Nuclear Chemistry: Dosages of Nuclear Radiation to Humans

Nuclear radiation has a major effect on matter; since nuclear radiation has an energy which is very high relative to the energies of chemical reactions, absorption of nuclear radiation by matter causes many chemical reactions to take place. When the matter which is the target is living tissue, these chemical reactions cause serious injury or death.

Quantitative measurement of nuclear radiation involves two types of units, those units which measure physical nuclear radiation itself and those units which measure the biological effect of nuclear radiation. Physical radiation units measure the activity of a source of radiation. The SI unit of physical nuclear radiation is the becquerel (Bq). A radiation source with an activity of one becquerel has one disintegration per second. An older unit of physical nuclear radiation which is still widely used is the curie (Ci); one curie is 3.7 x 10+10 Bq. Since the curie is a relatively large unit, its subdivisions of millicurie, microcurie, and picocurie are often encountered.

Biological radiation units measure the effect of nuclear radiation on living tissue. The SI unit of biological radiation effect is the gray. One gray corresponds to the transfer of one joule of energy to one kilogram of living tissue. The older unit of rad (rad or D [= 10 mSv]) is exactly 0.01 gray and is now obsolete. However, the older unit of roentgen (R) is still in common use. The roentgen was originally devised as a measurement unit for use with X-rays or gamma rays, and is that quantity of radiation which generates 2.1 x 10+9 ion pairs/cm3 of dry air or 1.8 x 10+12 ion pairs/g tissue. One roentgen is 0.0096 Gy or very nearly one rad.

[one rad = 0.01 gray = 10 mSv]
one roentgen of gamma = 0.0096 gray = one rem of any other radiation

A one-roentgen dose of alpha radiation does not produce the same effect as does a one-roentgen dose of gamma radiation. For this reason, the rem was devised as a unit to measure the additive effects of different types of radiation, especially low-level radiation, for those who work with radioactive materials. The rem, or radiation equivalent in man, is the dose of any type of radiation which in man has the same health effect as one roentgen of X-ray or gamma radiation. The rem is the most common unit used to measure health effects of radiation.

Dose 0 to 25 rem: No detectable clinical effect in humans.
Dose 25 to 100 rem: Slight short-term reduction in number of some types of blood cells; disabling sickness not common.
Dose 100 to 200 rem: Nausea and fatigue; vomiting if dose is greater than 125 rem; longer-term reduction in number of some types of blood cells.
Dose 200 to 300 rem: Nausea and vomiting first day of exposure; then up to a two-week latent period followed by appetite loss, general malaise, sore throat, pallor, diarrhea, and moderate emaciation. Recovery in about three months unless complicated by infection or injury.
Dose 300 to 600 rem: Nausea, vomiting, and diarrhea in first few hours; then up to a one-week latent period followed by loss of appetite, fever, and general malaise in the second week, followed by bleeding, inflammation of mouth and throat, diarrhea, and emaciation. Some deaths in two to six weeks. Eventual death for 50% if exposure is above 450 rem; others

recover in about six months.

Dose over 600 rem: Nausea, vomiting, and diarrhea in the first few hours, followed by rapid emaciation and death as early as the second week. Eventual death of nearly 100%.

One roentgen corresponds to about 1.8 x 10+12/6.023 x 10+23 = 3 x 10-12 moles of ion pairs. For a 70 kg standard man, the volume would be about 0.2 m3 or 2 x 10+5 cm3, so a full-body dose of 0.1 r would correspond to the generation of 2.1 x 10-7 moles/2 x 10+5 cm3 which is 1 x 10-12 molar in ion pairs. This is above the level of concentration of some enzymes in the body system.

Radiation can be measured either in physical radiation units, as by a Geiger counter, or in biological radiation units, which are usually the units of roentgens. Radiation effect is measured by film badges or dosimeters; the latter can contain dye solutions which are bleached by the radiation.

Nuclear radiation at low levels is a part of our environment. Cosmic radiation pervades the entire universe and solar radiation the entire solar system. Much of the solar radiation is blocked by reactions which take place in our atmosphere; in sea-level Miami the natural radiation level is about 65 millirem/year, while at the 1500 meter altitude of Denver it has risen to 125 millirem/year. An airline crew flying 720 h/year would pick up an additional 160 millirem. The long-lived isotopes found in bricks and mortar would add perhaps 7 millirem/year over the level found in a house built of wood.

These natural levels of radiation form a base upon which additional man-made dosages are added. Global nuclear fallout adds less than 4 millirem/year and nuclear power reactors perhaps 0.3 millirem/year. Television sets and smoke detectors each add perhaps 1 millirem/year, gas ranges and clocks 6 to 9 millirem/year. Airport X-rays add very little, perhaps 0.002 millirem, but a medical X-ray adds much more --103 millirem. The largest radiation dose is to smokers; a 1.5 pack-per-day smoker adds 9000 millirem/year from the combustion products, most of which goes directly to the lungs. Except for smokers and persons who work with nuclear radiation sources, the dosage from both natural and man-made sources is below 0.2 rem/year. For those who do work with nuclear radiation, a maximum safety level for a full-body dose is considered to be about 0.1 rem/day.