Concepts of Radioactivity

This section introduces some of the basic concepts of radioactivity. It is designed to provide the general reader with an overall understanding of the radiological sections of this report. A discussion of the analyses used to qualitatively quantify radioactive material, the common sources of radioactivity in the environment, and how they contribute to an individual's radiation dose are provided. Some general statistical concepts are also presented, along with a discussion of radionuclides of environmental interest at BNL.

RADIOACTIVITY

The atom is the basic constituent of all matter and is one of the smallest units into which matter can be divided. Each atom is composed of a tiny central core of particles, or nucleus, surrounded by a cloud of negatively charged particles called electrons. Most atoms in the physical world are stable, meaning that they are not radioactive. However, some atoms possess excess energy, which causes them to be physically unstable. In order to become stable, an atom rids itself of this extra energy by casting it off in the form of charged particles or electromagnetic waves, known as radiation.

COMMON TYPES OF RADIATION

The three most important types of radiation are described below:

ALPHA

An alpha particle is identical in makeup to the nucleus of a helium atom, consisting of two neutrons and two protons. Alpha particles have a positive charge and have little or no penetrating power in matter. They are easily stopped by materials such as paper and have a range in air of only an inch or so. Naturally occurring radioactive elements such as uranium and radon daughters emit alpha radiation.

BETA

Beta radiation is composed of particles that are identical to electrons. As a result, beta particles have a negative charge. Beta radiation is slightly more penetrating than alpha but may be stopped by materials such as aluminum foil and Lucite™ panels. They have a range in air of several feet. Naturally occurring radioactive elements such as potassium- 40 (K-40) emit beta radiation.

GAMMA

Gamma radiation is a form of electromagnetic radiation, like radio waves or visible light, but with a much shorter wavelength. It is more penetrating than alpha or beta radiation, capable of passing through dense materials such as concrete. X-rays are similar to gamma radiation.

NOMENCLATURE

Throughout this report, radioactive elements (also called radionuclides) are referred to by a name followed by a number, *e.g.*, cesium-137. The number following the name of the element is called the mass of the element and is equal to the total number of particles contained in the nucleus of the atom. Another way to specify the identity of cesium-137 is by writing it as Cs-137, where 'Cs' is the chemical symbol for cesium as it appears in the standard Periodic Table of the Elements. This type of abbreviation is used in the text and many of the data tables in this report.

SOURCES OF RADIATION

Radioactivity and radiation are part of the earth's natural environment. Human beings are exposed to radiation from a variety of common sources, the most significant of which are listed below.

COSMIC

Cosmic radiation primarily consists of charged particles that originate in space, beyond the Earth's atmosphere. This includes radiation from the sun and secondary radiation generated by the entry of charged particles into the Earth's atmosphere at high speeds and energies. Radioactive elements such as hydrogen-3 (tritium), beryllium-7, carbon-14, and sodium-22 are produced in the atmosphere by cosmic radiation. The average dose from cosmic radiation to a person living in the United States is about 26 mrem per year.

TERRESTRIAL

Terrestrial radiation is released by radioactive elements present in the soil since the formation of the Earth about five billion years ago. Common radioactive elements contributing to terrestrial exposure include isotopes of potassium, thorium, actinium, and uranium. The average dose from terrestrial radiation to a person living in the United States is about 28 mrem per year.

INTERNAL

Internal exposure occurs when radionuclides are ingested, inhaled, or absorbed through the skin. Radioactive material may be incorporated into food through the uptake of terrestrial radionuclides by plant roots. Human ingestion of radionuclides can occur when contaminated plant matter or animals that consume contaminated plant matter are eaten. Most exposure to inhaled radioactive material results from breathing the decay products of naturally occurring radon gas. The average dose from eating foods to a person living in the United States is about 40 mrem per year; the average dose from radon product inhalation is about 200 mrem per year.

MEDICAL

Millions of people every year undergo medical procedures that utilize radiation. Such procedures include chest and dental x-rays, mammography, thallium heart stress tests, and tumor irradiation therapies. The average dose from nuclear medicine and x-ray examination procedures in the United States is about 14 and 39 mrem per year, respectively.

