Course Title: **Radiological Control Technician**
Module Title: **Sources of Radiation**
Module Number: **1.05**

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
d. Inhaled.

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

a. Nuclear fallout
b. Medical exposures
c. Consumers products
d. Nuclear facilities.

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 natural 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 humans have revealed three main components: terrestrial radiation (which includes the radioactivities of the earth's surface, air and water), cosmic radiation, and the naturally occurring radionuclides deposited in the human body. One might add that man-made sources influence the contribution from some of these sources. The amount that 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 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 have been acquired. This lesson is devoted to the discussion of these background factors and the relative contribution of man-made radiation.

References:

1. "Basic Radiation Protection Technology"; Gollnick, Daniel; Pacific Radiation Press; 1983.

2. ANL-88-26 (1988), "Operational Health Physics Training"; Moe, Harold; Argonne National Laboratory, Chicago.

3. NCRP Report No. 45, "Natural Background Radiation in the United States."

4. NCRP Report No. 56, "Radiation Exposure from Consumer Product Miscellaneous Sources."

5. NCRP Report No. 93, "Ionizing Radiation Exposure of the Population of the United States."

NATURAL BACKGROUND RADIATION SOURCES

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

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 people are exposed. The amount of naturally occurring radioactive materials found in soil and rocks varies widely with the locale. The main contribution to the background is the gamma ray dose from decay of naturally occurring radioactive elements, chiefly of the **uranium** and **thorium** series and lesser amounts from radioactive ^{40}K and ^{87}Rb.

Because of the high concentration of the thorium mineral monazite, some regions in the world have an extremely high background radiation level. The majority of the population of the Kerala region in India receive 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 1 year. 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 1 ton of ^{40}K, 3 tons of ^{238}U, and 6 tons of ^{232}Th.

The amount of exposure one is subjected to, depends on the concentration of naturally ocurring radioactive elements in the soil, and the type of soil. Regarding the amount of exposure, three broad areas have been identified in the U.S. 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 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 28 mrem (280 μSv) in NCRP Report No. 93.

Radioactivity of Water

Depending on the type of water supply one is talking about, a number of naturally radioactive elements may turn up in it. For example, sea water contains a large amount of ^{40}K. On the other hand, many natural springs show some amounts of uranium, thorium, and radium. Almost all water should be expected to contain certain amounts of radioactivity. Because rain water will pick up radioactive substances from the 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.

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

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 that showed the effect increased, rather than decreased. These and other data showed that a high energy radiation, capable of completely penetrating the earth's atmosphere, was, really, coming from outer space. The name *cosmic rays,* was given to this high energy radiation.

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

At sea level and high latitudes, the rate of ionization is about 2.1×10^6 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 to the U.S. population from cosmic radiation is estimated to be 27 mrem (270 μSv). This dose rate would be expected to decrease slightly with latitude and increase with altitude.

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 certain energy. Otherwise, it may be

trapped in the earth's magnetic field. This gives rise to the second type of primary cosmic rays, the **geo-magnetically 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. Because 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 that 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. As they collide with elements constituting the earth's atmosphere, or decay on the way toward the earth's surface, secondary particles and photons are generated. Thus, a multiplication or radiation shower occurs in which as many as $l0^8$ secondary particles and photons may result from a single primary, high energy particle.

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 secondary particles and photons – secondary cosmic radiation. Below 20 km, the total intensity shows a decrease with height because of attenuation of the secondary particles and photons, without further increase in their number due to primaries. At less than 6 km of altitude, the highly penetrating muons, and the electrons they decay into, 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 that is needed for a charged particle to reach the earth's atmosphere is greatest at latitudes between 15 and 50 degrees. At sea level, the cosmic ray intensity is smallest 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.

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

c. Internal emitters

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

Because 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, naturally occurring radioactive elements: ^{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. The amount of ^{40}K 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 varies widely. Based on an average content of 0.2% by weight in soft tissue and 0.05% in bone, the yearly equivalent dose 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 that is taken into the body will be found in the skeleton. Much data have 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 ^{226}Ra is taken as 0.14 Bq/kg. The yearly dose rate produced by these components is estimated to be 0.5 mrem (5 μSv) to the gonads, 14.6 mrem (146 μSv) to bone surfaces and 2.2 mrem (22 μSv) to bone marrow.

