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To: Reverend Doe West
From: J. David Litster
Subject: Radiation and Radioactivity

Here is a brief introduction to some of the terms and ideas used to discuss radioactivity and radiation, which I hope some readers of your report may find useful.

What is Radiation?

The kind of radiation we are concerned with is called "ionizing radiation", which interacts with matter to produce charged ions by separating electrons from the atoms. The ions can cause cause chemical changes in tissue, such as modifying the DNA in cells, which may result in long term health consequences. The radiation must have enough energy to make ions. Radio waves, microwaves, and light are forms of electromagnetic radiation which do not have enough energy to produce ions. X-rays and gamma-rays are higher energy forms of electromagnetic radiation which do produce ions.

Commonly, ionizing radiation is produced by the decay of unstable (radioactive) nucleii. In addition to x-rays and gamma-rays, they can produce beta-rays (high energy electrons), alpha-particles (high energy helium nucleii), protons, and neutrons.

How is Radioactivity Measured?

The amount of radioactive material is measured in units of *curies*, abbreviated Ci. A curie is enough material to produce 370 billion (3.7×10^{10}) radioactive decays per second: that is the number produced by one gram of radium. Another unit of activity is the *becquerel*, which is one decay per second.

The amount of radiation absorbed by matter can be described by saying how much *energy* the matter has absorbed. A common unit is the *rad*, which means that one cubic centimeter has absorbed one erg of energy. An erg is a very small amount of energy. (It takes about 42 million ergs to increase the temperature of one cubic centimeter of water by one degree centigrade.) The radiation dose received by an organ, such as the thyroid gland, is usually expressed in rads[1].

[1] Modern writers may use the approved international unit called the *gray*. One gray equals 100 rads.

What is the Biological Effect of Radiation?

If we want to compare the biological effect of exposure to different amounts and kinds of ionizing radiation, we need to know what is called the whole body effective dose equivalent. That is expressed in terms of a unit called the *rem*, which stands for "roentgen equivalent man"[2]. To calculate the effective dose equivalent, the dose of radiation to different organs (bone marrow, lungs, thyroid, etc.) is multiplied by a factor corresponding to the biological effectiveness of the type of radiation. These effective doses for all the organs are multiplied by a weighting factor for each organ and added together. The resulting number, in rems or sieverts, is a measure of the risk of the radiation. All effective dose equivalents which have the same number of rems or sieverts are presumed to pose the same risk of harmful effects, no matter what the source of radiation or what organs received the radiation.

As Dr. James Adelstein explains in his letter of March 24, 1994, high doses of radiation (hundreds of rems) can have two kinds of biological effects in humans and animals. These effects appear shortly after exposure to the radiation, and may be repaired with time. With the studies at the Massachusetts State Schools, we need be concerned only with low doses of radiation (measured in millirems[3]) which have, if any, only delayed effects.

The delayed effects of low doses of radiation are of two kinds: increased incidence of cancer, and an increase in genetic defects. Dr. Adelstein's letter gives the current (conservative) estimates for what these delayed effects may be. In some cases, such as exposure of the thyroid to radiation from iodine-131, large scale epidemiological studies have been made[4], and we have a reasonably good idea of the delayed effects of low doses. Some scholars feel that where iodine-131 is concerned, the effective dose equivalent overestimates the risk by three times. In other situations, we can use the general risk factor proposed by the National Council on Radiation Protection and Measurements, which is that a 1000 millirem exposure carries an increased risk of 5 additional cancers per 10,000 individuals exposed.

