## LEARNING OBJECTIVES:

1.05.01 Identify the following four sources of natural background radiation including the origin, radionuclides, variables, and contribution to exposure.

a. Terrestrial
b. Cosmic
c. Internal Emitters
d. Radon

1.05.02 Identify the following sources of artificially produced radiation and the magnitude of dose received from each.

a. Medical Exposures
b. Consumer Products

## INTRODUCTION

Apart from the amount of radiation a worker may receive while performing work, they will also be exposed to radiation because of the very nature of our environment. All individuals are subject to some irradiation even though they may not work with radioactive substances. This natural source of exposure is often referred to as ***background radiation***.

Studies of the nature and origin of this source of exposure to man has revealed three main components: terrestrial radiation (which includes the radioactivity of the earth's surface, air and water), cosmic radiation, and the naturally occurring radionuclides of the human body. One might add that man-made sources influence the contribution from some of these sources. The amount which each of these factors contributes varies with the locale.

The study of these factors throughout the world is of value for a number of reasons. Foremost among these is that the use of such data provides a basis or standard from which allowable exposure limits for radiation workers may be developed. In areas where the levels are much higher because of larger concentrations of natural radioactive materials, knowledge may be gained about human hereditary effects at these increased levels. Such data are also needed in assessing the impact on, or contribution of a nuclear facility to the existing concentrations in a given area. In the design of buildings and/or shielding for low-level work, it is of value to know the radioactive contents of the substances used. Often the levels inside a building are higher than those outside of the building because this factor has been neglected.

Because of these needs, much data about background levels in many areas has been acquired. This section is devoted to the discussion of these background factors and the relative contribution of man-made radiation.

## NATURAL BACKGROUND RADIATION SOURCES

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| 1.05.01 | Identify the following four sources of natural background radiation including the origin, radionuclides, variables and contribution to exposure.<br><br>a. Terrestrial |

### *Terrestrial Radiation*

#### Radioactivity of the Earth

The presence of certain small amounts of radioactivity in the soil adds to the background levels to which man is exposed. The amount of radioactive materials found in soil and rocks varies widely with the locale. The main contribution to the background is the gamma ray dose from radioactive elements chiefly of the **uranium** and **thorium** series and lesser amounts from radioactive $^{40}K$ and $^{87}Rb$.

Due to the high concentration of monazite, a thorium mineral, some regions in the world have an extremely high background level. The majority of the population of the Kerala region in India receives an annual dose greater than 500 mrem. A small percentage of the inhabitants receive over 2,000 mrem per year

and the highest recorded value has been 5,865 mrem in one year. It is interesting to note that this value is more than what is allowed for a DOE radiation worker. The Minas Garais state in Brazil has an average terrestrial background dose rate of 1,160 mrem per year. Their maximum recorded dose rate has been 12,000 mrem per year. In the United States on the average, a square mile of soil, one foot deep, contains one ton of $^{40}K$, three tons of $^{238}U$ and six tons of $^{232}Th$.

The amount of exposure one is subjected to depends upon the concentration in the soil and the type of soil. In the U.S., three broad areas have been found. These are: the coastal region along the Atlantic Ocean and the Gulf of Mexico, the Colorado Plateau region, and the remainder of the country. The yearly whole body equivalent dose rates in these areas range from 15-35 mrem, 75-140 mrem, and 35-75 mrem, respectively. When absorbed dose rate measurements are weighted by population, and averaged over the entire U.S., the yearly average is estimated at **20 mrem** (200 µSv) in NCRP Report No. 160.

**Radioactivity of Water**

Depending upon the type of water supply one is talking about, a number of products may turn up. For example, sea water contains a large amount of $^{40}K$. On the other hand, many natural springs show amounts of uranium, thorium, and radium. Almost all water should be expected to contain certain amounts of radioactivity. Since rain water will pick up radioactive substances from air, and ground water will pick up activity present in rocks or soil, one would expect to find some radioactivity in water throughout the world.

The chief source of dose rate from this background factor occurs as the result of uptake of these waters by ingestion. This leads to an internal exposure. Any estimate of the dose rate from this source is thus included in the estimate of the dose rate from radioactivity in the human body. The transfer of radioactive substances to the body seems to be mainly by food intake except in cases of very high water concentrations.

