Facts and Information About Radiation Exposure by Willem Post; dated 15 March, 2011

Elements that contain unstable nuclei are radioactive; they are called radionuclides. They decay by releasing mostly alpha and beta particles accompanied by gamma rays. An alpha particle has low-energy, is positively charged and consists of two protons and two neutrons, i.e., a helium atom without its 2 electrons; it can be stopped by tissue paper or human skin. A beta particle is a high-energy, negatively charged electron (negatron) or a positively charged positron; it can be stopped by a sheet of aluminum. Gamma rays are high energy, short-wavelength, electromagnetic radiation; they can be stopped by concrete or lead.

The energy released by radionuclides may knock electrons out of their orbits around an atom's nucleus. This process is called ionizing radiation. Ionizing radiation damages living tissues, leads to changes in constituents of the cell, including the DNA of chromosomes, and results in changes in structure and function of the cells and organ systems. Understanding the potential for ionizing radiation to effect changes to living tissues requires knowing how much radioactive energy is absorbed by the tissues.

Background radiation comes from outer space, the earth, natural materials (including natural foods), and even other people.

US natural background radiation exposure is an average of 3.6 mSv/yr; Australia 2.4 mSv/yr, Ramsar (Iran) 260 mSv/yr

US total radiation exposure, background plus all other sources, is an average of 6.2 mSv/yr per person, increased from 3.6 mSv/yr about 20 years ago when CT scans were much less common.

Background (3.6 mSv/yr): radon, cosmic, solar, terrestrial (potassium, uranium, thorium)
Human-made (2.6 mSv/yr): CT scans 55%, other diagnostic & therapeutic 24%, other 21%

Examples of industries with significant occupational radiation exposure:

- Airline crew (the most exposed population)
- Industrial radiography
- Medical radiology and nuclear medicine
- Uranium mining
- Nuclear power plant and nuclear fuel reprocessing plant workers
- Research laboratories (government, university and private)

PROTECTION

Multiple-layer, aluminized suits with face masks and leaded-glass goggles provide skin protection against alpha and beta particles. The addition of breathing filters provide protection against ingesting airborne, gamma-ray-emitting radionuclides; inhaling alpha and beta particles emitted by radionuclides and the associated gamma rays may cause cancer. Contaminated air filters need to be frequently replaced.

There is no such portable protection against the gamma rays emitted from radionuclides-contaminated surfaces and spilt liquids.

Advising people to stay indoors is of marginal value, because houses have air leakage of about 1 to 4 air changes per hour (ACH), depending on outdoor wind and temperature conditions; a minimum of 0.5 ACH is needed for health requirements.

UNITS OF IONIZING RADIATION AND WEIGHING FACTORS

Absorbed Dose: A gray (Gy) is a unit of ionizing radiation dose absorbed by biological matter, either through the skin or ingested. The effect of the dose takes into account the amount of ionizing radiation energy absorbed, the type of radiation and the susceptibility of various organs and tissues to radiation damage.

To gauge biological effects the Absorbed Dose is multiplied by weighing factor We, which is dependent on the type of ionizing radiation. Such measurement of biological effect is called "Equivalent Dose" and is measured in sievert (Sv).

Equivalent Dose: Gy x We = Sv

For x-rays, gamma rays, electrons, positrons, muons: We = 1, and 1 Gy x 1 = 1 Sv
For neutrons of different energy levels: We varies from 5 to 20, and 1 Gy varies from 5 to 20 Sv
For alpha particles, fission fragments, heavy nuclei: We = 20, and 1 Gy x 20 = 20 Sv

Example: The Equivalent Dose of mixed radiation may be 0.3 mGy x (We = 5, slow neutron) + 6 mGy x (We = 1, gamma rays) + 0.1 mGy x (We = 20, fast neutron) = 9.5 mSv

Effective Dose: Gy x We x Wt

For bone surface, skin: Wt = 0.01
For bladder, breast, liver, esophagus, thyroid: Wt = 0.05

For bone marrow, colon, lung, stomach: Wt = 0.12
For gonads (testes, ovaries): Wt = 0.20

Example: The above calculated Effective Dose for a bladder may be 9.5 mSv x (Wt = 0.05, bladder) = 0.475 mSv

During an X-ray test, the dense bone tissue absorbs radiation energy causing some instant ionizing damage, such as creating free radicals inside bones, whereas the radiation energy easily passes through the less dense fleshy tissues to the film in old X-ray systems, to the digital sensor in new X-ray systems.