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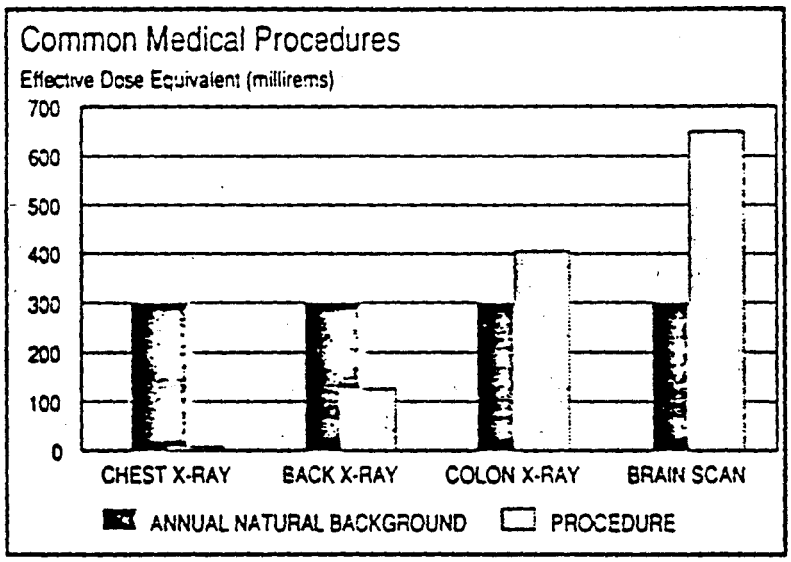
[2]Modern writers may use the approved international unit called the *sievert*. One sievert equals 100 rems.

[3]1 millrem is 1/1000 rem, or 1/100000 sievert.

[4]L.-E. Holm, K.E. Wiklund, G.E. Lundel, N.A. Bergman, G. Bjelkengren, U.C. Ericsson, E.S. Cederquist, M.E. Lidberg, R.S. Lidberg, H.V. Wicklund, and J.D. Boice, Jr., "Cancer Risk in Population Examined with Doses of ^{131}I", *J. Nat. Cancer Inst.* 81, 302-306 (1989).

The whole body effective dose equivalent for some common medical procedures is shown in the graph below, along side the annual 300 millirem natural background effective dose equivalent which is received by residents of the Boston area.



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A PRIMER ON RADIATION

Radiation Comes from Cosmos, Our Bodies; How Much Radiation Is Considered Safe?

Editor's Note: The table below compares 1. the radiation exposures to the whole body which are the established Federal standard for various activities (Note: The first Federal standard for fetuses of pregnant radiation workers went into effect yesterday.); 2. amounts of natural background radiation; 3. common sources of additional radiation; 4. amounts from medical treatment (very high radiation to a limited part of the body); and 5. amounts from diagnostic research (low levels from radioactive tracer elements). The source of this information is Francis Masse, director of the Radiation Protection Office of the Massachusetts Institute of Technology. Masse is a past president of the Health Physics Society and served in 1987-89 as chairman of the National Academy of Sciences panel which reviewed the exposure of soldiers to radiation from atmospheric testing in the 1940s and 1950s.

ASTRONAUTS: 25,000 MILLIREMS PER SHUTTLE MISSION

The highest recommended limit for radiation exposures is for astronauts-- 25,000 milliRems per Space Shuttle mission, principally from cosmic rays. This amount is beyond the average 300+ milliRems of natural sources of radiation and any medical radiation a person has received.

25,000 milliRems per year was the Federal occupational limit during World War II and until about 1950 for radiation workers and soldiers exposed to radiation. The occupational limit became 15,000 milliRems per year around 1950. In 1957, the occupational limit was lowered to a maximum of 5,000 milliRems per year.

AVERAGE NATURAL BACKGROUND: 300 MILLIREMS PER YEAR

The average exposure in the United States, from natural sources of radiation (mostly cosmic radiation and radon), is 300 milliRems per year at sea level. Radiation exposure is slightly higher at higher elevations--thus the exposure in Denver averages 400 milliRems per year.

(A milliRem is 1/1000th of a Rem. According to McGraw-Hill's Dictionary of Scientific and Technical Terms, a Rem is a unit of ionizing radiation equal to the amount that produces the same damage to humans as one roentgen of high-voltage x-rays. The name is derived from "Roentgen equivalent man." Wilhelm Roentgen discovered ionizing radiation in 1895 at about the same time that Pierre and Marie Curie discovered radium.)