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| 1.05.01 | Identify the following four sources of natural background radiation including the origin, radionuclides, variables and contribution to exposure.<br><br>b. Cosmic |

***Cosmic Radiation***

Much work has been carried out in the study of cosmic radiation. This factor in background levels was discovered during attempts to reduce background. Though detection devices showed a response even in the absence of any known sources, it was assumed this background was due entirely to traces of radioactive substances in the air and ground. Thus, if a detector was elevated to a greater height above the earth's surface, the background should be greatly reduced. The use of balloons carrying ion chambers to great heights yielded data which showed the effect increased, rather than decreased. These and other data showed that radiation was really coming from outer space. The name *cosmic ray was* given to this high energy.

Further study has shown that cosmic radiation consists of two parts: **primary** and **secondary**. The primary component may be further divided into galactic, geomagnetically trapped radiation, and solar.

**Primary**

The **galactic cosmic rays** come from outside the solar system and are composed mostly of positively charged particles. Studies have shown that outside the earth's atmosphere, cosmic rays consist of 87% protons, of 11% alpha particles, and about 1% each of other heavier nuclei and electrons at latitudes above 55 degrees. These particles may have energies in the range of about 1 GeV and higher.

As a charged particle approaches the earth, it is acted upon by the earth's magnetic field. In order to pass on through to the earth, the particle must have a certain momentum. Otherwise, it may be trapped by the earth's magnetic field. This gives rise to the second type of primary cosmic rays, the **geomagnetically trapped radiation**.

**Solar cosmic rays** are produced following severe solar flares on the surface of the sun. These rays consist of protons. The events are classed as high energy or low energy. The high energy events can be observed by ground-level neutron

devices. The low energy events are more frequent but must be detected at high altitude. Since these events produce radiation throughout the solar system, they are of great importance in shielding design for manned space missions.

**Secondary**

Secondary cosmic rays result from interactions which occur when the primary rays reach the earth's atmosphere. When the high energy particles collide with atoms of the atmosphere, many products are emitted: pions, muons, electrons, photons, protons, and neutrons. These, in turn, produce other secondaries as they collide with elements or decay on the way toward the earth's surface. Thus, a multiplication or shower occurs in which as many as $10^8$ secondaries may result from a single primary.

Most of the primary rays are absorbed in the upper 1/10 of the atmosphere. At about 20 km and below, cosmic rays are almost wholly secondary in nature. The total intensity of cosmic rays shows an increase from the top of the atmosphere down to a height of 20 km. Although the primary intensity decreases, the total effect increases because of the rapid rise in the number of the secondaries. Below 20 km, the total intensity shows a decrease with height because of attenuation of the secondaries without further increase in their number due to primaries. At less than 6 km of altitude, the highly penetrating muons, and the electrons they produce, are the dominant components.

At the earth's surface, the secondary cosmic rays consist mainly of muons (hard component), electrons and photons (soft components), and neutrons and protons (nucleonic component). At sea level about 3/4 of the cosmic ray intensity is due to the hard component.

Because of the earth's magnetic field, cosmic ray intensity also varies with latitude. The energy which is needed for a charged particle to reach the earth's atmosphere at the geomagnetic equator is larger than that needed at other latitudes. The effect is greatest for latitudes between 15 and 50 degrees. Above 50 degrees, the intensity remains almost constant. Thus, the lowest value of the intensity occurs at the geomagnetic equator, and the effect is expressed as the percentage increase at 55 degrees over that at the equator. At sea level, the effect is small for the ionizing component (10%) but is larger for the neutron component.

The dose rate produced by this source of background may be divided into two parts. The portion caused by the ionizing component is estimated from ion chamber readings. The portion caused by the neutron component is hard to

measure because the dose rate depends so much on the energy spectrum of the neutrons. For the neutron dose estimates one must rely on calculations.

At sea level and high latitudes, the ionization rate is about 2.1 x $10^6$ ion pairs per cubic meter. Using a neutron calculation, the sea level dose would be increased by about 5%. Taking into account the dose variation with altitude and the population distribution with altitude, the average yearly equivalent dose rate to the U.S. population from **cosmic radiation** is estimated to be **30 mrem** (300 µSv). This equivalent dose rate would be expected to decrease slightly with latitude and increase with altitude. For example at Denver, the yearly dose would be about 50 mrem (500 µSv).

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| 1.05.01 | Identify the following four sources of natural background radiation including the origin, radionuclides, variables and contribution to exposure.<br><br>c. Internal Emitters |

***Internal Emitters* (Radioactivity of the Human Body)**

Since small amounts of radioactive substances are found throughout the world in soil and water, some of this activity is transferred to man by way of the food chain cycle. A number of studies have been made to try to find a correlation between the amounts in soil and that in man. Results have not shown a clear-cut relationship as yet.

