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RADIATION AND PUBLIC HEALTH

PHYSICIANS FOR SOCIAL RESPONSIBILITY PRESENTATION

ON THE MEDICAL CONSEQUENCES OF RADIATION

Ionizing Radiation Basics

Ionizing radiation is radiation with enough energy to remove electrons in the process of interacting with an atom, causing the atom to become charged or ionized. Ionizing radiation has enough energy to produce free radicals, break chemical bonds, produce new chemical bonds and cross-linkages between macromolecules, and damage molecules in human cells that regulate vital cell processes like DNA and RNA, which in turn may lead to cancer.[1] Cells are built to repair certain levels of damage at low doses, but higher doses can cause cell death.

There are three main types of ionizing radiation: alpha, beta, and gamma.

(α) **Alpha particles** are energetic, positively charged particles that rapidly lose energy when passing through matter.

(β) **Beta particles** are fast moving electrons emitted from the nucleus during radioactive decay.

(γ) **Gamma particles** are highly energetic photons that penetrate deeply and are difficult to stop. Gamma rays and x-rays have essentially the same properties but are different in origin: x-rays originated from processes outside the nucleus, while gamma rays originate from within the nucleus of an atom.

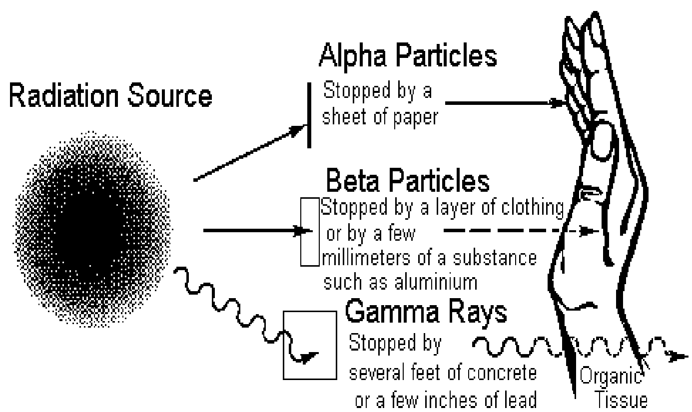

FIGURE 1: THE PENETRATING POWERS OF ALPHA, BETA, AND GAMMA RAYS, NORTH DAKOTA DEPARTMENT OF HEALTH

Dose

To determine biological effects of radiation, one must know or estimate how much energy is deposited per unit mass of the part or whole of the body with which the radiation is interacting. The international (SI) unit of measure for absorbed dose is the gray (Gy), which is defined as 1 joule of energy deposited in 1 kilogram of mass. The old unit of measure for this is the rad, which stands for "radiation absorbed dose." - 1 Gy = 100 rad. Absorbed dose is not the best indicator of biological effect. The risk of stochastic or random effects can be measured better with equivalent dose. Equivalent dose is a quantity which takes into effect 'radiation quality', which relates to the degree to which type of ionizing radiation will produce biological damage.

[1] American Cancer Society, "Radiation Exposure and Cancer" http://www.cancer.org/docroot/ped/content/ped_1_3x_radiation_exposure_and_cancer.asp (2010).

The effective dose is the sum of weighted equivalent doses in all the organs and tissues of the body. Effective dose is found by calculating a weighted average of the equivalent dose to different body tissues with weighting factors designed to reflect the different radio-sensitivities of the tissues. The biological effect, then, depends not only on the amount of the absorbed dose but also on the intensity of ionization in living cells caused by different type of radiations, ie. that different amounts and types of radiations may penetrate various kinds of cells and tissues differently. Alpha radiation can cause 5-20 times more harm than the same amount of the absorbed dose of beta or gamma radiation. The unit of equivalent dose is the sievert (Sv). The old unit of measure is the rem. 1 Sv = 100 rem. The most likely pathway for individuals to be exposed to radiation is with medical testing and background radiation. The chart below demonstrates the various doses an individual would receive in different medical treatments.