All of these limits are for the amount of radiation exposure in addition to background radiation and medical radiation.

ADULT: 5,000 MILLIREMS PER YEAR

The current Federal occupational limit of exposure per year for an adult (the limit for a worker using radiation) is "as low as reasonably achievable; however, not to exceed 5,000 milliRems" above the 300+ milliRems of natural sources of radiation and any medical radiation. Radiation workers wear badges made of photographic film which indicate the exposure to radiation. Readings typically are taken monthly. A Federal advisory committee recommends that the

(MORE)

lifetime exposure be limited to a person's age multiplied by 1,000 milliRems (example: for a 65-year-old person, 65,000 milliRems).

MINOR: 500 MILLIREMS PER YEAR
The maximum permissible exposure for a minor under 18 working with radiation is one-tenth the adult limit or not to exceed 500 milliRems per year above the 300+ milliRems of natural sources, plus medical radiation. This was established in 1957 and reviewed as recently as 1990.

FETUS: 500 MILLIREMS OR 50 PER MONTH (NEW RULE JAN. 1)
New federal regulations went into effect New Year's Day, establishing for the first time an exposure limit for the embryo or fetus of a pregnant woman exposed to radiation at work. The limit for the gestation period is 500 milliRems, with a recommendation that the exposure of a fetus be no more than 50 milliRems per month.

WEIGHT VARIABLES
Like alcohol intoxication levels, levels of exposure to radioactivity (due to radioactivity deposited in the body) depend on a person's weight. A diagnostic tracer of one micro Curie of radioactive calcium 45, given orally, would result in an exposure of 3.7 milliRems for a 100 pound person, and half of that, 1.85 milliRems, for a 200 pound person.

THERAPEUTIC RADIATION
Therapeutic radiation treatment that is delivered by administering radioactive material via the mouth or by injection usually results in high, very localized doses to a small part of the body, which absorbs most of the radioactivity. The radioactivity concentrates and remains in the target organ (example: the thyroid) for a longer period of time than does the radioactivity that is distributed to the rest of the body. The radiation exposure for other parts of the body is a function of the amount of radioactivity per pound and the time the radioactivity is present in the tissue.

GEORGE BUSH'S HYPERTHYROID PROBLEM
For example, a hyperthyroid problem such as that experienced by former President George Bush is typically treated with a radioactive iodine drink designed to deliver about 10,000,000 milliRems of radioactive iodine to the thyroid. It would coincidentally deliver a dose to the rest of the body of about 20,000 milliRems. Another example, using a slightly lower dose of radioactivity, is used for cancerous tumors. A radiation dose to kill a cancerous tumor often sends a radiation beam delivering 6,000,000 milliRems to the cancerous tissue, but the whole body equivalent dose is much less, as it was in the thyroid example cited above.

What is a lethal dose from a single instance of radioactivity? According to studies made after the atomic bomb explosions in 1945 at Hiroshima and Nagasaki, half of the people died whose entire bodies were exposed to 450,000 milliRems of radioactivity from the atomic bomb. All persons died whose bodies were exposed to 600,000 milliRems of radioactivity.

See Table, Next Page.

Federal Standards, Permissible Levels Of Radiation Exposure to Whole Body
(1994 unless *noted otherwise)*

MilliRems Above Natural Background Levels (Average 300) and Medical Radiation

+25,000 Astronauts, per Space Shuttle mission. *This also was the annual occupational limit for adults from World War II through 1950.*

+15,000 1950 to 1957 Occupational limit per year for adults, including radiation workers and soldiers. Limit changed in 1957 to +5,000 milliRems.

+5,000 (Since 1957) Occupational limit per year for adult radiation workers, including soldiers exposed to radiation. It is "as low as reasonably achievable; however, not to exceed 5,000 milliRems." It is recommended that lifetime cumulative exposure is not to exceed the age multiplied by 1,000 milliRems.