Based on an average concentration of ^{238}U of 0.26 Bq/kg in bone, the estimated doses in man are 4.8 mrem (481μSv) 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 doses 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 ~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 39 mrem (390 μSv) as listed by the NCRP Report No. 93.

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

d. Inhaled radionuclides

Inhaled Radionuclides **(Radioactivity of the Air)**

The background radiation 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 into radioactive ^{222}Rn , a gas called radon. In the thorium chain, the decay of ^{224}Ra results in the radioactive gaseous product ^{220}Rn, called thoron.

Because uranium and thorium are present to some extent throughout the crust of the earth, ^{222}Rn and ^{220}Rn 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 radon and thoron in the air depends on the uranium and thorium content of a certain area. In any given area, the weather conditions will greatly affect the concentrations of these radioactive elements. 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 of radon and thoron 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 is included as an **inhaled radionuclide**.

Among other radioactive products that are found in air in measurable amounts are ^{14}C, ^{3}H, ^{22}Na, and ^{7}Be. These are called **cosmogenic** radionuclides, because 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 various inhaled radionuclides (primarily radon) is estimated at 200 mrem (2,000 μSv) by the NCRP Report No. 93.

MAN-MADE BACKGROUND RADIATION SOURCES

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

a. Nuclear fallout

Nuclear Fallout

The term *fallout* has been applied to debris that settles to the earth as the result of a nuclear blast. This debris is radioactive and thus a source of potential radiation exposure to man. Radioactive fallout is not considered naturally occurring but is definitely a contributor to background radiation sources.

Because of the intense heat produced in a nuclear explosion during a very short time, matter that is in the vicinity of the bomb is quickly vaporized. This includes fission products formed in the explosion, unused bomb fuel, the bomb casing and parts and, in short, any and all substances that happen to be in the immediate presence of detonation. These vaporized products are caught in the fireball that expands and rises very quickly. As the fireball cools and condensation occurs, a mushroom-shaped cloud is formed, containing small solid particles of debris as well as small drops of water. The cloud continues to rise to a height that is a function of the bomb yield and the meteorological factors of the area. For yields in the megaton range (1 megaton equals an energy release equivalent to one million tons of TNT), the cloud top may reach a height of 25 miles.

The fallout that occurs may be described as local or worldwide. The portion of debris that becomes local fallout varies from none (in the case of a high-altitude detonation) to about half (in the case of a surface contact detonation). The height at which the bomb goes off is thus quite important in the case of local fallout. If the fireball touches the surface of the earth, it will carry aloft large amounts of surface matter. Also, because of the vacuum effect created by the rapid rise of the fireball, other matter may be taken up into the rising fireball. This leads to the formation of larger particles in the cloud that tend to settle out quickly. If the width of the fireball is not too great, the fallout pattern will be roughly a circle around ground zero. Ground zero is the exact location on the earth's surface where the detonation occurs.

Other bits of matter will fall out at various stages. The distance from ground zero at which they strike the surface and the time it takes depend on the height from which they fall, their size, and the wind patterns at all altitudes. This results in a cigar-shaped pattern downwind of the burst point. Local fallout usually occurs within the first 24 hours after the blast.

If the height of the burst is such that the fireball does not touch the surface, then the debris is carried aloft and dispersed into the atmosphere. This matter then descends to earth at a later time and is called worldwide fallout.

The stay, or residence time of this debris in the atmosphere is a function of the bomb yield. For yields in the kiloton range, the debris is not projected into the stratosphere. It is limited to a region called the troposphere, between about 9,000 and 17,000 meters. In this region, there is quite a bit of turbulence as well as precipitation. The debris is removed rather quickly, from about 1 day to 1 month.

