Radiation: Introduction

- Much has been learned since Roentgen discovered x-rays in 1895 and Becquerel discovered radiation in 1896.
- Radiation burns were first seen in 1896, and x-rays were used to cure a basal cell carcinoma by 1899.
- Studies of exposed workers included scientists, medical staff, radium dial painters, uranium miners, industrial radiographers and nuclear energy workers.

Radiation: Introduction (Cont.)

- Other studied groups include patients exposed for diagnosis and therapy, Japanese atomic bomb survivors, people exposed to fallout from weapons tests and reactor accidents, those exposed via sealed sources and people with naturally high exposure.
- Radiation detecting and quantifying equipment has become increasingly sensitive, allowing for dose-response relationships.
- Industrial radiation levels can be limited to those with extremely low health risks.

Physical Principles

- Emitted energy from radioactive materials and x-ray machines is in the form of high speed particles and electromagnetic photons.
- Transfer of energy to living tissues can disrupt molecular organization.
- Energy is measured in electron volts (eV), which are often used as keV (10^3 eV) and MeV (10^6 eV).
- Atoms consist of a nucleus, with positively charged protons and uncharged neutrons, surrounded by negatively charged electrons.

Physical Principles (Cont.)

- The number of protons is known as the atomic number, and determines the nature of an element.
- Every naturally occurring element except sodium and gold can have different numbers of neutrons, altering the atomic weights, and yielding different isotopes.
- Some isotopes are unstable (due to abnormal proton/neutron ratios) and decay, releasing high energy particles and rays, and producing new elements.

Physical Principles (Cont.)

- All unstable radioisotopes have unique characteristics of the type of emitted radiation, radiation energy, and decay rate
- The decay rate constant is the fraction of a radioisotope that has decayed in a given time (hr., day, year)
- The time in which half of a radioisotope has decayed is the half-life, with 1/4 left after two half-lives, 1/8 after three, etc.
- Radioisotopes often decay into other unstable isotopes, with their own half-lives

Physical Principles (Cont.)

- Units of radioactivity are based on decays per second, with 1 becquerel (Bq) equal to 1 and 1 curie (Ci) equal to 3.7×10^{10}.
- Two radiation types are emitted as particles.
- Alpha particles are helium nuclei ($_2He^{4++}$), which decrease the atomic number by 2 and the atomic weight by 4.
- Alpha particles transfer a high amount of energy over a short penetration distance (blocked by a sheet of paper), and are extremely hazardous if inhaled or ingested.

Physical Principles (Cont.)

Beta particles are electrons ($_{-1}\beta^{0}$) ejected by the splitting of a neutron to a proton and an electron, yielding no change in atomic mass, and an atomic number increased by 1.

Beta particles have a range of energies and can travel from 5 cm to 3 m, with higher energy betas penetrating deeper into tissues.

Particles can collide with electrons, ejecting them from atoms, resulting in ionization and loss of particle energy.

Alphas decrease energy faster than betas.

Physical Principles (Cont.)

When a beta particle collides with an atomic nucleus (e.g. lead), there is an abrupt change in velocity and an x-ray is produced.

For this reason, beta sheeting materials usually have atomic numbers no higher than 13 (aluminum), due to their smaller nuclei.

X-rays and gamma rays are high energy electromagnetic radiation, identical except for their origin and slightly different spectra.

Both ionizing radiations penetrate deep tissues.

Exposure Standards

Exposure effects are related to the energy absorbed in tissues, the type of radiation, and the sensitivity of target tissues.

Two exposure units are the rad and the gray (Gy) with 1 gray equal to 100 rads.

A quality factor (Q) or weighting factor (W_R) of 20 for alpha particles, or 1 for beta and gammas, converts rads to rems, and grays to sieverts (Sv), allowing for different levels of exposure.

Exposure Standards (Cont.)

Burns, epilation and other effects with threshold exposures and magnitudes based on dose are called deterministic (nonstochastic).

Cancer and genetic effects, for which zero thresholds are postulated and probabilities are based on dose are called stochastic.

The Nuclear Regulatory Commission (NRC) sets limits based on recommendations from the International Commission on Radiological Protection (ICRP).

Exposure Standards (Cont.)

To prevent deterministic effects, the limits are 15 rems (0.15 Sv) to the eye lens, and 50 rems (0.5 Sv) to all other tissues (skin).

To limit stochastic effects, the limit for whole body irradiation (usually gamma and x-rays) is 5 rems (50 mSv) in a year.

In 1991, the ICRP recommended combining the two effects in ICRP 60, with whole body occupational limits of a five year average of 20 mSv per year (and a maximum 50 mSv/yr) and a public limit of 1 mSv in a year.

Health Effects

For deterministic effects, extremely high thresholds ranging from 200-6000 rads are needed to produce organ injuries in 1-5% of those exposed.

