Lecture 16. Air toxics. Radioactivity.

Objectives:
1. Toxicity.
2. Exposure and dose.
3. Toxic effects of air pollutants.
4. Radioactivity: sources, physiological effects.

Readings: Turco: p. 183-218; Brimblecombe: p. 149-166

1. Toxicity

Toxic air pollutants are also referred to as air toxics or hazardous air pollutants (HAPs). They are generally defined as those pollutants that are known or suspected to cause serious health problems.

- "Routine" toxic air pollutants are emitted by a variety of industrial sources, motor vehicles, and indoor sources.
- Toxic air pollutants may exist as particulate matter or as vapors (gases).

Which pollutants are considered toxic?

In general, Government agencies are most concerned about substances that fit one or more of these descriptions:

- Can cause serious health effects, such as cancer, birth defects, immediate death, or other serious illnesses.
- Are released to the air in large enough amounts to be toxic.
- Reach many people

Toxicology studies both the adverse effects of chemicals on health and the conditions under which those effects occur.

Major toxic chemicals:

toxic heavy metals (arsenic, cadmium, chromium, iron, lead, manganese, mercury, nickel, vanadium, zinc);

toxic gases (carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide);

toxic organic vapors (acetone, benzene, carbon tetrachloride, glycol ethers, methylene chloride, vinyl chloride, etc.)

toxic particles (soot, dust, asbestos)

NOTE: see tables 7.1, 7.2, and 7.3 in Turco (1997) for effects of various toxics on humans.

2. Exposure and dose.

Exposure is defined by the concentration of a toxin in the local environment and the mode and duration of contact that an individual has with it. Thus, exposure defines the potential for receiving it.

Dose is the amount actually received, or absorbed, in the body, leading to physiological effects.

Dose can be estimated as

D = C R t

where **D** is the estimated dose, **C** is the concentration of a given toxin, **R** is the rate at which air is taken into the lungs, and **t** is the length of time spent in the toxic environment.

- Often, in determining the effects of a toxic compound, the exposure is stated only in terms of the concentration and duration. The actual dose is never calculated.

Maximum tolerated dose (MTD) is the largest amount of a toxin that can be gain by an animal (or human) without killing it.

Lethal dose (LD_{50}) is the dose causing death for 50% of exposed population.

- LD_{50} reveals one of the basic principles of toxicology: not all individuals exposed to the same dose of a substance will respond in the same way.

Health risk assessment is defined as the process of estimating both the probability that an event will occur and the probable magnitude of its health effects over a specified time period. It combines experimental (lab studies) and mathematical models.

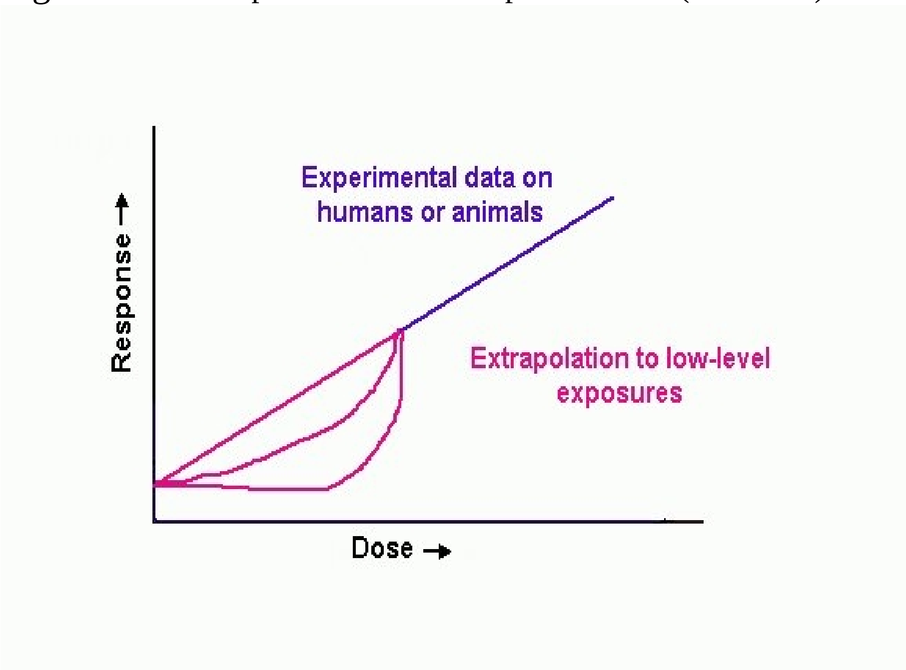
NOTE: more information on risk assessment can be found in Gerba C.P. Risk Assessment. In: "Pollution Science" Pepper I.L., Gerba C.P., and Brusseau M.L. (Eds.), Academic Press, 1996.

NOTE: we will use a box model for risk assessment of urban smog in Lecture 21.