Medical Treatments and Effective Radiation Dose[2]

Procedure	Effective Dose
Plain Film X Ray (Skull- Lateral)	1 mrem (0.1 mSv)
Plain Film X Ray (Pelvis-AP)	70 mrem (0.7 mSv)
Nuclear Medicine Scan (Bone)	440 mrem (4.4 mSv)
Barium Enema (10 images, 137 sec flouroscopy)	700 mrem (7 mSv)
CT Scan (Abdomen)	1,000 mrem (10 mSv)
Coronary Angiogram	460-1,580 mrem (4.6-15.8 mSv)

The biological effect of radiation also depends greatly on the age, sex, size, and genetic factors. In general, fetuses, infants, and children are most susceptible to radiation, and women are more susceptible than men. Pregnant women are put at great risk by radiation, not only for the biological effects that may injure the mother, but the effects to the fetus, and also the long-term genetic consequences (particularly if the fetus is female) posed by different kinds of radiation.

Medical Treatments and Effective Radiation Dose (Fetus Exposure)[3]

Procedure	Effective Dose to Fetus (Early Pregnancy)*
Nuclear Medicine Scan (Bone)	460 mrem (4.6 mSv)
Nuclear Medicine Scan (Liver)	600 mrem (6 mSv)
AP Pelvis Study	144 mrem (1.44 mSv)
AP Lumbar Spine Study	225 mrem (2.25 mSv)

*note that studies as to biological effects of radiation on the fetus are estimates beyond this point (based on medical ethics), but the estimated dose goes up as the fetus matures.

[2] Michael G. Stabin PhD, CHP, "Doses from Medical Radiation Sources," Health Physics Society (12/18/2009) http://www.hps.org/hpspublications/articles/dosesfrommedicalradiation.html

[3] *Ibid*.

Internal, External, and Skin Contamination Exposure

External exposure to radiation may occur from sources outside the body such as medical imaging equipment, rocks and dust.

Internal exposure to radiation may occur when radioactive material gets inside the body through ingestion, inhalation, or absorption. Internal radioactive materials produce radiation exposure the entire time they are in the body until the material is no longer radioactive (it decays) or is removed naturally by the body. Unlike the skin on the outside of the body, there is nothing inside to protect cells and tissues from the potentially damaging effects of alpha and beta particles.