Ingested radioactive particles cause much greater ionizing damage to body tissues for longer periods of time than high energy electromagnetic waves, such as X-rays.

CONVERSION EQUIVALENCE

International System of units (SI Units) and corresponding Common Units

- the becquerel (Bq) is the unit of radioactivity that corresponds to the curie (Ci)
- the gray (Gy = 1 Joule/kg) is the unit of absorbed dose that corresponds to the rad
- the sievert (Sv = 1 J/kg x We) is the unit of Equivalent Dose that corresponds to the rem
- coulomb/kilogram (C/kg) is the unit of exposure that corresponds to the roentgen (R)

1 Joule = 6,200 billion megaelectronvolt (MeV) = 1 Watt.second
1 Bq = 1 disintegration per second (dps)
kBq/sq m = 1,000 Bq of radioactive particulate over an area of 1 sq m
1 TBq = 27 Curies, or 1 pCi = 0.037 Bq
1 GBq = 27 mCi
1 MBq = 27 uCi
37 GBq = 1 Ci

1 rad = 0.01 Gy
1 rem = 0.01 Sv
1 roentgen (R) = 0.000258 coulomb/kilogram (C/kg)
1 coulomb = 1 amp.second; it is a flow of one amp of electric charge for one second.

RADIATION DOSES

The extent and time period of exposure to a dose is important to determine the likely biological damage to a human body. A healthy adult body has a given capacity to repair damage from radiation. Thus a full body exposure to a big dose over a short time is generally more harmful because the body cannot keep up with repairs, than a full body exposure of a small dose over a long time which the body usually can repair as it occurs.

Ingesting (breathing, eating) radioactive particulate, such as radioactive dust blown by the wind from a nuclear plant fire or atomic bomb test, is harmful. As the radioactive particulate enters the cell, it damages the DNA which affects the expression of chromosomes which, in some cases, does not show up for decades as a tumor or cancer, making it difficult to establish cause and effect.

Exposure to other DNA-altering contaminants in the environment, such as urban pollution, lead from paints and gasoline, radon in stone buildings, herbicides, pesticides, industrial waste and agricultural run-off, and lifestyle exposures, such as from smoking, drugs, alcohol and pollutants in the workplace further complicates any cause and effect analyses.

If a significant quantity of radioactive particulate stays in parts of the body, such as radioactive iodine in the thyroid or radioactive polonium (in cigarette smoke) in the lungs, it may cause DNA damage that leads to:

- tumors (thyroid, ovaries, breasts, prostate, lungs, etc.) that may become cancerous
- leukemia, i.e., cancer of the blood and bone marrow
- birth defects
- neurological defects that may hinder future mental development resulting in lower IQs

As a significant part of the US soil, water, fauna (includes people) and flora was exposed to radioactive isotopes from atomic testing in Nevada, mostly during the 40s, 50s and 60s, adverse public health impacts, some lasting more than one generation, have occurred.

RADIATION EXPOSURE MODELS

There are several models to predict the long-term, biological damage caused by ionizing radiation. Three of them are discussed below. The collection and analyses of data to validate one model over another is an ongoing process. Because the current data is inconclusive, scientists disagree on which method should be used. As noted above, any radiation dose needs to be adjusted with energy and tissue weighing factors and subjective factors, such as for a pregnant woman, to determine cancer risks.

Linear No Threshold Model: The linear no threshold model (LNT) is a method for predicting the long-term, biological damage caused by ionizing radiation and is based on the assumption that the risk is directly proportional to the dose at ALL dose levels, i.e., the sum of several very small doses have the same effect as one larger dose. The LNT model does not hold for low-dose ionizing radiation.

Threshold Model: The threshold model assumes very small doses of ionizing radiation have negligible harmful effects below a certain threshold and do have harmful effects above it. The model is widely used in toxicology.

The LNT model predicts higher cancer risks than the threshold model. However, there is little evidence that the LNT model applies in case of cumulative doses totaling less than 100 mSv/yr, i.e., a healthy adult body can repair the damage of these doses. However, this may not be the case for the fetus of pregnant women, newborn infants, young children, sickly/weak/old people, etc. At doses totaling more than 100 mSv/yr, a healthy adult body may not be able to cope with the damage; cancer risks may increase as the dose increases.