- Most toxicity data come from animal experiments in which researches expose laboratory animals (mostly mice and rats) to high concentrations or doses and observe corresponding effects. The goal of **a dose-response assessment** is to obtain a mathematical relationship between the amount (concentration) of a toxicant to which a human is exposed and the risk of an adverse outcome from the dose.

NOTE: lab data are obtained for large doses. Therefore, there is a problem how to extrapolate to lower doses. Consequently, dose-response curves are subject to controversy because their results change depending on the method of extrapolation.

Figure 16.1 Extrapolation of dose-response curves (U.S. EPA).



Major sources of uncertainties of the risk assessment:

- extrapolation from high to low doses (see Figure 16.1)
- extrapolation from animal to human responses
- extrapolation from one route of exposure to another
- limitations of analytical methods
- estimates of exposure

3. Toxic effects of air pollutants.

Four major sources of information on health effects in human populations:

1. Summaries of self-reported symptoms in exposed persons.
2. Case reports prepared by medical personnel.
3. Correlation studies, in which differences in disease rates in human populations are associated with differences in environmental conditions.
4. Epidemiological studies (that compare the health status of a group of persons who have been exposed to a suspected agent with that of a non-exposed control group).

Acute toxicity is an adverse effect seen soon after a one-time exposure to a chemical.

Chronic toxicity results from long-term exposure (for instance, cancer).

Route of the chemicals in a human body:

absorption, distribution, metabolism, and excretion (ADME).

Adsorption is a process to gain a chemical by the body. The possible ways to gain a chemical: **ingestion** (by drinking or eating), **inhalation** and **skin absorption**.

Distribution is a process of distributing throughout the body a chemical absorbed into the body.

Metabolism describes how living organisms convert absorbed chemicals into other chemicals.

Excretion is a process of removal of a chemical from the body.

Organ systems affected by toxicants:

- skin (skin irritation; allergy; skin cancer)

major toxics: acids, formaldehyde, arsenic.

- lungs

major toxics: reactive gases (ozone, formaldehyde, ammonia, chlorine, sulfur dioxide), particulates (silica, asbestos, coal, dust), organic solvents.

- liver

major toxics: chloroform, carbon tetrachloride, organic solvents.

- kidneys

major toxics: heavy metals (mercury, cadmium, lead).

- central nervous system

major toxics: carbon monoxide, certain pesticides, nerve gases (any substance that lower oxygen to the brain).

- reproductive system (toxics can kill the embryo or fetus or cause other damaging changes th at result in mental retardation, deformed organs, etc.)

major toxics: various toxic chemicals (referred as teratogens)

- immune system (immunotoxic substances cause suppressing of its function or overreaction)

major toxics: tree and flower pollens, PCBs (polychlorinated biphenyls).

4. Radioactivity is one of the most widespread toxins in the environment. Every day we are exposed to natural and human-made sources of radioactivity.

- **The nuclei of heavy elements (with atomic numbers > 84)** are unstable due to repulsion caused by the Coulomb force.

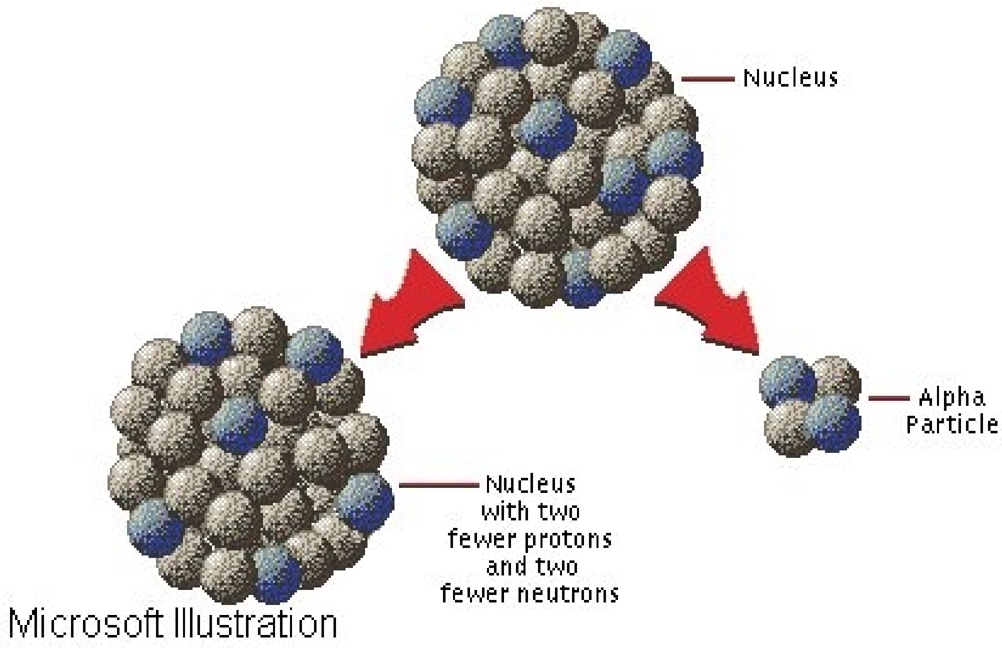
NOTE: recall atomic number, protons, neutrons, isotopes, etc. introduced in Lecture 5

Radioactivity is the products of decay of unstable atomic nuclei.