If the burst is in the megaton range, the debris is carried into the stratosphere. In this region little mixing will occur, and the absence of rain or snow prevents this matter from being washed down. The time that it takes for this debris to return to the troposphere and be washed down varies. It is a function of both the height in the stratosphere to which the debris is lifted and the locale at which the burst occurs. It may take up to 5 years or more for this debris to return to earth. On the other hand, for bursts in the northern hemisphere in which the debris is confined to only the lower part of the stratosphere, the half-residence time is thought to be less than 1 year. Half-residence time is the time for one-half of the debris to be removed from the stratosphere.

In all, there are more than 200 fission products that result from a nuclear blast. The half-life of each of these products covers the range from a fraction of a second to millions of years. Local fallout will contain most of these products. Because of the time delay in the appearance of worldwide fallout, only a few of these products are important from that standpoint. Because local fallout is confined to a relatively small area, its effect on the human population can be negated by proper choice of test sites, weather conditions, and type of burst. The fallout of interest from the standpoint of possible effects on man due to testing is the worldwide fallout.

A number of factors must be considered when one attempts to assess the hazard from worldwide fallout. Because of the associated time delay before worldwide fallout shows up, many fission products and activation products decay out in transit. Others, because they are produced in such small amounts, are diluted so that they do not produce much of an effect. Also, once the fallout does arrive, to be of importance internally, there must be a transfer to the body and absorption into the body organs. All these factors combine to limit the number of fission products that may have an effect on man. The main contribution comes from ^{90}Sr, ^{137}Cs, ^{131}I, ^{14}C, and ^{3}H, with minor contributions from ^{85}Kr, ^{55}Fe, and ^{239}Pu. Although the U.S. ceased atmospheric testing in 1962, the inventory of fission products from previous bursts has committed man to future doses. NCRP Report No. 93 lists the annual average effective dose from nuclear fallout exposure at less than 1 mrem (10 μSv). However the total dose commitment, to be delivered over many generations, is 140 mrem (1400 μSv).

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

b. 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. In 1970, 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. The NCRP Report No. 93 lists the average annual effective dose in the U.S. for diagnostic X-rays and nuclear medicine as 39 mrem (390 μSv) and 14 mrem (140 μSv), respectively. This gives a combined average annual effective dose from medical exposures of 53 mrem (530 μSv).

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, 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 photo-fluorographic.

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 gastrointestinal series.

The **photo-fluorographic** process uses 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 10-year intervals. Surveys were conducted in 1961, 1970, and 1980. Because of budget cutbacks, the 1980 survey does not contain as much useful data as the one produced in 1970. The concept of "Genetically Significant Dose" (GSD) is used in most publications covering background radiation. The GSD includes only the fraction of the radiation that 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 because of 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 used 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 that 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. A thyroid scan and lung function test, are examples of this type of test.

Because 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 that 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.

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

c. Consumer products

Consumer Products

In NCRP Report 56, a number of consumer products and miscellaneous sources of radiation exposure to the U.S. population are discussed. In general, two groups of sources have been found:

1. Those in which the equivalent dose is relatively large and many people are exposed.

2. Those in which the equivalent dose is small, but many people are exposed; or the equivalent dose is large but only a few people are exposed.

Such products as television sets, luminous-dial watches, smoke detectors, static eliminators, tobacco products, airport luggage inspection systems, building materials and many other sources have been studied. The estimated annual average whole body dose 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.

Television Receivers

Television receivers have the potential for three X-rays sources: the picture tube, the shunt regulator and the vacuum tube regulator. In 1960, the ICRP and the NCRP recommended that limits be established such that receivers produce less than 0.5 mrem/hr, at any access point 5 cm from the surface of the set. In May of 1967, a major manufacturer recalled 149 big screen sets. Of this group, two sets were found to produce exposures in excess of 100 mR/hr. Due to the ever increasing improvements in TV manufacturing, solid state, and the use of “hold down” circuits, the annual exposure is being reduced. X-ray emissions can be kept below 0.1 mR/hr with low voltage within manufacture specifications. Higher emissions can result if the voltage is increased by repairman in order to increase picture quality. It is estimated that the U.S. total average exposure from watching TV is between 0.5 and 1.5 mrem/yr.

