv)	Whole Pop. (1E-2/Sv)
Fatal Cancer	4.0	5.0
Nonfatal Cancer	0.8	1.0
Severe genetic effects	0.8	1.3
TOTAL	5.6	7.3

What is probability of detriment from 2 mSv/y for 10 years to adult worker?

2E-3 Sv/y x 5.6E-2/Sv x 10 y = 1.1E-3

From maximum occupation dose for 30 years

50E-3 Sv/y x 5.6E-2/Sv x 30 y = 0.084

Biological Effects Concepts

Time	Event
10^{-18} seconds	Absorption of Ionizing Radiation
10^{-16} seconds	Ionization, Excitation
10^{-12} seconds	Radical formation, bond breakage
10^{-12} to 10^{-6} seconds	Radical reaction
Min. to Hrs.	Cellular Processes
Hrs. to Months	Tissue Damage
Years	Clinical effects
Generations	Genetic Effects

- **Linear Effect of Dose**
  - **Any amount radiation above background is harmful**
  - **Basis of radioisotope exposure limits**
  - **http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/**

  - **Low level radiation effect not so clear**

Intake limits

- **Air and water**
  - **nuclide specific (include daughter)**
  - **Class refers to lung retention (Days, Weeks, Years)**
  - **Annual limits on Intake (ALI) derived from 0.05 Sv total dose or 0.5 Sv dose to an organ or tissue**
  - **Derived air concentration (DAC) comes from ALI**

DAC = ALI/(2000 hr x 60 min/hr x 2E4 mL/min)

			Table 1 Occupational Values			Table 2 Effluent Concentrations		Table 3 Releases to Sewers
			Col. 1	Col. 2	Col. 3	Col. 1	Col. 2	
				Inhalation				
Atomic No.	**Radio-nuclide**	**Class**	Oral Ingestion ALI (µCi)	ALI (µCi)	DAC (µCi/ml)	Air (µCi/ml)	Water (µCi/ml)	Monthly Average Concentration (µCi/ml)
95	Am-241	W, all compounds	8E-1 Bone Surf	6E-3 Bone Surf	3E-12	-	-	-
			(1E+0)	(1E-2)	-	2E-14	2E-8	2E-7

Isotope data found at: http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb

Laboratory usage

- **ALI and DAC basis of activities levels in the laboratory**
  - http://rms.unlv.edu/radiological/Form%202%20-%20Risk%20Assessment%20and%20Control%20Guideline%20for%20RAM%20(2).pdf
- **Use data to correlate isotope mass, experimental method, and activity level**

ATTACHMENT 2
UNLV RISK ASSESSMENT and CONTROL GUIDELINE for
UNSEALED-RADIOACTIVE MATERIALS

Rad Safety Level	Risk Level	Activity per Experiment * (all apply)	Control Measures	Bioassay Requirement and Periodicity	Air Monitoring
1	**MINIMAL RISK:** Unlikely to produce a dose to a Worker greater than 100 mrem. (**1 ALI intake = 5000 mrem**, **0.01 ALI intake = 50 mrem**)	≤ **.01** ALI-Ingestion Max. = **50** μCi	• General supervision by the Authorized User • Instruction to Workers on rad risks and proper handling procedures • In procedures and post use survey by Worker • Monthly inspection and quarterly survey by Radiation Safety Office	**None**	**None**
2	**LOW RISK:** Possible to receive an annual dose in excess of 5 rem. Mitigated by the Worker: • understanding, and applying good health physics work practices and procedures • use of engineering and contamination control measures (**1 ALI intake = 5000 merm**)	**Non Airborne** >**.01** to ≤ **1.0** ALI-Ingestion **Airborne** ≤ **.01** ALI-Limiting **All** Max. = **5** mCi	• Instruction to Worker on rad risks and proper handling procedures • Review, understand and apply research protocol • Lab specific training by Authorized User followed by routine supervision • In-procedure monitoring and post use surveys by Worker • Monthly inspection and quarterly survey by Radiation Safety Office	**None** **None**	**None** **None**

ATTACHMENT 2
UNLV RISK ASSESSMENT and CONTROL GUIDELINE for
UNSEALED-RADIOACTIVE MATERIALS (cont.)