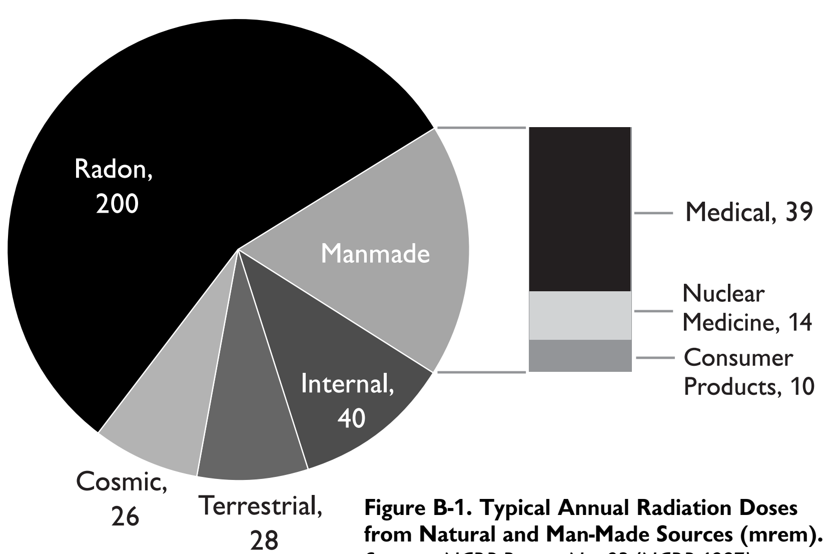

Figure B-1. Typical Annual Radiation Doses from Natural and Man-Made Sources (mrem). *Sources: NCRP Report No. 93 (NCRP 1987).*

ANTHROPOGENIC

Sources of anthropogenic (man-made) radiation include consumer products such as static eliminators (containing polonium-210), smoke detectors (containing americium-241), cardiac pacemakers (containing plutonium-238), fertilizers (containing isotopes of the uranium and thorium decay series), and tobacco products (containing polonium-210 and lead-210). The average dose from consumer products to a person living in the United States is 10 mrem per year (excluding tobacco contributions).

DOSE UNITS

The amount of energy that radiation deposits in body tissues or organs, when corrected for human risk factors, is referred to as dose equivalent or, more generally, as dose. Radiation doses are measured in units of rem. Since the rem is a fairly large unit, it is convenient to express most doses in terms of millirem (1,000 mrem = 1 rem). To give a sense of the size and importance of a 1 mrem dose, Figure B-1 indicates the number of mrem received by an individual in one year from natural and background sources. These values represent typical values for residents of the United States. Note that the alternate unit of dose measurement commonly used internationally and increasingly in the United States is the sievert, abbreviated Sv. One Sv is equivalent to 100 rem. Likewise, 1 millisievert (mSv) is equivalent to 100 mrem.

The unit used to express the quantity of radioactive material in a sample is the curie (Ci). This is a measure of the rate at which radioactive atoms are transformed to stable atoms. Since the curie is a relatively large unit for measuring environmental samples, the picocurie (pCi) is often used. This unit is equal to one trillionth of a Ci, or 0.037 decays per second. The alternate unit for quantifying radioactivity is the becquerel, abbreviated Bq. One becquerel is equal to 1 decay per second. Additional units of measure and their conversion factors can be found on the inside of the back cover of this report.

TYPES OF RADIOLOGICAL ANALYSIS

The quality of environmental air, water, and soil with respect to radioactive material can be assessed using several types of analysis. The most common analyses are described below.

GROSS ALPHA

Alpha particles are emitted in a range of different energies. An analysis that measures all alpha particles simultaneously, without regard to their particular energy, is known as a gross alpha activity measurement. This type of measurement is valuable as a screening tool to indicate the magnitude of alpha-emitting radionuclides that may be present in a sample.

GROSS BETA

This is the same concept as described above, except that it applies to the measurement of beta particle activity.

TRITIUM

Due to the nature of the radiation, a low energy beta particle, emitted from the tritium atom, it is detected and quantified by liquid scintillation counting method. (More information on tritium is presented in the next section.)

STRONTIUM-90

Due to the nature of the radiation emitted by strontium-90, a special analysis is required. Samples are chemically processed to separate and collect any strontium atoms that may be present. The collected atoms are then analyzed separately. (More information on strontium-90 is presented in the next section.)

GAMMA

This analysis technique identifies specific radionuclides. It measures the particular energy of a radionuclide's gamma radiation emissions. The energy of these emissions is unique for each nuclide, acting as a "fingerprint" to identify a specific nuclide.

STATISTICS

Two important statistical aspects of measuring radioactivity are uncertainty in results and negative values.

UNCERTAINTY

Because the emission of radiation from an atom is a random process, a sample counted several times will yield a slightly different result each time; a single measurement is, therefore, not definitive. To account for this phenomenon, the concept of uncertainty is applied to radiological data. In this report analysis results are displayed with x ± y format, where x is the result and ± y is the 95 percent confidence interval of the result. That is, there is a 95 percent probability that the true value of x lies between x + y and x - y. Conversely, there is a 5 percent probability that the true value of x lies outside of this range.

NEGATIVE VALUES

There is always a small amount of natural radiation in the environment. The instruments used in the laboratory to measure radioactivity in BNL site environmental media are sensitive enough to measure the natural, or background, radiation along with any contaminant radiation in a sample. To obtain a true measure of the contaminant level in a sample, the natural (or background) radiation level must be subtracted from the total amount of radioactivity measured by an instrument. Due to the randomness of radioactive emissions and the very low concentrations of some contaminants, it is possible to obtain a background measurement that is larger than the actual contaminant measurement. When the larger background measurement is subtracted from the smaller contaminant, a negative result is generated. The negative results are reported because they are essential when conducting statistical evaluations of data.