Radiation Hormosis Model: The radiation hormosis model holds that chronic low doses of ionizing radiation, in addition to background radiation, are beneficial by activating repair mechanisms that protect against disease; they are not activated in absence of the additional ionizing radiation. One way to increase one's chronic ionizing radiation exposure is to move from a low-lying area to the high mountains. The model predicts the least cancer risks by assuming that radiation is beneficial for very low doses, while still recognizing that it is harmful in large doses.

BANANA EQUIVALENT DOSE, BED

All foods are slightly radioactive, some more than others. All food sources combined expose a person to about 0.4 mSv per year on average.

The average radioactivity of bananas is 130 Bq/kg, or about 19.2 Bq per 150 gram banana. It contains about 450 mg of potassium of which the isotope potassium-40 makes up 0.0117%, or about 53 ugram.

Eating 1,000 bananas, or 40 tablespoons of peanut butter, or smoking 1.4 cigarettes equals a dose of about 0.1 mSv, or one millimort. Cigarette smoke does radioactive damage to a person's body, especially the lungs.

Bananas are radioactive enough to regularly cause false alarms on radiation sensors used to detect illegal smuggling of nuclear material at US ports.

For comparison:

100 Bq/kg: human adult
126 Bq/kg: carrots
130 Bq/kg: banana
207 Bq/kg: brazil nuts

ISOTOPES IN DRINKING WATER AND FOOD

Airborne radioactive isotopes from the Chernobyl and Fukushima Nuclear Power Plant fires were spread by the weather and have entered the soil, water, and the fauna and flora. The isotopes are most harmful if they enter the human body through inhalation, ingestion or open wounds.

The isotopes of greatest concern for drinking water and food (including seafood and kelp) are:

tritium: half-life about 12.3 years, weak beta emitter, does not collect in body, is eliminated with urine.
strontium-90: half-life 29 years, strong gamma-ray emitter, collects in bones and teeth
iodine-131: half-life 8.1 days, beta and gamma emitter, collects in thyroid
cesium-137: half-life 30 years, beta and strong gamma-ray emitter, collects in fleshy tissue, such as kidneys
radium-226: half-life 1,620 years, collects in bones, liver, breast; a major source is flyash from coal plants

Grazing cows concentrate iodine-131 in their milk, causing milk consumers, such as infants, to be excessively exposed, and concentrate cesium-137 in their flesh. Pregnant women, nursing mothers, fetuses and young children face the greatest danger from iodine-131, because it accumulates in the thyroid.

Children are at much higher risk than adults because they are growing, and their thyroid glands are more active and in need of iodine. The gland is smaller in children than in adults, so a given dose of iodine-131 will deliver a higher dose of radiation to a child's thyroid and potentially do more harm.

According to the Centers for Disease Control and Prevention, if an adult and a newborn ingest the same dose of radioactive iodine, the thyroid dose will be 16 times higher to a newborn than to an adult; for a less than 1-year-old, eight times the adult dose; for a 5-year-old, four times the adult dose.

Pregnant women take up more iodine-131 in the thyroid, especially in the first trimester. The iodine crosses the placenta and reaches the fetus; its thyroid takes up more iodine as pregnancy progresses. During the first week after birth a baby's thyroid activity increases up to fourfold and stays at that level for a few days, so newborns are especially vulnerable.

Potassium iodide can protect the thyroid by saturating it with normal iodine. People in Japan have been advised to take it.

EXIT SIGNS AND WRISTWATCHES

- A luminous EXIT sign (1970s) contains about 1,000,000 million Bq (1 TBq), or 27 Curies of tritium. They often end up in landfills causing the leacheate to be contain up to 250,000 pCi/liter, which may be similar to some nuclear plant tritium leaks.