In the human body, $^{40}$K, $^{87}$Rb, $^{226}$Ra, $^{238}$U, $^{210}$Po, and $^{14}$C are the main radionuclides of concern. Of these, **$^{40}$K** is the most abundant substance in man. The amount in food varies greatly, so that intake is quite dependent on diet. However, variations in diet seem to have little effect on the body content. The content of $^{40}$K in body organs of man varies widely. Based on an average content of 0.2% by weight in soft tissue, 0.05% in bone, the yearly equivalent dose rate to the gonads is estimated to be 19 mrem (190 µSv); 15 mrem (150 µSv) to bone surfaces; and 15 mrem (150 µSv) to bone marrow. $^{87}$Rb contributes only a few percent of these values.

Most of the **$^{226}$Ra** which is taken into the body will be found in the skeleton. Much data has been gathered on the concentration in humans, and the present assumed average skeletal concentration is taken as about 0.29 Bq/kg. The skeletal content of **$^{228}$Ra** is taken as 0.14 Bq/kg. The yearly dose rate produced

by these components is estimated to be .5 mrem (5 µSv) to the gonads, 14.6 mrem (146 µSv) to bone surfaces and 2.2 mrem (22 µSv) to bone marrow.

Based upon an average concentration of **$^{238}$U** of 0.26 Bq/kg in bone, the estimated doses in man are 4.8 mrem (48 µSv) to bone surfaces and 0.9 mrem (9 µSv) to the marrow. From the estimated content in the gonads, the annual equivalent dose is estimated to be about 1 mrem (10 µSv).

Similarly, the **$^{210}$Po** decay chain contribution is taken as 2.22 Bq/kg, yielding annual equivalent dose of 24 mrem (240 µSv) to bone surfaces and 4.9 mrem (49 µSv) to bone marrow. The soft tissue concentration is taken as 0.111 Bq/kg, but is about twice that in the gonads. This gives an annual gonad equivalent dose of 6 mrem (60 µSv).

The average whole body content of carbon is taken as 23%. However, **$^{14}$C** is present in normal carbon only to a very small extent ($^{14}C/^{12}C \sim 10^{-12}$), so that only a small amount of $^{14}$C is present. The annual average equivalent dose turns out to be about 1 mrem (10 µSv) total body. In soft tissue, the annual dose is 0.7 mrem (7 µSv). The annual dose to the bone surfaces is 0.8 mrem (8 µSv), and to the bone marrow, 0.7 mrem (7 µSv).

The U.S. annual average equivalent dose for all **internal emitters** (food chain) in the body is **30 mrem** (300 µSv) as listed by the NCRP Report No. 160.

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| 1.05.01 | Identify the following four sources of natural background radiation including the origin, radionuclides, variables and contribution to exposure.<br><br>d. Radon |

***Radon (Inhaled Radionuclides)***

The background which is found in air is due mainly to the presence of radon and thoron gas, formed as daughter products of elements of the uranium and thorium series. The decay of $^{238}$U proceeds to $^{226}$Ra. When $^{226}$Ra emits an alpha as it decays, the gas $^{222}$Rn is formed, which is called radon. In the thorium chain, the decay of $^{224}$Ra results in the gaseous product $^{220}$Rn, which is called thoron.

Since uranium and thorium are present to some extent throughout the crust of the earth, these products are being formed all the time. Since they are gases,

they tend to diffuse up through the earth's surface to become airborne. In turn, the decay products of these gases attach themselves to dust in the air.

The amount of these gases in the air depends upon the uranium and thorium content of a certain area. In any given area, the weather conditions will greatly affect the concentrations of these gases. It is also common to find that the levels indoors are higher than those outdoors. This is a function of the material of the building and the ventilation rate. In mines and other underground caverns, the concentrations have been found to be quite high.

Some homes in Grand Junction and Durango, Colorado, have been found to have high radon levels. This was traced to the use of uranium mill tailings, residues rich in radium, as backfill. This discovery has led to radon measurements in homes in other areas of the country. Some homes in Pennsylvania are situated on land with naturally elevated radium concentrations, giving rise to increased indoor radon levels. Investigations have been made of radon levels in homes in the Chicago area. Their results indicated that 6% of the homes studied had radon concentrations comparable to those found at Grand Junction. Because of the potential population dose from this source, much more work on defining this potential problem is being carried out.

The major source of exposure from radon in air occurs when the daughter products attach themselves to aerosols and are inhaled. This leads to an internal dose to the lungs. As for external exposure, the external gamma dose rate from $^{222}$Rn and $^{220}$Rn is estimated to be less than 5% of the total external terrestrial dose rate. The contribution of inhaled radon gas to the annual average effective dose equivalent is included as an **inhaled radionuclide**.