Rad Safety Level	Risk Level	Activity per Experiment * (all apply)	Control Measures	Bioassay Requirement and Periodicity	Air Monitoring
3	**MODERATE RISK:** Likely to receive an annual dose in excess of 5 rem. Mitigated by: • the Worker has thorough knowledge of radiation safety principles and practices, plus task specific training • use of engineering and contamination control measures • consistent use of task specific control measures • demonstrating ability to effectively control radiation hazards	**Non-Airborne** > **1.0** to ≤**50** ALI-Ingestion **Airborne** > **.01** to ≤**50** ALI-Limiting **All** Max. = **50** mCi	• Protocol approval by Authorized User and RSO • Lab specific training of Worker by Authorized User followed by routine supervision • In-procedure monitoring and post use surveys by Worker • Monthly inspection and survey by Radiation Safety Office		
			Non-airborne > 10 ALI (ingestion) **requires fume hood** **Airborne** • ≥ **0.01** ALI (limiting), **requires fume hood** • ≥ **10** ALI (limiting), **requires negative pressure glove box**	**Baseline bioassay and quarterly bioassay required >5** ALI (limiting) dispersible-airborne	**Routine air monitoring** required if **> 0.01** ALI (inhalation) of dry, dispersible material. **Continuous air monitoring** required if **>0.1** ALI (inhalation) of dry, dispersible material. **Breathing Zone Air-sampling (BZA)** is required when working with ≥ **1** ALI (inhalation) dry, dispersible materials (airborne).

Rad Safety Level	Risk Level	Activity per Experiment * (all apply)	Control Measures	Bioassay Requirement and Periodicity	Air Monitoring
4	**HIGH RISK:** Very likely to receive an annual dose in excess of 5 rem. Mitigated by: • the Worker has advanced knowledge in radiation safety principles and practices, plus task specific training and procedures • consistently using task specific control measures • demonstrating the ability to effectively control radiation hazards	**Non-Airborne** **>50 to ≤ 1,000** ALI-Ingestion **Airborne** **> 50** to **≤1,000** ALI-Limiting **All** Max. = **1000** mCi	• Protocol approval by Authorized User and RSO • Authorized User MUST be present in lab • Initial applied training of Worker by Authorized User followed by routine supervision • In-procedure monitoring and post use surveys by Worker • Weekly survey by Authorized User/Staff • Monthly inspection and survey by Radiation Safety		
			Non-Airborne ≥**100** ALI-(limiting), **requires negative pressure glove box** **Airborne** ≥ **10** ALI (limiting), **requires negative pressure glove box** - 1,000 ALI (limiting) maximum	**Baseline bioassay and quarterly bioassay required.** Work activity review by the Radiation Safety Office may increase bioassay frequency.	**Continuous air monitoring** required **Breathing Zone Air-sampling (BZA)** required

ATTACHMENT 1
EVALUATION of AIRBORNE RADIOACTIVE MATERIALS (cont.)

Nuclide	Limiting Values - Radiological Health*				Rad Level 1**	Rad Level 2	Rad Level 3		Rad Level 4	
	ALI Ingestion (µCi)	ALI Inhalation (µCi)	Ratio Ingestion /Inhalation	Limiting ALI (µCi)	Less Than (µCi)	Not Airborne & Less Than (µCi)	If NOT Airborne Less Than (µCi)	If Airborne Less Than (µCi)	If NOT Airborne Less Than (µCi)	If Airborne Less Than (µCi)
Am-241	0.8	0.006	133	0.01	0.000060	0.80	40	0.30	800	6.00
Am-242m	0.8	0.006	133	0.01	0.000060	0.80	40	0.30	800	6.00
Am-243	0.8	0.006	133	0.01	0.000060	0.80	40	0.30	800	6.00
Ba-133	2,000	700	2.86	700	7.00	2,000	50,000	35,000	1,000,000	700,000
C-14	2,000	2,000	1.00	2,000	20	2,000	50,000	50,000	1,000,000	1,000,000
Cd-109	300	40	7.50	40	0.400	300	50,000	2,000	300,000	40,000
Cl-36	2,000	2,000	1.00	2,000	20	2,000	50,000	50,000	1,000,000	1,000,000
Cm-244	1.0	0.010	100	0.01	0.00010	1.00	50	0.50	1,000	10
Cm-248	0.2	0.002	100	0.002	0.000020	0.20	10	0.10	200	2.00
Co-57	4,000	700	5.71	700	7.00	4,000	50,000	35,000	1,000,000	700,000
Co-60	200	30	6.67	30	0.300	200	50,000	1,500	200,000	30,000
Cs-137	100	200	0.50	100	1.00	100	50,000	5,000	100,000	100,000
Eu-152	800	20	40	20	0.200	800	50,000	1,000	800,000	20,000
Eu-154	500	20	25	20	0.200	500	50,000	1,000	500,000	20,000
Eu-155	4,000	90	44	90	0.900	4,000	50,000	4,500	1,000,000	90,000
Gd-148	10	0.008	1,250	0.01	0.000080	10	500	0.40	10,000	8.00
H-3	80,000	80,000	1.00	80,000	50	5,000	50,000	50,000	1,000,000	1,000,000
Hf-175	3,000	900	3.33	900	9.00	3,000	50,000	45,000	1,000,000	900,000
I-125	40	60	0.67	40	0.400	40	2,000	2,000	40,000	40,000
I-131	30	50	0.60	30	0.300	30	1,500	1,500	30,000	30,000
Mn-54	2,000	800	2.50	800	8.00	2,000	50,000	40,000	1,000,000	800,000