RADIONUCLIDES OF ENVIRONMENTAL INTEREST

Several types of radionuclides are found in the environment at BNL due to historical operations and include the following:

STRONTIUM-90

Strontium-90 is a beta-emitting radionuclide with a half-life of 28 years (i.e., after 28 years only one half of the activity from the original remains). It is found in the environment principally as a result of fallout from aboveground nuclear weapons testing. (Fallout refers to the deposition of radionuclides on soils and water bodies as a result of being dispersed high into the Earth's atmosphere during nuclear explosions.) Strontium-90 released in the 1950s and early 1960s is still present in the environment today due to its long half-life. Additionally, nations that were not signatories of the Nuclear Test Ban Treaty of 1963 have conducted tests that have contributed to the global strontium-90 inventory. This radionuclide was also released as a result of the 1986 Chernobyl accident in the former Soviet Union.

The data in this environmental report are reported by method of analysis. Because strontium-90 requires a unique method of analysis, it is reported as a separate parameter in the data tables. The level of sensitivity for detecting strontium-90 using state-of-the-art analysis methods is quite low (less than 1 pCi/L), which makes it possible to detect strontium-90 at levels that are indicative of the environmental sources described above.

TRITIUM

Among the radioactive materials that are used or produced at BNL, tritium has received the most public attention. Tritium exists in nature and is formed when cosmic radiation from space interacts with the gaseous nitrogen in the Earth's upper atmosphere. Approximately 4 million Ci (1.5E5 TBq) per year are produced in the atmosphere in this way, with the total global quantity being about 70 million Ci (2.6E6 TBq) at any given time (NCRP 1979). As a result of the 1950s and early 1960s aboveground weapons testing program, the global atmospheric tritium inventory was increased by a factor of about 200. Other human activities such as consumer product manufacturing and nuclear power reactor operations have also released tritium into the environment. Commercially, tritium is used in products such as self-illuminating exit signs and wrist watches (exit signs may contain as much as 25 Ci [925 GBq] of tritium). It also has many uses in medical and biological research as a labeling agent in chemical compounds and is frequently used in universities and other research settings.

Of the sources mentioned above, the most significant contributor to tritium in the environment has been aboveground nuclear weapons testing. In the early 1960s, the average tritium concentration in surface streams in the United States reached a value of 4,000 pCi/L (148 kBq/L) (NCRP 1979). Approximately the same concentration was measurable in precipitation. Today, the level of tritium in surface waters in New York State is below 200 pCi/L (7.4 kBq/L) (NYSDOH 1993), less than the detection limit of most analytical laboratories.

Tritium has a half-life of 12.3 years. When an atom of tritium decays, it releases a beta particle, causing transformation of the tritium atom into stable (nonradioactive) helium. This beta radiation has a very low energy when compared to the emissions of most other radioactive elements. The body's outer layer of dead skin cells easily stops tritium beta radiation and therefore, only when taken into the body, can tritium cause an exposure. Because of its low energy radiation and short residence time in the body, the health threat posed by tritium is very small for most credible exposures.

Environmental tritium is found in two forms: (1) gaseous elemental tritium and (2) tritiated water (or water vapor), in which at least one of the hydrogen atoms in the H_2O water molecule has been replaced by a tritium atom (hence, its shorthand notation HTO). All tritium released from BNL sources is in the form of HTO.

CESIUM-137

Cesium-137 is a man-made, fission-produced radionuclide with a half-life of 30 years. It is found in the environment as a result of past aboveground nuclear weapons testing and can be observed in the upper levels of environmental soils at very low concentrations, usually less than 1 pCi/g (0.04 Bq/g). It is a beta-emitting radionuclide, but can be detected by gamma spectroscopy by the gamma emissions of its decay product, barium-137m.

SCIENTIFIC NOTATION

Since many of the numbers used in measurement and quantification in this report are either very large or very small, many zeroes would be required to express their value. Because this is inconvenient, scientific notation is used as a kind of numerical shorthand. Scientific notation is based on the principle of representing numbers in multiples of ten. For example, the number one million could be written as 1,000,000. Alternatively, this number could be written in scientific notation as 1×10^6. That is, "one times ten raised to the sixth power." Since even this shorthand can be cumbersome, it can be reduced even further by using the capital letter E to stand for 10^x, or "ten raised to the power of some value x." Using this notation, 1,000,000 would be represented as 1E+06. Scientific notation is also used to represent very small numbers like 0.0001, which can be written as 1×10^{-4} or 1E-04. This notation is used in the text and some tables in this report.

PREFIXES

Another method of representing very large or very small numbers without the use of many zeroes is to use prefixes to represent multiples of ten. For example, the prefix "milli" means that the value being represented is one thousandth of a whole unit, so that one-milligram is equal to one thousandth of a gram.

DEFINITION OF RADIOLOGICAL TERMS

Radiological terms are used throughout this report where radiation and radioactive material are discussed. The definitions of commonly used radiological terms are found in Appendix A.

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