# RADIOACTIVITY AND HOW IT AFFECTS YOU

All of us are exposed to nuclear radiation every day of our lives from naturally occurring minerals within the earth, traces of radioactive elements within our bodies and cosmic rays from the sun and stars. These sources are mostly unavoidable. However, you should be concerned about local concentrations of nuclear radiation from uranium mine waste, dissolved radioactive elements in the underground water supply, such as radium salts and radon, and wind blown dust and gases from man made radioactive waste around the hundreds of sites dedicated to nuclear power plants, nuclear weapons manufacturing plants and nuclear waste landfills. Radioactive elements are unstable and give off highly energetic charged particles that can damage the genetic blueprint of the living cell. Some of the time the cell can no longer function or repair itself and dies, but occasionally the cell multiplies uncontrollably and becomes a cancer. Obviously, the size, energy and penetrating distance of nuclear particles determine the damage to living matter and the number of breaks and changes in the genetic code.

Nuclear particles are forcefully ejected by unstable atomic elements, each with its own preferred method of releasing the overabundance of energy contained in its nucleus. It first must vibrate itself into the proper pattern. If you were to shake a coin out of a piggy bank you would succeed only when the coin and the slot were aligned and moving in the right direction. Although no one can predict when an individual unstable nucleus of the radioactive atom will give up its excess energy, the time it takes for half of a large number of these atoms to decay can be predicted with statistical accuracy. This is know as the half life of the radioactive element. After ten half life periods have passed, less than a tenth of one percent of the radiation will remain. Some half-life times are long enough to require the radioactive source to be isolated from public exposure for decades, centuries or even millennia.

## ALPHA PARTICLES

The excess energy contained in the atom is released in one of a few basic particles and energetic waves. The Greek alphabet is used to name the particles (in the order of their discovery). The alpha particle is the heaviest. It is produced when the heaviest elements decay. The alpha particle contains two neutrons and two protons and leaves the nucleus at around a tenth the speed of light. Its energy is transferred within a short distance to the surrounding media. However, its short flight knocks about 450,0 00 electrons out of the surrounding atoms. The alpha particle emitter will not penetrate the outer layer of our skin, but is dangerous if inhaled or swallowed. The delicate internal workings of the living cell forming the lining of the lungs or internal organs, most certainly will be changed (mutated) or killed outright by the energetic alpha particle. The number of lung cancer cases among uranium miners from inhaled and ingested alpha sources is much higher than those of the public at large. Radon, the gas produced by the decay of radium-226, also emits alpha particles, which poses a hazard to lungs and airways when inhaled. Homes built in areas with high ground radioactivity should be tested for radon buildup in enclosed basement spaces.

## BETA PARTICLES

The beta particle is an energetic electron given off by the nucleus of unstable isotopes to restore an energy balance. The Rad*Scanner can detect most energetic beta particles through the case. Weaker beta particles can be detected through the tube window. Although the beta particle is around 8000 times smaller than the alpha particle, it is capable of penetrating much deeper into living matter. Each encounter with a living cell, and there may be many before the beta energy is dissipated, is likely to dam age some of the chemical links between the living molecules of the cell or cause some permanent genetic change in the cell nucleus. If the damage occurs within the generative cells of the ovaries or testes, the damage may be passed to new generations. The normal background radiation level must contribute to the mutation of the gene pool. Most mutations are undesirable with a very few leading to "improvements". Any increase in the background level of radiation should be considered harmful.

## GAMMA RAYS

The next "particle" is the very high energy "X-ray" called the gamma ray. It is an energetic photon or light wave in the same electromagnetic family as light and x-rays, but is much more energetic and harmful. It is capable of damaging living cells as it slows down by transferring its energy to surrounding cell components. The Rad*Scanner detects energetic gamma rays through the case walls. Gamma ray sources are used to find flaws in pipes and vessels and to check the integrity of welds in steel.