Radioactive decay produces alpha (α) and beta (β) particles and gamma (γ) rays which carry a large part of the nucleus binding energy.

- Alpha particles are the nucleus of helium, consisting of two protons and two neutrons and caring a positive charge associated with protons. Beta particles are high velocity electrons that carry negative charge. Gamma rays are high-energy electromagnetic radiation with very short wavelengths (see Lecture 15).

Figure 16.2 Radioactive production of α-particles.



Example of alpha decay:

alpha decay of radium (atomic number 88): $^{226}Ra \rightarrow {}^{222}Rn + \alpha$

NOTE: 226 means sum of protons + neutrons (or mass number) (see Lecture 5).

Example of beta decay:

beta decay of bismuth (atomic number 83): $^{214}Bi \rightarrow {}^{214}Po + \beta$

NOTE: the mass number does not change with beta decay but the atomic number of the decaying species increases.

<u>Four principal decay chains</u> (named according to the initial heavy element):

actinium, Ac (atomic number 89);

thorium, Th (atomic number 90);

uranium, U (atomic number 92);

neptunium, Np (atomic number 93)

Half-life of a radioactive species is the time it would take for half the existing atoms to decay.

Law of radioactive decay

$$N(t) = N(0)/2^{p}, \quad p = t/t_{1/2}$$

where **N(t)** is the total number of radionuclides at time **t**; **N(0)** is the initial number of radionuclides at t = 0; and $t_{1/2}$ is the half-life time.

Table 16.1 Half-lives of common radioactive elements.

Radio-nuclides	*Common name*	*Half-life*
^{3}H	Tritium	12.3 years
^{14}C	Carbon-14	5715 years
^{60}Co	Cobalt-60	5.3 years
^{85}Kr	Krypton-85	10.4 years
^{90}Sr	Strontium-90	28.0 years
^{131}I	Iodine-131	8.04 years
^{137}Cs	Cesium-137	30.2 years
^{234}U	Uranium-234	245,000 years
^{235}U	Uranium-235	700 million years
^{238}U	Uranium-238	4.5 billion years
^{239}Pu	Plutonium-239	24,400 years
^{226}Ra	Radium-226	1622 years
^{222}Rn	Radon-222	3.8 days
^{218}Po	Polonium-218	30.5 minutes
^{214}Bi	Bismuth-214	19.7 minutes
^{214}Po	Polonium-214	1.6×10^{-4} sec

Sources of radioactivity:

- **natural radioactivity** (galactic cosmic rays; Earth's radioactive elements)
- **sources caused by human activities** (nuclear weapons, reactors, nuclei power plants).

Units of radiative doses:

Roentgen, R, (is defined in terms of ionization of air by the energetic photons of X-rays or gamma rays).

Rad (is defined in terms of the energy absorbed by 1 kg of a material)

1 Rad = 1/ 100 J/kg

Rem (is the dose of ionizing radiation from any source that produces the same biological effect in humans as does 1 roentgen of X-rays or gamma radiation)

Physiological effects of radioactivity:

the energetic particles and electromagnetic radiation emitted by radionuclides can damage human tissue. Gamma rays are the most penetrating.

Radiation sickness is caused by acute (short-term) exposure to nuclear radiation.

- The lethal acute whole-body dose of energetic radiation is in range of 450 to 600 rem for an average person (that is, LD_{50})

Table 16.2 Typical radiation exposures for a person living in the United States.

Source	Exposure (millirems/year)
Cosmic radiation	50
From the earth	47
From building materials	3
In human tissues	21
Inhalation of air	5
Total from natural sources	126
X-ray diagnosis	50
Radiotherapy	10
Nuclear power industry	0.2
TV tubes, industrial wastes, etc.	2
Radioactive fallout	4
Total from human activities	67
TOTAL	193

Problem. The half-life of molebdenum-99 is 67 hours. How much of 1 mg sample of ^{99}Mo remains after 335 hours?

Solution.

The law of radioactive decay states that

$$N(t) = N(0) / 2^p, \quad p = t / t_{1/2}$$

where **N(t)** is the total number of radionuclides at time **t**; **N(0)** is the initial number of radionuclides at t = 0 (in our case **N(0) = 1 mg);** and $t_{1/2}$ is the half-life time (in our case $t_{1/2}$ is67 hours).

Thus, $p = t / t_{1/2} = 335 \text{ h} / 67 \text{ h} = 5$

Therefore $N(t=335 \text{ h}) = N(0) / 2^p = 1 \text{ mg} / 2^5 = \underline{0.031 \text{ mg}}$