These effects include sterilization, cataracts, nephrosclerosis, liver failure, hypothyroidism, breast atrophy, bladder ulcers and bone damage.

Stochastic effects occur via the ionization or excitation of relatively few molecules, followed by a series of biological events.

DNA damage can cause point mutations.

Health Effects (Cont.)

- Mutations can be reversed by cellular machinery, if corrected prior to DNA replication.
- Point mutations to somatic cells may result in abnormalities in cells after the DNA has been replicated.
- Point mutations to germ cells may cause hereditable genetic effects that can be passed on to subsequent generations.
- Biological effects of point mutations are cumulative.

Health Effects (Cont.)

- The probability of developing stochastic effects can be compared with those in people only exposed to background levels.
- Below 25 rads, the probability of producing observable stochastic effects is low enough to be masked by background incidence.
- Free radicals, highly reactive molecules with unpaired electrons,can be produced when radiation acts on water.
- Free radicals can damage critical molecules.

Health Effects (Cont.)

- Peroxides can be produced from hydroxyl (•OH) free radicals, also causing damage.
- Early effects of acute exposure include changes in blood-forming, skin, reproductive, gastrointestinal and central nervous systems.
- Changes in the peripheral blood count, especially the death of undifferentiated stem cells, are sensitive indicators of overexposure.
- The skin is prone to damage, with first-degree burns at 300 rads, second-degree at 1000 rads, and third-degree above several thousand rads.

Health Effects (Cont.)

- GI tract irradiation damages or kills basal epithelial cells, causing nausea, vomiting, nausea, hemorrhage, septicemia, electrolyte imbalance and dehydration.
- Gut doses above 1000 rads result in permanent basal cell destruction and death within 1-2 weeks of exposure.
- Temporary male sterility can occur at testicular doses of only 30 rads, with permanent effects above 750 rads.and impotence occurs above 3000 rads.

Health Effects (Cont.)

- Women can experience fertility changes and irregular menstrual cycle after an ovarian dose of several hundred rads.
- Significant death of CNS cells occurs above several thousand rads, with unconsciousness in minutes and death in hours to days.
- Whole body doses above 100 rads lead to acute radiation syndrome, which is a combination of previously listed effects.
- Delayed effects can occur after a severe overexposure or several lesser exposures.

Health Effects (Cont.)

- Depending on the dosage, delayed effects may occur after earlier ones disappear.
- Continued exposure can occur from external or internally deposited sources of radiation.
- A single acute inhalation or ingestion of radioactive materials can lead to chronic irradiation of tissue near the site of deposition.
- Delayed deterministic effects include cataracts and retarded mental and physical development, years after large doses.

Health Effects (Cont.)

Atomic bomb survivors had increased leukemia risk between 3.9-6.4% per rad of bone marrow exposure.

For radioactive materials, the toxic levels are orders of magnitude lower than for non-radioactive materials.

Mixtures of radium and zinc sulfide glow, due to absorption of emitted alpha particles.

Health Effects (Cont.)

Women swallowed luminous radium paint for clocks and dials by pointing their brushes between their lips, causing bone damage including osteogenic sarcoma.

Radium is retained in bones for 25-35 years after exposure, where it is toxic above 0.1 μg and carcinogenic above 1 μg.

Radon gas and its short-lived decay products (daughters) have been associated with lung cancer in miners.

Health Effects (Cont.)

A working level (WL) is a unit of radon daughters with 100 pCi of radon per liter of air.

A working month's (170 hours') exposure at a 1 WL level is called a working level month (WLM).

Continuous 30 day exposure to 1WL is equal to 4.235 WLM.

The average exposure in American homes is 0.0125 WL, or 0.64 WLM in 30, 24 hr days.

Health Effects (Cont.)

The average exposure of groups of miners with excess lung cancer was 22-822 WLM.

Internal dosimetry models consider both radiological and biological parameters.

Radiological parameters include type and energy of radiation, half-life of the radionuclide, and radioactive progeny.

Biological parameters are chemical form, ingestion or inhalation rate, particle size, respiration, metabolism, retention, excretion and organ size.

Health Effects (Cont.)

If the kinetics of a radioactive material is known, one can determine via bioassays, the dose from the intake of any radioisotope.

Soluble radionuclides can be placed in three categories based on their fate, whether that is uniform distribution, specific organ concentration or skeletal deposition.

Bone depositors with short half-lives (<15 days) stay on the surface, exposing the endosteum , while ones with longer half-lives deposit deeper, exposing the marrow.

Health Effects (Cont.)

Treatments given to hasten removal may include increased water consumption (for tritium), and chelation therapy (for bone depositing cations).

In vivo bioassays can only be used for gamma emitters and beta emitters near dense nuclei, which result in x-rays.

In vitro bioassays involve the analysis of bodily fluids, excretions, or exhaled air to estimate the intake of radioisotopes.