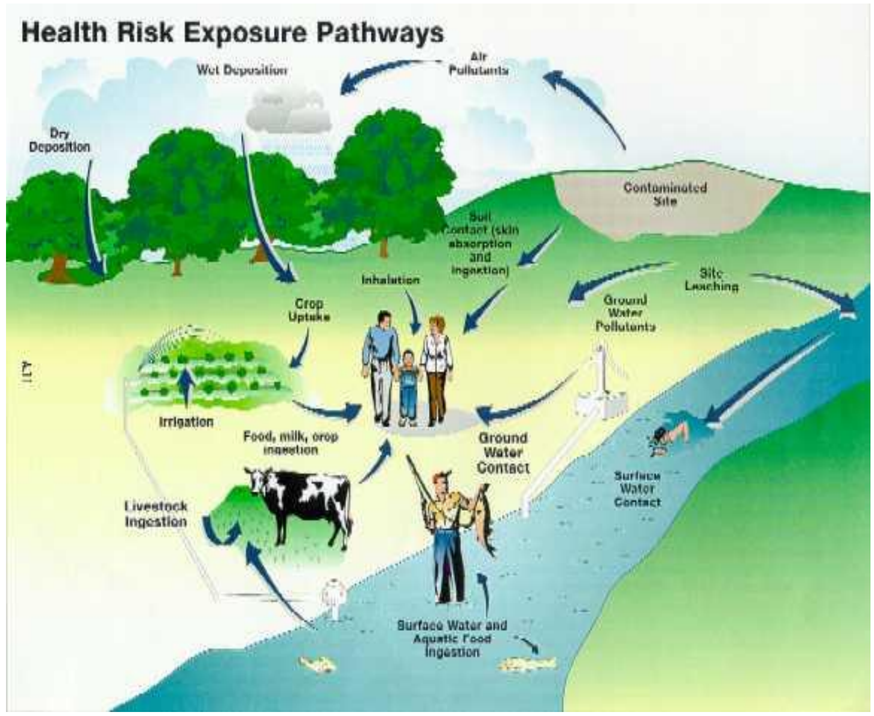

FIGURE 2: RADIATION EXPOSURE PATHWAYS, U.S. ARMY CORPS OF ENGINEERS

Internally, alpha particle can be very harmful. If alpha emitters are inhaled, ingested (swallowed), or absorbed into the blood stream, sensitive living tissue can be exposed to alpha radiation.[4] Alpha particles are particularly hazardous internally because an alpha particle does not travel very far and its energy is deposited within a small volume, increasing the chance of cell death. Beta particles are more penetrating than alpha particles but are less damaging over equally traveled distances. They travel considerable distances in air but can be reduced or stopped by a layer of clothing or by a few millimeters of a substance, such as aluminum. Some beta particles are capable of penetrating the skin and causing radiation damage, such as skin burns. However, as with alpha-emitters, beta-emitters are most hazardous when they are inhaled or ingested.[5] Gamma rays are a radiation hazard for the entire body. While gamma rays can easily pass completely through the human body, a fraction will always be absorbed by tissue.[6]

Skin contamination is something that might occur if liquid radioactive materials are accidentally spilled on the skin. Some beta particles can deliver a skin radiation dose if they are on the skin long enough. Some x- and gamma-ray emitters can also deliver a skin radiation dose but, additionally, they may be a hazard to other body tissues because the x or gamma ray-emitting radioactive material is sitting on the skin and the x or gamma rays can pass through the skin into the body.

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[4] *Ibid*.
[5] *Ibid*.
[6] United States Environmental Protection Agency, Office of Air and Radiation, *Ionizing Radiation Factbook* (March 2007), http://www.epa.gov/radiation/docs/402-f-06-061.pdf.

Radioactive material on the skin that is absorbed or passes through a cut and gets inside the body is considered an internal radiation hazard.[7]

Partial Exposure vs. Total Body Exposure

With natural background radiation, the whole body is exposed. With something like an x-ray, just that area such as the heart or kidneys, is exposed. With most nuclear medicine, many different parts of the body might be exposed at the same time with some of the areas or organs getting a larger dose than others. Radioactive material is usually injected into a patient and gets passed through the body by the blood, finally stopping in specific organs. In that case, the total body receives some radiation dose while the organ or organs that collect the radioactive material receive more radiation dose.

The amount of the body and location within the body receiving a radiation dose are related to the potential harmful effects.[8]

Acute Exposure vs. Chronic Exposure

Radiation exposure might be short-term or long-lasting. The range can be a medical x-ray exposure in which the time of exposure is short—the machine is on and off within a very short period of time—or the kind of long-term exposure that comes from radioactive materials in soil, which present small repeated amounts of radiation exposure that occur over a lifetime. Depending on the source, time of an exposure can vary—in some cases, the time will be very short, seconds or less, and in other cases it will be occurring continuously over a lifetime. Being exposed to radiation in a short period of time or over a long period of time is no indication of the total radiation dose and, thus, the possible health effects that may occur.[9]

Acute radiation syndrome describes a situation in which the entire body is exposed to a large amount of radiation, typically in a short period of time. The symptoms described in the table could apply to emergency workers at the Chernobyl accident in Ukraine in 1986 or victims of the Hiroshima and Nagasaki bombs.

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[7] Health Physics Society, "Skin Contamination," *Radiation Answers* 2007, May 25 2010. http://www.radiationanswers.org/radiation-introduction/radiation-exposure/external-internal/skin-contamination.html

[8] Health Physics Society, "Partial vs. Total Body Exposure," *Radiation Answers* 2007, May 25 2010. http://www.radiationanswers.org/radiation-introduction/radiation-exposure/partial-total-body.html

[9] Health Physics Society, "Acute vs. Chronic Exposure" *Radiation Answers* 2007, May 25 2010. http://www.radiationanswers.org/radiation-introduction/radiation-exposure/acute-chronic.html