## COMMON RADIOACTIVE ITEMS

Radium dial, glow-in-the-dark watch and clock faces and compasses, especially those painted in the first half of the 20th century contain large amounts of alpha and gamma emitters that can raise count rate by ten to twenty times or more next to the watch. Rates from a night table alarm clock manufactured in the fifties emit about 40 counts per minute a foot in front of the glass cover. Recently, a fad in jewelry has led to the use of bare watch faces and other parts from broken watches combined as pins or brooches. Some of these have the radium containing paint on them and are quite dangerous. The paint could flake or rub off and be inhaled or eaten.

Watches manufactured since the mid 1960's use tritium, H3, a radioactive form of heavy hydrogen, with a half-life of 12.26 years or Promethium-147, a totally man-made radioactive element with a half-life of 2.64 years. Both of these elements are weak beta and gamma emitters and cannot send many particles beyond the cover glass of the watch. However, greater quantities of these elements must be used to make the same amount of light from luminous paint.

Thorium oxide coated gas lamp mantles used in ornamental gas lanterns and gas burning camping lamps are radioactive. The thorium oxide is chosen because it can be raised to white heat without decomposing. However, the mantle does become extremely fragile and will powder into a fine ash which can potentially be inhaled or ingested. Thorium is a natural alpha emitter with the potential for increasing lung tumours. Thorium disintegrates to produce radon-220, an alpha particle emitting radioactive gas. Other uses of thorium include improving alloys of tungsten and magnesium. Thoriated tungsten welding rods are partly vaporized in the arc welding process. Filaments in electronic tubes and television picture tubes have be coated in thorium oxides to produce electrons more easily.

Cerium oxide, a powdery pink glass and jewellery polishing compound, while not radioactive in itself, is extracted from monazite sands containing thorium oxide. Trace amounts of thorium oxide remain with the extracted cerium oxide. Thorium oxide is a potent alpha particle emitter that poses a serious threat to internal organs if inhaled or ingested.

Most smoke detectors contain about 1 microcurie of Americium 241, an alpha emitter deposited on a thin piece of metal foil surrounded by a metal shield. The alpha particles cannot escape unless the smoke detector is taken apart or vaporized in a fire, but some gamma rays are emitted. The Rad*Scanner reads about 30 counts per minute higher than the background average when place on top off a smoke alarm. The half-life of Am-241 is 458 years and certainly will outlast the useful life of the smoke detector.

Antistatic brushes for photographic use in removing dust from film negatives contain Polonium 210, an alpha emitter that will vaporize appreciably at 55 degrees C (130 degrees F), a temperature that is reached easily on the dashboard of an automobile on a hot summer day. This could be another inhalation danger, if the manufacturing method does not adequately contain the Polonium.

The fluorescent lamp starters, the small cylindrical package mounted in some types of lighting fixtures, contains a glass, gas-filled bulb with less than 15 nanocuries of krypton 85, a beta and gamma emitting radioactive gas with a 10.4 year half life. The purpose of the krypton is to ionize the other gases in the starter tube to assist the lamp starting on a cold morning. Actual amounts must be smaller. The Rad*Scanner has not detected any increase in count levels around these devices.

Pottery glazes and art glass, some ceramic glazed jewellery and cloisonné enamelled jewellery contain high percentages of uranium oxides to produce bright yellows and oranges. Fiesta Red china dishes by Fiestaware produced through 1971 emit gamma and beta. Acidic foods left in contact with this chinaware will dissolve small amounts of these radioactive elements which will be ingested. Enamelled jewellery made with these glazes and worn next to the skin is hazardous.

Some gemstones, notably natural zircons, are radioactive. Additionally, some topaz, beryl and tourmaline stones were treated with neutrons from atomic reactors to deepen or change their color. This treatment left some stones hot enough to be of concern, about 0.2 milliroentgens per hour. Some artificial diamonds are made from metal oxides, such as yttrium oxide stabilized with thorium oxide, a radioactive compound.

Some porcelain teeth, artificially colored with uranium containing metal oxides to improve the reflective appearance, can expose the mouth to 1000 millirem per year for each cap. This is two and a half times the average whole body yearly exposure from all natural sources and medical X-rays.