- NRC limit for a wristwatch = 25 mCi of tritium/watch = 25,000,000 pCi of tritium/watch = 925,000 Bq

SOME INTERESTING Bq VALUES

100 Bq: Japan maximum iodine-131/liter for drinking water (babies)
300 Bq: Japan maximum iodine-131/liter for drinking water (older children, adults)
740 Bq: EPA maximum tritium/liter for drinking water, or 20,000 pCi of tritium/liter
1,000 Bq: one kg of coffee
1,000 Bq: one kg of granite (such as a kitchen countertop)
2,000 Bq: one kg of coal ash
2,000 Bq: Japan maximum iodine-131/kg of fish and vegetables
3,000 Bq: radon in a 100 sq meter Australian home
3,000 Bq: I.A.E.A. maximum iodine-131/liter for drinking water (older children, adults)
5,000 Bq: one kg superphosphate fertilizer
7,000 Bq: human adult (100 Bq/kg x 70 kg)
7,000 Bq: Canada (Ontario) maximum tritium/liter for drinking water
10,000 Bq: Switzerland maximum tritium/liter for drinking water
30,000 Bq: household smoke detector with americium
30,000 Bq: radon in a 100 sq meter European home
500,000 Bq: one kg uranium ore (Australian, 0.3%)
925,000 Bq: tritium in one wristwatch
1 million Bq: one kg of low level radioactive waste
25 million Bq: one kg of uranium ore (Canadian, 15%)
70 million Bq: radioisotope for medical diagnostic purposes
1,000,000 million Bq: one luminous EXIT sign with tritium (1970s) = 27 Curies
10,000,000 million Bq: one kg of 50-yr-old, vitrified, high-level nuclear waste
100,000,000 million Bq: radioisotope source for medical therapy = 2,700 Curies

RADIATION DOSES FROM VARIOUS SOURCES

The below table indicates additional radiation above average background exposure:

0.001 mSv: one backscatter wave scan at an airport for about 10 seconds
0.007 mSv: one bitewing X-ray, F-speed film for about 0.4 second
0.01 mSv: living near a nuclear plant for one year
0.014 mSv: one dental X-ray, Panorex, digital for about 18 seconds
0.02 mSv: sleeping next to another person for one year
0.03-0.05 mSv: one airplane cross-country flight of about 6 hours
0.036 mSv: eating one banana per day for a year
0.05 mSv: nuclear plant design standard at perimeter fence for one year
0.1 mSv: living in a brick house instead of a wood-frame house for one year
0.1-0.2 mSv: one skull X-ray for about 0.5 seconds
0.1-0.5 mSv: one chest X-ray for about 0.5 seconds
0.3 mSv: one mammogram for about 0.5 seconds
0.6-1.7 mSv: one abdomen X-ray for about 0.5 seconds
1.5 mSv: EPA maximum for an average adult for one year
2.2 mSv: airline crew member, short flights for one year
2-4 mSv: one head CT scan for about 10 minutes
3-6 mSv: airline crew member, cross-country flights, 900 hrs/yr
3-8 mSv: one barium X-ray for about 0.5 seconds
10 mSv: cooking with natural gas (radon) for a year
5-15 mSv: one full-body CT scan for about 20 minutes
6-18 mSv: one chest CT scan for about 10 minutes
9 mSv: airline crew member, polar flights, such as Tokyo-NYC, 900 hrs/yr

13 mSv: smoking one pack of cigarettes per day for a year
20 mSv: nuclear plant worker, maximum 5-year average*+
50 mSv: cardiac catheterization, coronary angiogram, heart x-ray studies for about 1 hour
50 mSv: nuclear plant worker, maximum total exposure in one year
50-100 mSv: changes in blood chemistry
100 mSv: lowest clearly carcinogenic level; 1 millimort
0.25 Sv: temporary sterility in men
0.50-0.55 Sv: nausea, fatigue within hours
0.70-0.75 Sv: vomiting and hair loss in 2-3 weeks
1-2 Sv: for about an hour, 0 to 5% fatal
2-6 Sv: external-immediate severe skin burns, internal-50% fatal
8-30 Sv: for about an hour, 100% fatal

The above list shows that an airline crew member smoking a pack of cigarettes per day will significantly increase his/her chances of developing cancer and that female crew members should not be flying, smoking and cooking with natural gas during pregnancy.

* Workers exposed to ionizing radiation, such as nuclear plant workers, usually wear personal dosimeters that total various exposures for a period. The total exposure is not to exceed a 5-year average of 20 mSv, with any one year not to exceed 50 mSv. The actual exposures usually are significantly less.

+ Annual dose limits declined from 150 mSv in the 1950s, to 20 mSv at present.

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GRAPHICAL PRESENTATION OF RADIATION DOSES FROM VARIOUS SOURCES

A graphical presentation of radiation doses from various sources was prepared by Randall Munroe and Ellen, Senior Reactor Operator at the Reed Research Center.

Note: some data do not indicate the exposure period.

http://xkcd.com/radiation/

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