Acute Radiation Syndrome

Syndrome	Dose*	Prodromal Stage	Latent Stage	Manifest Illness Stage	Recovery
Hematopoietic	0.7 Gy (mild symptoms may occur as low as 0.3 Gy)	•Symptoms are anorexia, nausea and vomiting. • Onset occurs 1 hour to 2 days after exposure. • Stage lasts for minutes to days.	• Stem cells in bone marrow are dying, although patient may appear and feel well. • Stage lasts 1 to 6 weeks.	•Symptoms are anorexia, fever, and malaise. • Drop in all blood cell counts occurs for several weeks. • Primary cause of death is infection and hemorrhage. • Survival decreases with increasing dose. • Most deaths occur within a few months after exposure.	• In most cases, bone marrow cells will begin to repopulate the marrow. • There should be full recovery for a large percentage of individuals from a few weeks up to two years after exposure. • Death may occur in some individuals at 1.2 Gy (120 rads). • The LD50/60† is about 2.5 to 5 Gy (250 to 500 rads)
Gastrointestinal	Less than 10 Gy(some symptoms may occur as low as 6 Gy)	• Symptoms are anorexia, severe nausea, vomiting, cramps, and diarrhea. • Onset occurs within a few hours after exposure. • Stage lasts about 2 days.	• Stem cells in bone marrow and cells lining GI tract are dying, although patient may appear and feel well. • Stage lasts less than 1 week.	• Symptoms are malaise, anorexia, severe diarrhea, fever, dehydration, and electrolyte imbalance. • Death is due to infection, dehydration, and electrolyte imbalance. • Death occurs within 2 weeks of exposure.	• The LD100‡ is about 10 Gy (1000 rads)
Cardiovascular/central nervous system	> 50 Gy (some symptoms may occur as low as 20 Gy)	• Symptoms are extreme nervousness and confusion; severe nausea, vomiting, and watery diarrhea; loss of consciousness; and burning sensations of the skin. • Onset occurs within minutes of exposure. • Stage lasts for minutes to hours.	• Patient may return to partial functionality. • Stage may last for hours but often is less.	• Symptoms are return of watery diarrhea, convulsions, and coma. • Onset occurs 5 to 6 hours after exposure. • Death occurs within 3 days of exposure.	• No recovery is expected.

Chronic exposure to radioactivity can have a multitude of effects. Chronic exposure to radiation could be received in occupational exposure, i.e. nuclear workers. The effects of high doses are well known but epidemiological studies showing deterministic effects for low-dose radiation are few and far between.

BEIR VII

The National Academies' BEIR VII report concluded in 2005 that any exposure to radiation can have detrimental health effects. The report was focused on low-dose, low-LET — "linear energy transfer" ionizing radiation defined in the range of nearly zero to 100 mSv. Data suggests that low-level radiation has a "linear, no-threshold risk," which means even the smallest dose of radiation has the potential to cause harm to human health. The models in the study predicted that about one out of 100 people would likely develop solid cancer or leukemia from an exposure of 100 mSv. For reference, the typical yearly background radiation exposure for individuals is 3 mSv. About 42 additional people in the same group would be expected to develop solid cancer or leukemia from other causes. Roughly half of those cancers would result in death.[10] According to NAS's estimates, about 3 percent of American public will get a cancer from background radiation, which is equivalent to almost 9 million people of the current U.S. population. [11]

More studies need to be done to determine the long-term medical consequences of exposure to relatively low-levels of ionizing radiation. Recent evidence suggests links between not only cancer and low-level radiation, but potentially heart disease and stroke as well.[12]

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[10] BEIR VII Report, "Health Risks from Exposure to Low-Levels of Ionizing Radiation," National Academies of Science (2005). http://www.nap.edu/openbook.php?isbn=030909156X

[11] Calculation is based on NAS risk figures in the table on page 28 of the BEIR VII report using EPA's background radiation figure of 350 millirems per year.

[12] Little MP, Gola A, Tzoulaki I. A Model of Cardiovascular Disease Giving a Plausible Mechanism for the Effect of Fractionated Low-Dose Ionizing Radiation Exposure. *PLoS Computational Biology*, 2009; 5 (10.