Radon, a gaseous breakdown product of radium, can build up in enclosed spaces such as basements. A potent alpha emitter, radon is believed to cause as many as 30,000 lung cancer deaths each year in the United States, alone. The United States Environmental Protection Agency has mandated some very sophisticated procedures for measuring trace amounts of radon gas at the levels likely to be found in enclosed spaces. A known volume of air is forced through a filter and the filter is checked for radioactive radon breakdown products. If above average count level within enclosed interior spaces such as basements and ground floor level closets are detected by the Rad*Scanner, additional approved tests for radon should be done.

Potassium-40, a strong beta emitter with a long half life of over 1.3 billion years, makes up only a small proportion (less than 0.02%) of naturally occurring potassium salts. The long half-life means relatively few atoms of potassium-40 decay at a time. The total radioactivity is about 1/1000 of an equal weight of uranium salts. Potassium salt deposits in some places has a higher concentration of potassium-40. Since potassium is indispensable for life of plants and animals, we will find it in almost all foods. Some brands of "salt substitute" made mainly from potassium salts might be marginally more radioactive than others, depending on the source of the ingredients.

During normal operation, nuclear power reactor losses from buildup of gasses and easily vaporized elements are continuously released in small amounts: tritium, iodine, cesium, krypton and xenon. Of these, the tritium can oxidize to form radioactive water and organic compounds. Radioactive iodine concentrates in the thyroid gland and contributes to thyroid malfunctions and tumours. Cesium compounds settle in the bones. Radioactive krypton and xenon are inert gases that do not readily form compounds, but are slightly soluble in body fat and decay to form elements that settle in bone tissue.

## NATURALLY RADIOACTIVE MINERALS

Among the representative list of minerals that are radioactive, a number are listed below. These are concentrated enough to be of interest to mining companies. In addition, many areas have dissolved radioactive salts in sub-surface water greatly in excess of environmentally safe limits and must be treated and filtered to specifically remove this hazard.

In some areas of the USA, mining companies use chemical solutions pumped into the ground to wash out uranium salts. In the USA alone, a quarter of the drinking water supplies contain 2000 picocuries per liter of radon gas. Five percent of the domestic water supplies have radon levels above 10,000 picocuries per liter. Water pumped from private wells should be tested for radioactivity.

In the process of oil exploration and recovery, uranium and radium bearing formations are drilled through and the fluids used to cool and lubricate the drilling bits can be contaminated.

This drilling fluid or "mud" often was left to dry in an open pit. Insoluble radium compounds can build up or "plate up" to alarming levels on the pipe.

Over three billion cubic feet of mine wastes from the uranium and thorium extraction still await proper disposal. These waste heaps remain about 85% as radioactive as the original ore from the radioactive breakdown products of uranium and thorium. Thousands of tons of ore were transported for processing to areas near major population centers, like Niagara, NY, Salt Lake City, Utah, Cincinnati, Ohio and Chicago, IL. In some cases, the mining wastes were used to make concrete for buildings and roads. These m ounds of milling wastes are persistent sources of soluble radium salts and radon gas.

Some radioactive minerals collected are:

Autunite, $Ca(UO_2)_2 (PO_4)_2 \cdot 10\text{-}12\ H_2O$, Hydrated calcium uranium phosphate formed as mixed yellow or green tetragonal platelets that fluoresce bright yellow-green. Cornwall,England; Mount Pine, North Carolina; Western Colorado; Marysville, Utah; near Spokane, Washington. Mount Painter, Australia; Autun, France. Novacekite, Mg rich form of Autunite.

Brannerite, $UTi_2O_6$, A uranium titanate with rare earth and iron oxides varying the composition in rounded black or brown pebbles and triclinic crystals. Found in W. Custer County, Idaho; Elliot Lake District, Ontario,Canada; Transvaal, S. Africa.

Carnotite, $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$, A potassium uranium vanadate in sandy or powdery bright yellow masses. Found in Arizona, Colorado, Nevada, New Mexico, Pennsylvania, Utah in USA; Elliot Lake, Ontario, Canada; Radium Hill, Australia; Katanga; Mexico.

Monazite, (Ce, La, Yt, Th)($PO_4$), Mixed rare earth and thorium phosphates in white, yellow to brown monoclinic prismatic waxy looking crystals. Found in granite and gneiss worldwide.