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EVALUATION of AIRBORNE RADIOACTIVE MATERIALS (cont.)

Nuclide	Limiting Values - Radiological Health*				Rad Level 1**	Rad Level 2	Rad Level 3		Rad Level 4	
	ALI Ingestion (µCi)	ALI Inhalation (µCi)	Ratio Ingestion /Inhalation	Limiting ALI (µCi)	Less Than (µCi)	Not Airborne & Less Than (µCi)	If NOT Airborne Less Than (µCi)	If Airborne Less Than (µCi)	If NOT Airborne Less Than (µCi)	If Airborne Less Than (µCi)
Na-22	400	600	0.67	400	4.00	400	50,000	20,000	400,000	400,000
Np-237	0.5	0.004	125	0.004	0.000040	0.50	25	0.20	500	4.00
P-32	600	400	1.50	400	4.00	600	50,000	20,000	600,000	400,000
P-33	6,000	3,000	2	3,000	50	5,000	50,000	50,000	1,000,000	1,000,000
Pb-210	1.0	20	0.05	1.00	0.010	1.00	50	50	1,000	1,000
Po-210	3.0	0.60	5.00	0.60	0.0060	3.00	150	30	3,000	600
Pu-236	2.0	0.020	100	0.02	0.00020	2.00	100	1.00	2,000	20
Pu-238	0.9	0.007	129	0.01	0.000070	0.90	45	0.35	900	7.00
Pu-239	0.8	0.006	133	0.01	0.000060	0.80	40	0.30	800	6.00
Pu-240	0.8	0.006	133	0.01	0.000060	0.80	40	0.30	800	6.00
Pu-241	40	0.30	133	0.30	0.0030	40	2,000	15	40,000	300
Pu-242	0.8	0.007	114	0.01	0.000070	0.80	40	0.35	800	7.00
Ra-226	2.0	0.60	3.33	0.60	0.0060	2.00	100	30	2,000	600
Sb-125	2,000	500	4.00	500	5.00	2,000	50,000	25,000	1,000,000	500,000
Sm-147	20	0.070	286	0.07	0.00070	20	1,000	3.50	20,000	70
Sr-85	3,000	2,000	1.50	2,000	20	3,000	50,000	50,000	1,000,000	1,000,000
Sr-90	30	4.00	7.50	4.00	0.040	30	1,500	200	30,000	4,000
Tc-99	4,000	700	5.71	700	7.00	4,000	50,000	35,000	1,000,000	700,000
Tc-99m	80,000	200,000	0.40	80,000	50	5,000	50,000	50,000	1,000,000	1,000,000
Th-229	0.6	0.001	667	0.001	0.000009	0.60	30	0.05	600	0.90
Th-230	4.0	0.006	667	0.01	0.000060	4.00	200	0.30	4,000	6.00
Th-232	0.7	0.001	700	0.001	0.000010	0.70	35	0.05	700	1.00
Tl-204	2,000	2,000	1.00	2,000	20	2,000	50,000	50,000	1,000,000	1,000,000
U-232	2.0	0.008	250	0.01	0.000080	2.00	100	0.40	2,000	8.00
U-233	10	0.040	250	0.04	0.00040	10	500	2.00	10,000	40
U-235	10	0.040	250	0.04	0.00040	10	500	2.00	10,000	40
U-238	10	0.040	250	0.04	0.00040	10	500	2.00	10,000	40
Zn-65	400	300	1.33	300	3.00	400	50,000	15,000	400,000	300,000
Zr-95	1,000	100	10	100	1.00	1,000	50,000	5,000	1,000,000	100,000

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	ALI Ingestion (µCi)	ALI Inhalation (µCi)	Ratio Ingestion /Inhalation	Limiting ALI (µCi)	Less Than (µCi)	Not Airborne & Less Than (µCi)	If NOT Airborne Less Than (µCi)	If Airborne Less Than (µCi)	If NOT Airborne Less Than (µCi)	If Airborne Less Than (µCi)
Tc-99	4,000	700	5.71	700	7.00	4,000	50,000	35,000	1,000,000	700,000