+500 Occupational limit per year for a minor under 18 years of age exposed to radiation. An embryo or a fetus of a pregnant worker exposed to radiation (a new regulation as of Jan. 1, 1994) is not to exceed more than 500 cumulated total milliRems before birth, and it is recommended that the exposure of a fetus be limited to no more than about +50 milliRems per month.

Sources of Naturally-Occurring Radiation
(Whole Body Equivalents)

25 to 35 Human body's own radiation dose per year from radioactive elements and minerals in the body.

300 Average annual natural background radiation, sea level (includes your own body radiation, cosmic radiation and radon).

400 The city of Denver's average annual natural background radiation (altitude 5,000 feet).

Common Additional Sources of Radiation
(Whole Body Equivalents)

+12 Coast-to-coast U.S. round trip flight in airplane at 35,000 feet of altitude.

+10 Annual increase due to daily use of salt substitute (potassium chloride) or eating a diet heavy in such potassium-rich foods as bananas and Brazil nuts. Potassium is an essential dietary element that is present mostly in the muscles.

+2 Annual exposure due to watching four hours of television every day.

Therapeutic Doses of Radiation to A Part of the Body
(Whole Body Equivalents)

+20,000 Therapeutic radioactive iodine treatment of thyroid gland. A localized dose delivers 10,000,000 milliRems to the thyroid, and about 20,000 milliRems to the rest of the body. A radiation dose to kill a cancerous tumor often sends a radiation beam delivering 6,000,000 milliRems to the cancerous tissue, but the whole body equivalent dose is much less, as in the thyroid case.

Doses of Radiation for Medical Diagnosis or Research Purposes
(Whole Body Equivalents)

+500 to +200 Cardiac stress test.

+245 Exposure of one 70 pound youth in Federal research at the Fernald School by MIT in the 1940s, using trace elements to track iron absorption while eating cereal. The research showed iron supplements should not be taken with meals.

+172 Average exposure of 17 youths, ages 12 to 17, avg. weight 100 lbs., in the above research.

+127 Exposure of heaviest youth, 135 lbs., in the above research.

+2 to +7 Exposure received by 45 youths, ages 10 to 16, in Federal research in the 1950s by the Fernald School, with the assistance of MIT. The study used radioactive calcium 45 to track calcium absorption. One adult (age 21) received a higher dose, resulting in an exposure equal to 11 milliRems for the whole body.

+2 One Chest X-ray (the whole body equivalent). A typical X-ray exposes the chest to a dose equal to 20 milliRems at the entrance and 1 milliRem at the exit. Averaging this exposure over the whole body yields a whole body equivalent of about 2 milliRems.

The U.S. Food & Drug Administration's current regulations state,
" The amount of radioactive material to be administered shall be such that the subject receives the smallest radiation dose with which it is practical to perform the study without jeopardizing the benefits to be obtained by the study. Under no circumstances may the radiation dose to any adult research subject from a single study, or cumulatively from a number of studies conducted within one year, be generally recognized as safe if such doses exceed the following:

Single dose for an adult	3,000 milliRems
Annual total dose	5,000 milliRems

For a research subject under 18 years of age at the last birthday, the radiation dose shall not exceed 10% of that set forth above."

Therefore, the single exposure limit for a child is 300 milliRems (whole body equivalent) and the annual total exposure cannot exceed 500 milliRems.

Since 1968, medical researchers at the institution doing the research have been required to follow informed consent procedures. These procedures require the assent (if feasible) of a child 7 years of age or older, and the consent of both parents if there is any perceived risk involved in the research.. For research involving any perceived risk, there also has to be a relationship between the study and a child's disorder or disease.

If there is direct benefit that is likely to accrue from participation in the study, then a researcher needs the assent of the child (age 7 or older) and the consent of at least one of the parents. In such direct benefit research situations, the permitted levels of radiation can be exceeded.

END

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