Thorianite, $ThO_2$, Thorium dioxide in dark grey to black cubic crystals. Found in Easton, Pennsyvania; Betroka, Madagascar; Balagoda, Sri Lanka. Uranothoranite is a thorium rich mineral found with thoranite.

Thorite, $ThSiO_4$, Thorium silicate in yellow-brown to black, tetragonal or pyramidal crystals or masses. Found in Champlain, New York; Esmark, Norway.

Torbernite, $Cu(UO_2)_2(PO_4)_2 \cdot 12H_2O$, A copper uranium phosphate in greenish tabular crystals or scales. Found in Cornwall, England; New Mexico, Hannibal Mine, S. Dakota; the La Sal Mountains of Utah, USA; Mount Painter, Australia; Schneeberg, Germany.

Tyuyamunite, $Ca(UO_2)_2(VO_4)_2 \cdot 10H_2O$, A hydrous calcium uranium vanadate in greenish yellow scales or masses. Found in Montrose County, Colorado, Garfield County, Utah, USA; Turkestan, USSR.

Uraninite, $UO_2$, Uranium dioxide in greenish or grayish brown or black cubic crystals or masses also known as pitchblende or cleveite.

Uranophane or uranotile , Ca(UO2)2(Si2O7 . 6H2O, A hydrated calcium uranium silicate in yellow needle-like crystals or crystaline masses. Found in Mitchell County, N. Carolina, USA; Silesia, Czechoslovakia; Saxony, Germany.

Zircon, the semi-precious stone, can be radioactive, even to the extent that it changes crystal structure over a long period of time.

TERMS AND DEFINITIONS

Atomic number - The number of protons in the nucleus of the atom. Since the protons are positively charged, enough negatively charged electrons are collected around the nucleus to neutralize or charge balance the atom. These protons and electrons give the atom its unique chemical nature.

Atomic mass - The sum of the weights of both the neutrons and the protons in the atom.

Electron - A small negatively charged particle that surrounds the nucleus with a mass about 1/1800 that of the proton . Beta particles are energetic electrons ejected from a radioactive nucleus.

Element - the most basic physical substance composed of all the same type of atoms. Each atom will have the same number of protons. The number of neutrons can differ.

Isotope - Atoms with the same number of protons, but differing in the number of neutrons present in the nucleus. Most elements have more than one isotope.

Neutron - An electrically neutral particle found in the nucleus with a mass almost that of the proton. In the fission process, neutrons are liberated.

Nucleus - The densely packed kernel of the atom containing protons and neutrons. The diameter of the nucleus is 100,000 to 200,000 smaller than the whole atom.

Photon - The smallest unit of light. The photon is often described as a electromagnetic wave or wave packet. Light photons from red to blue in the visible spectrum have increasing energy. X-rays and gamma rays are energetic photons with thousands to millions of times the energy of light photons.

Proton - An electrically positive particle found in the nucleus of the atom. Each proton is balanced by the charge of an electron surrounding the nucleus. The electrically neutral atom has the same number of negative electrons as positive protons.

UNITS OF RADIATION MEASUREMENT

The curie is the number of particles per second from 1 gram of Radium = 3.7 x 10 E10 counts/second = 37 billion cps. = 37 billion Becquerel.

1 Becquerel (Bq) = 1 count per second = 1 event per second

1 microcurie = 1 uCi = 37,000 Bq = 37,000 cps.

1 microcurie = 2.22 x 10E6 disintegrations / minute = 2,220,000 cpm.

1 nanocurie = 1 billionth of a curie = 2,220 disintegrations / minute.

1 picocurie = 2.2 disintegrations / min.

Dosage units:

Gray (Gy) = 1 Joule/kg

Sievert (Sv) = Gray x QF, where QF is a "quality factor" based on the type of particle.

QF for electrons, positrons, and xrays = 1 QF = 3 to 10 for neutrons, protons dependent upon the energy transferred by these heavier particles.

QF = 20 for alpha particles and fission fragments.

The Sievert is a measure of biological effect.

Converting older units:

1 rad = 1 centigray = 10 milligrays ( 1 rad = 1cGy = 10 mGy )

1 rem = 1 centisievert = 10 millisieverts ( 1 rem = 1cSv = 10 mSv )

1 mrad = 10 uGy

Nominal background radiation absorbed dose of 100 mrad/year = 1 mGy/yr.