Among other radioactive products which are found in air in measurable amounts are $^{14}$C, $^{3}$H, $^{22}$Na, and $^{7}$Be. These are called **cosmogenic** radionuclides, since they are produced in the atmosphere by cosmic rays. None of these products add a significant amount to the background dose rate.

The U.S. annual average equivalent dose for **Radon** is estimated at **230 mrem** (2,300 μSv) by the NCRP Report No. 160.

## MAN-MADE BACKGROUND RADIATION SOURCES

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| 1.05.02 | Identify the following sources of artificially produced radiation and the magnitude of dose received from each.<br><br>a. Medical Exposures |

### *Medical Exposures*

The exposure to the U.S. population from X-rays used in medical and dental procedures is the largest source of man-made radiation. It is estimated that more than 300,000 X-ray units are in use in the U.S., and that about 2/3 of the U.S. population is exposed. The estimated annual average bone marrow equivalent dose from dental and medical X-rays to the U.S. population was about 78 mrem (780 µSv). In addition to the exposure from X-rays, nuclear medicine programs use radiopharmaceuticals for diagnostic purposes. Radiologists also use radionuclides for therapy treatment. It has been estimated that more than 10 million doses are administered each year. NCRP Report No. 160 gives the equivalent dose for medical radionuclides as ~ **300** mrem/yr

1) computed tomography (total average dose ~ 150 mrem/yr)
2) nuclear medicine (total average dose ~ 75 mrem/yr)
3) radiography/fluroscopy (total average dose ~ 75 mrem/yr)

### Diagnostic X-Rays

There are many different types and styles of X-ray machines used in the medical field. An X-ray machine generally consists of the X-ray tube, an electrical source of high voltage, a type of filament, and radiation shielding to collimate the beam to some limited size and shape. A diagnostic X-ray machine is used to obtain an image of some part of the body on some type of storage material. There are three general types of diagnostic X-ray equipment: radiographic, fluoroscopic, and photofluorographic.

**Radiography** involves the use of an X-ray tube and a photographic plate. The patient is placed between the two and an image is produced on the film of the area exposed. A common "chest X-ray" is an example of a radiographic X-ray.

In a **fluoroscopic** X-ray machine the film cassette is substituted with an imaging device (image intensifier). This enables the radiologist to observe the part of the

body exposed live on a video monitor. A blocking agent, such as barium, is often swallowed by the patient to allow the medical staff to observe internal processes in action. A fluoroscopic examination can be used to locate ulcers in a "GI series."

The **photofluorographic** process utilizes an X-ray tube, a fluorescent screen and a camera. This practice is similar to radiographic X-rays, with the substitution of a fluorescent screen for the film. The radiologist can take several pictures on one roll of film of the image on the fluorescent screen. Photofluorography is used for screening large numbers of individuals such as in the military or prison.

As science gradually became more aware of the potential hazards associated with radiation exposures, the doses received from diagnostic X-rays have been closely examined. Medical diagnostic exposures contribute more than 50% of the dose to the U.S. population from artificial sources. The U.S. Public Health Services has been tasked with tracking medical X-ray procedures at ten year intervals. The concept of "Genetically Significant Dose" (GSD) is used in most publications covering background radiation. The GSD includes only the fraction of the radiation which actually deposits energy in the gonads (ovaries and testes) of persons of childbearing potential. Dose rates that produce a small exposure over a year's time cannot be expected to produce any acute somatic radiation injury. Late effects from this exposure are almost negligible at these low dose rates. Genetic mutations are transmitted on to our offspring who will then be exposed during their lifetimes. The cumulative effect on genetic mutations over several generations might show a very slight increase due to background radiation.

**Medical Radionuclides**

Radionuclides are used in medicine by two general classifications: Nuclear Medicine for diagnostic procedures and Radiation Oncology for radiation therapy. Because this science is utilized by a limited portion of the U.S. population, its contribution to the average U.S. dose is not significant.

Radionuclides are used to determine the extent of a medical problem in a patient. The radionuclide is "attached" to a pharmaceutical which is administered to the patient. The drug has the properties to deposit the radioisotope in the organ of concern. Then using external radiation detectors, the medical staff can determine abnormalities in the organ. Thyroid scan and lung function tests are examples.