Shoe-Fitting Fluoroscopes

In the 1950s, the use of fluoroscopes was widespread in shoe stores. It was estimated that 10,000 of these were in use in 1953. Exposures to the feet ranged from 7 to 14 Roentgens per 20 second exposure. The concurrent exposure to the pelvis ranged between 30 and 170 mR per exposure. Shoe-fitting fluoroscopes have been banned or restricted in most states.

Radioluminous Watches

Radium-226 was used widely in the earlier part of the last century in luminescence paints for watches, clocks, and dials. No radium-226 watches have been sold in the U.S. since 1970. It is estimated that 10 million of these watches are still in use. Individual dose can reach 310 mrem/yr for the wearer of a watch containing 4.5 uCi of radium-226. The average dose to radium watch wearers is, approximately, 3 mrem/yr.

The majority of luminescent watches on the market today contain either tritium (^{3}H) or promethium-147 (^{147}Pm.) It's estimated that the 16 million who wear tritium watches receive 0.6 mrem/yr, and the 2 million who wear promethium watches receive 0.25 mrem/yr.

Dental Prostheses

Porcelain teeth and crowns are composed principally of feldspar minerals that contain small quantities of naturally occurring potassium-40 (^{40}K.) To create a natural appearance, dentures are doped with small amounts of uranium. A 1974 study in Great Britain indicated that porcelain teeth containing 0.10% uranium could deliver an annual equivalent dose to the oral mucosa of almost 600 rem by alpha particles and 2.8 rem by beta particles. On the average, dentures produced in the U.S. contain about 0.02% uranium.

Approximately 19 million persons in the U.S. wear full dentures, and 60 million wear crowns. About one half of dental prostheses are porcelain, the rest are made of acrylics and do not require uranium "aging." It is assumed that if those wearing porcelain dentures receive an equivalent dose of 60 rem per year from alpha radiation, the contribution to the average annual population dose to the basal mucosa of the mouth would be estimated to be 10 to 15 rem (NCRP Report No. 56).

Miscellaneous

There are many additional consumer products that may be included as a source of radiation. Polonium and lead isotopes have been found in tobacco products and contribute a dose-equivalent to small areas of the bronchial epithelium of up to 8 rem/yr to smokers. Building materials, smoke detectors, lantern mantles, and ceramic glazes are all known sources. Another source of radiation exposure to the public arises from the wide use of coal. Coal contains ^{14}C, ^{40}K, uranium, and thorium and when burned, the resulting fly ash released to the atmosphere carries some of this radioactivity with it. This leads to inhalation of airborne fly ash producing lung exposure. The dose rate in the vicinity of one of these plants has been estimated to be in the range of 0.25 to 4 mrem/y (2.5-40 μSv/y).

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

d. Nuclear facilities

Nuclear Facilities

By 1988, 90 nuclear power plants had been licensed in the U.S. In addition, over 300 other reactors, classed as non-power reactors, are being operated. In order to provide fuel for these reactors, mining and milling of uranium ore is carried out, and fuel fabrication plants are operating. There are several hundred mines, 20 uranium mills, and 21 fuel fabrication facilities in the U.S.

Sources of radiation from nuclear reactors consist of prompt neutrons, gamma rays, and possible exposures from contamination or environmental releases. The NRC has been tasked by the federal government to calculate doses for populations living within 50 miles of a nuclear facility. Three radionuclides released during routine operations, which contribute to the population dose, are ^{3}H, ^{14}C, and ^{85}Kr. Current estimates of the yearly average equivalent dose in the U.S. from environmental releases is <1 mrem (10 μSv).

Table 1. Summary of All Radiation Contributors

	Source	Annual Exposure (mrem yr)
Natural Background	Terrestrial	28
	Cosmic	27
	Internal Emitters	39
	Inhaled (Radon)	200
Man-Made Background	Nuclear Fallout	<1
	Medical Exposures	53
	Consumer Products	10
	Nuclear Facilities	<1
	Rounded Total	**360**