Nominal background radiation dose biological equivalent of 100mrem/year = 1mSv/yr.

Occupational whole body limit is 5 rem/yr = 50 mSv/yr. ( Recently proposed that levels be reduced to 2 rem/yr.)

2.5 mrem/hr or 25 uSv/hr is maximum average working level in industry.

Exposure rate from Naturally Occurring Radioactive Material (NORM) ; an empirically derived conversion factor for Ra-226 decay series: 1.82 microR/ hour = 1 picoCurie/gram.

Radiation Definitions and Units
Radioactivity
Unit Disintegrations/sec (tps, transformations per sec ) Abbr.
Bequerel 1 (bequerel is the standard international unit) Bq
Curie 3.7 x 10e10 Bq (tps of 1 gm Radium 226) Ci
Microcurie 3.7 x 10e4 Bq mCi
Nanocurie 3.7 x 10e1 Bq nCi
Picocurie 3.7 x 10e-2 Bq pCi

Specific Activity (Bq/gm)

can be calculated from At.Wt Ra226 x Half.Life Ra226

At.Wt element x Half.Life element

Dosage
Unit Equivalent Dose Energy
Roentgen old gamma unit. approx 0.93 rads.
Rad 100 ergs/gram or 0.01 gray or 1 centigray
Gray 1 joule / kg tissue or 100 rads
Rem rads x Q factor estimating Relative Biological Effectiveness
RBE gamma = 1
RBE beta = 1
RBE neutrons = 5-20
RBE alpha = 20
Sievert 100 rem (sievert is the standard international unit)

LET Linear Energy Transfer - similar concepts and ratios to RBE

WLM Working Level Month (170 hours)

For uranium mining = exposure to air containing 100 picocuries (3.7 bequerels) / litre of radon222 and its decay products.

Constants
Constant
SI
cgs

Avagadro’s Number 6.0247 10 e23 mol-1 (atoms/Mol) 6.0247 E23 mole-1 (atoms/Mol)

Energy 1 eV = 1.6 x 10 e-19 Joules (J)
Energy 1 MeV = 1.6 x 1 e-22 Joules
Gas Constant 8.3144 J mole-1 deg.K -1 8.3144 E7 ergs mole-1 deg.K-1
Plank’s Constant 6.6262 E-34 Js 6.6262 E-27 ergs

Standard International Unit Scaling
Term Scale Factor
femto 10 e-15

pico 10 e-12 (trillionth)
nano 10 e-9 (billionth)
micro 10 e-6 (millionth)
milli 10 e-3 (thousandth)
unit 1
kilo 10 e3 (thousand)
mega 10 e6 (million)
giga 10 e9 (billion )
tera 10 e12 (trillion)

Source: Nuclear Wastelands, IPPNW, MIT Press 1995. Based on BEIR V (Committee on the Biological Effects of Ionizing Radiation).

Radiation Levels correlated with Health Damage
Whole body radiation in sieverts
[rems] Health Damage - Immediate Health Damage - Delayed

10

[1,000] or more Death from brain injury and swelling.

## 6-10

[600-1,000] Weakness, nausea, vomiting and diarrhoea followed by apparent improvement. After several days: fever, diarrhoea, blood discharge from the bowels, haemorrhage of the larynx, trachea, bronchi or lungs, vomiting of blood and blood in the urine. Death in about 10 days. Autopsy shows destruction of hematopoietic tissues, including bone marrow, lymph nodes and spleen; swelling and degeneration of epithelial cells of the intestines, genital organs and endocrine glands.

## 2.5-6

[250-600] Nausea, vomiting, diarrhoea, epilation (loss of hair), weakness, malaise, vomiting of blood, bloody discharge from the bowels or kidneys, nose bleeding, bleeding from gums and genitals, subcutaneous bleeding, fever, inflammation of the pharynx and stomach, and menstrual abnormalities. Marked destruction of bone marrow, lymph nodes and spleen causes decrease in blood cells especially granulocytes and thrombocytes. Radiation-induced atrophy of the endocrine glands including the pituitary, thyroid and adrenal glands. From the third to fifth week after exposure, death is closely correlated with degree of leukocytopenia. More than 50% die in this time period. Survivors experience keloids, ophthalmological disorders, blood dyscrasis, malignant tumours, and psychoneurological disturbances.