- Up to 1 ALI-ingestions
  - →10 µCi limit
- A=3.7E5 Bq, λ= 4.88E-18 s^{-1}
- A/ λ=N, N=7.58E22=0.126 moles=30 g U
  - →Level 3, non-airborne 500 µCi limit
  - →1500 g U, in fume hood

• Level 3 for for ^{99}Tc, non-airborne
- Up to 50000 µCi limit
- A=1.85E9 Bq, λ= 1.03E-13 s^{-1}
- A/ λ=N, N=1.79E22=2.98E-2 moles=2.95 g Tc

Hot Atom Chemistry

- Chemical processes that occur during nuclear reactions
  - Also called Szilard-Chalmers process
- Example: Activity of I extracted from water and ethyl iodide
  - Precipitated at AgI
- Chemical reactions produced by nuclear transformation
  - Neutron irradiation of ethyl iodide
    - → Iodine extracted into aqueous phase
      - * $^{127}I(n,\gamma)^{128}I$
        - Possible to produce specific isotope
- Need to overcome bond energy
  - Neutron does not normally contain sufficient energy
  - Gamma decay can provide suitable energy from recoil
    - → M is atom mass, E is gamma energy in MeV
      - * Nucleus excited 6-8 MeV

$$R(eV) = \frac{537E_\gamma^2}{M}$$

Table 11-3 Recoil Energies in Electron Volts Imparted to Nuclei by Gamma Rays of Various Energies

M	$E_\gamma = 2$ MeV	$E_\gamma = 4$ MeV	$E_\gamma = 6$ MeV
20	107	430	967
50	43	172	387
100	21	86	193
150	14	57	129
200	11	43	97

Hot Atom Chemistry

- **Bonds are broken due to reaction energy**
  - **Bond energies on the order of eV**
- **Conditions needed**
  - **Bond of produced atom must be broken**
  - **Should not recombine with fragments**
  - **Should not exchange with target molecule**
    - → **Slow kinetics**
  - **Separation of new species**
- **Halogens produced in this method**
  - CCl_4
  - $C_2H_2Cl_2$
  - C_2H_5Br
  - $C_2H_2Br_2$
  - C_6H_5Br
  - CH_3I
    - → **Used to produce ^{38}Cl, ^{80}Br, ^{82}Br, ^{128}I**

Hot Atom Chemistry: Chemical Reactions

- Beta reactions can also be exploited
  - $TeO_3^{2-} \rightarrow IO_3^{-} + e^{-}$
    - → Recoil is not quantized
      - * Kinetic energy shared
      - * E is maximum beta energy (MeV)
        - $R_{max}(eV)=573E(E+1.02)/M$
        - 0.5 MeV in 100 amu is about 4 MeV
      - * Energy is distributed
        - Translational, rotational, vibrational
      - * Bond usually not broken
  - Internal conversion set atom in excited state
    - → Rearrangement of electrons and drive chemical reactions
    - → Separation of isomers

Table 11-4 Approximate Recoil Energies Expected with Various Nuclear Events (from reference C5)

Nuclear Process	Range of Recoil Energy (eV)[a]
β^- Decay	10^{-1}–10^2
β^+ Decay	10^{-1}–10^2
α Decay	$\sim10^5$
IT	10^{-1}–1
EC	10^{-1}–10^1
n_{th}, γ	$\sim10^2$
n, p	$\sim10^5$
Fission	$\sim10^8$

[a] Based on a hot-atom mass of ~100, the most probable kinetic energy for a given nuclear process, and a range of nuclear energies most frequently encountered.

Review

- **Interaction of radiation with matter**
- **Dosimetry**
  - **Calculations**
  - **Units**
  - **limitation**
  - **Influence of particles**
  - **Measurements**
- **Hot Atom Chemistry**
  - **Energetic processes**

Questions

- **Compare DAC for isotopes of Pu and Cs**
- **Perform a dose calculation for 1 mg internal exposure of ^{210}Po**
- **Use DAC to evaluate experimental limits for ^{241}Am**
- **Calculate the dose from 500000 Bq of ^{241}Am at 0.050 m**
- **What are the different masses of ^{99}Tc permitted for the various laboratory safety levels at UNLV.**
- **What are the principles of hot atom chemistry**

Questions

- **Comment on the blog**
- **Respond to PDF Quiz 7**