Since the radioisotope is internally deposited either by mouth or by injection, it should decay by emitting only photons. Isotopes emitting alpha or beta particles would be locally absorbed in the organ and would not contribute to the information signal. Another consideration in radionuclide selection would be the effective half-life. To maintain organ doses ALARA, isotopes with a few hour half-life are optimum. Technetium-99m and Indium-113m are commonly used radiopharmaceuticals.

Radiation Oncology (study/treatment of tumors) uses radionuclides for tumor treatment. In the United States Cobalt-60 is generally used for the high activity sealed source. This consists of a mechanical device which moves the source to an opening in a collimator which projects a beam of photons used for treatment. A typical 6,000 curie Cobalt-60 source delivers about 100 rad/minute to a tumor.

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| 1.05.02 | Identify the following sources of artificially produced radiation and the magnitude of dose received from each.<br><br>b. *Consumer Products* |

***Consumer Products***

In NCRP Report 160, a number of consumer products and miscellaneous sources of radiation exposure to the U.S. population are discussed.

Such products as tobacco products, commercial air travel, building materials and many other sources have been studied. The estimated annual average whole body dose equivalent to the U.S. population from **consumer products** is approximately **10 mrem** (100 µSv). The major portion of this exposure (approximately 70%) is due to radioactivity in building materials.

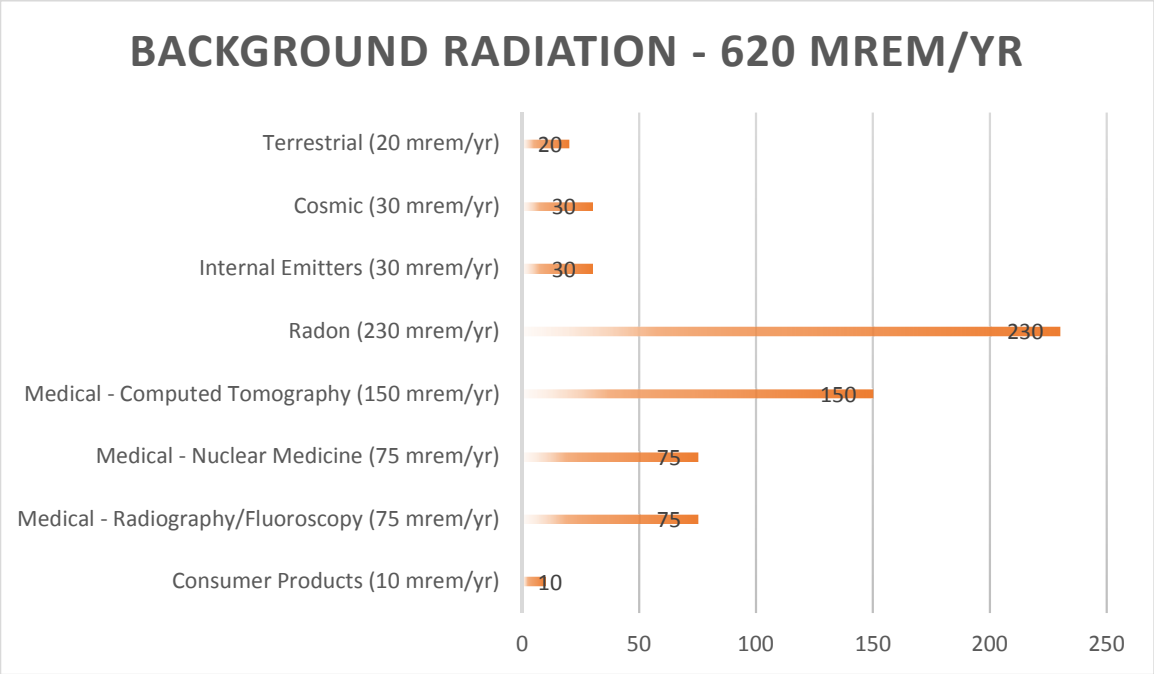
**Other minor contributors**

Other contributors to dose include industrial sources and atmospheric testing of nuclear weapons. These levels are considered minimal and are not included as part of the total effective dose.

> **Note:** *It has been close to 40 years since atmospheric testing has been conducted.*

**Total Background Radiation**

The average annual total effective dose to the general population from naturally occurring and manmade sources according to the NCRP Report No. 160 is approximately 620 mrem.



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3. **NCRP Report No. 45** "Natural Background Radiation in the United States".
4. **NCRP Report No. 95** "Radiation Exposure from Consumer Product Miscellaneous Sources".
5. **NCRP Report No. 93** "Ionizing Radiation Exposure of the Population of the United States".
6. **NCRP Report No. 160** "Ionizing Radiation Exposure of the Population of the United States".