## 1.5-2.5

[150-250] Nausea and vomiting on the first day. Diarrhoea and probable skin burns. Apparent improvement for about two weeks thereafter. Foetal or embryonic death if pregnant. Symptoms of malaise as indicated above. Persons in poor health prior to exposure, or those who develop a serious infection, may not survive. The healthy adult recovers to somewhat normal health in about three months. He or she may have permanent health damage, may develop cancer or benign tumours, and will probably have a shortened lifespan. Genetic and teratogenic effects.

0.5-1.5

[50-150] Acute radiation sickness and burns are less severe than at the higher exposure dose. Spontaneous abortion or stillbirth. Tissue damage effects are less severe. Reduction in lymphocytes and neutrophils leaves the individual temporarily very vulnerable to infection. There may be genetic damage to offspring, benign or malignant tumours, premature ageing and shortened lifespan. Genetic and teratogenic effects.

## 0.1-0.5

[10-50] Most persons experience little or no immediate reaction. Sensitive individuals may experience radiation sickness. Transient effects in lymphocytes and neutrophils. Premature ageing, genetic effects and some risk of tumours.

## 0-0.1

[0-10] None Premature ageing, mild mutations in offspring, some risk of excess tumours. Genetic and teratogenic effects.

0.0005
[0.05] 50 millisieverts annual maximum
recommended radiation dosage limit. Calculated cost/benefit matters.

Modified after: No Immediate Danger, Rosalie Bertell.

Cancer Risk Estimates
Estimate Fatal Cancers / person-sievert
BEIR V, 1990 0.08 based on Hiroshima Nagaskai data
ICRP 60, 1991 0.05
UNSCEAR, 1993 0.11
US EPA, 1993 incidence risk 0.06 implies 0.04

Source: Nuclear Wastelands, IPPNW, MIT Press 1995, p72-4.

Tissue Weighting Factors, Wf
Tissue or Organ Wf ICRP 26 Wf ICRP 60
Gonads 0.25 0.20
Bone Marow (red) 0.12 0.12
Colon - 0.12
Lung 0.12 0.12
Stomach - 0.12
Bladder - 0.05
Breast 0.15 0.05
Liver - 0.05
Esophagus - 0.05
Thyroid 0.03 0.05
Skin - 0.01
Bone Surface 0.03 0.01
Remainder 0.30 0.05
From Health Physics, Cember, McGraw Hill, 1993, p292.

ICRP 60 (1990) Recommended Dose Limits
Application Occupational Public
Whole body 20 mSv/year

Effective dose averaged over 5 years

- maximum is 50 mSv/year

1 mSv in 1 year
Annual equivalent dose to
Lens of the eye
Skin
Hands and feet
150 mSv
500 mSv
500 mSv
15 mSv
50 mSv
Health Physics, Cember, McGraw Hill, 1993, p291.

Micro-quantitation related to alpha particles in tissue

Histoquantitation Diameter (microns) (u) Volume (cu microns) (cu)

## Cell diameter 7 u 179.59 cu

Alpha tracks diameter 70 u 179,594 cu This volume can contain 1000 cells of 7 u diameter. There are 5,600 zones of this size per cu.mm.

Radiation Levels correlated with Cell Damage
Radiation Level Cell Damage
>= 2.5 kBq Necrosis - Lymph node sclerosis
0.4 kBq/gm or
0.01Gy/day Lymphopenia
Apoptosis

0.4 Bq/g or 0.18 Gy Liver cell damage - enzyme elevation

Micronucleus induction/binucleated cell

72 eV Sister Chromatin exchange induction (SCE) (3.4 SCE per cell per gray)

## Chromosome damage

0.19 Gy Cell cycle delay with raised p53 level (G1 phase delay)

## Cell dynmanics impairment

0.9 - 4.4 Gy Malignant transformation: Rats - Lundgren et al 1995

0.076 /Gy Skin cell cancer induction incidence risk

Transgenerational genome impairment