Concepts of Radioactivity

INTRODUCTION

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 quantify radioactive material, the common sources of radioactivity in the environment, and how each contributes to an individual's radiation dose are provided. Some general statistical concepts are also presented, along with a discussion of radionuclides of environmental interest on the BNL site.

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. The three most important types of radiation are described below.

COMMON TYPES OF RADIATION

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 radon emit alpha radiation.

BETA Beta radiation is composed of particles, which 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 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 essentially a form of gamma radiation.

NOMENCLATURE

Throughout this report, radioactive elements (also called radionuclides) are referred to by a name followed by a number, e.g., potassium-40. 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 potassium-40 is by writing it as K-40, where 'K' is the chemical symbol for potassium as it appears in the standard Periodic Table of the Elements. This type of abbreviation is used in many of the data tables in this report.

DOSE UNITS

The amount of energy that radiation deposits in body tissue, 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 C-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.

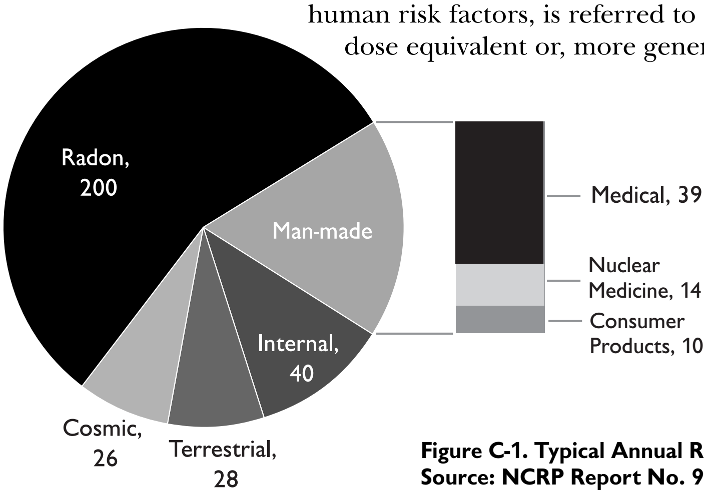

Figure C-1. Typical Annual Radiation Doses from Natural and Man-made Sources (mrem), Source: NCRP Report No. 93 (NCRP 1987).

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 plant matter or animals that consume 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, tumor irradiation therapies, and many others. The average dose from nuclear medicine and x-ray examination procedures in the United States is about 14 and 39 mrem per year, respectively.

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), tobacco products (containing polonium-210 and lead-210), and many others. The average dose from consumer products to a person living in the United States is 10 mrem per year.

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 as follows.

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 emitted from the tritium atom, it is detected and quantified by liquid scintillation counting method. (More information on tritium is included below.)

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 included below.)

GAMMA SPECTROSCOPY — 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.

The unit used to express the quantity of radioactive material in a sample is the curie, abbreviated 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 curie, or 0.037 decays per second. The alternate unit for quantifying radioactivity is the becquerel, abbreviated Bq. One Bq is equal to 1 decay per second.

STATISTICS

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. Each individual analysis result is shown in this report in the format of $x \pm y$, where x is the result and $\pm y$ 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 — Since natural radiation is present everywhere, uncontaminated environmental media such as soil, air, and water will show some degree of radioactivity. This has to be taken into consideration when analyzing a potentially contaminated sample. There must be a reasonable assurance that natural background radiation is not mistaken for contamination in an unknown sample. To address this, an instrument background is established prior to each unknown sample analysis. This is an analysis of a sample that is composed of the same material as the unknown, but that is known to be clean. When measuring the very small amounts of radioactive material typically encountered in environmental media, where only a few radiation events are counted, it is common for the sample result to be less than the instrument background. When the background is subtracted, a negative net value results, signifying that the sample contains no added radioactive material.

RADIONUCLIDES OF ENVIRONMENTAL INTEREST

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 lengthy 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 Brookhaven National Laboratory, 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 is of a very low energy when compared to the emissions of other radioactive elements and it is easily stopped by the body's outer layer of dead skin cells; 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 short hand 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 are 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 10x, or "ten raised to the power of some value x." Using this notation, 1,000,000 would be represented as 1E6. Scientific notation is also used to represent very small numbers like 0.0001, which can be written as $x\ 10^{-4}$ or 1E-4. This notation is used in 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.

REFERENCES

NCRP. 1979. *Tritium in the Environment.* NCRP Report No. 62. National Council on Radiation Protection and Measurements. Bethesda, Maryland.

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