Radiation and Radioactivity

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This is a self paced lesson on the basics of radiation and radioactivity. It was developed by the University of Michigan's Student Chapter of the Health Physics Society.

Sources of more information:

- Glossary of Terms
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The Student Chapter of the Health Physics Society of the University of Michigan

The University of Michigan Student Chapter of the Health Physics Society (UMSCHPS) began in 1993. It is a large student chapter, boasting an active membership of over 12 members. The chapter is a fully chartered arm of the National Health Physics Society and a sanctioned student organization of the University of Michigan. A committee has been established from interested members of our student chapter and result is this WWW site.

Our chapter has over 4 years of WWW/HTML experience and have created hundreds of web pages.

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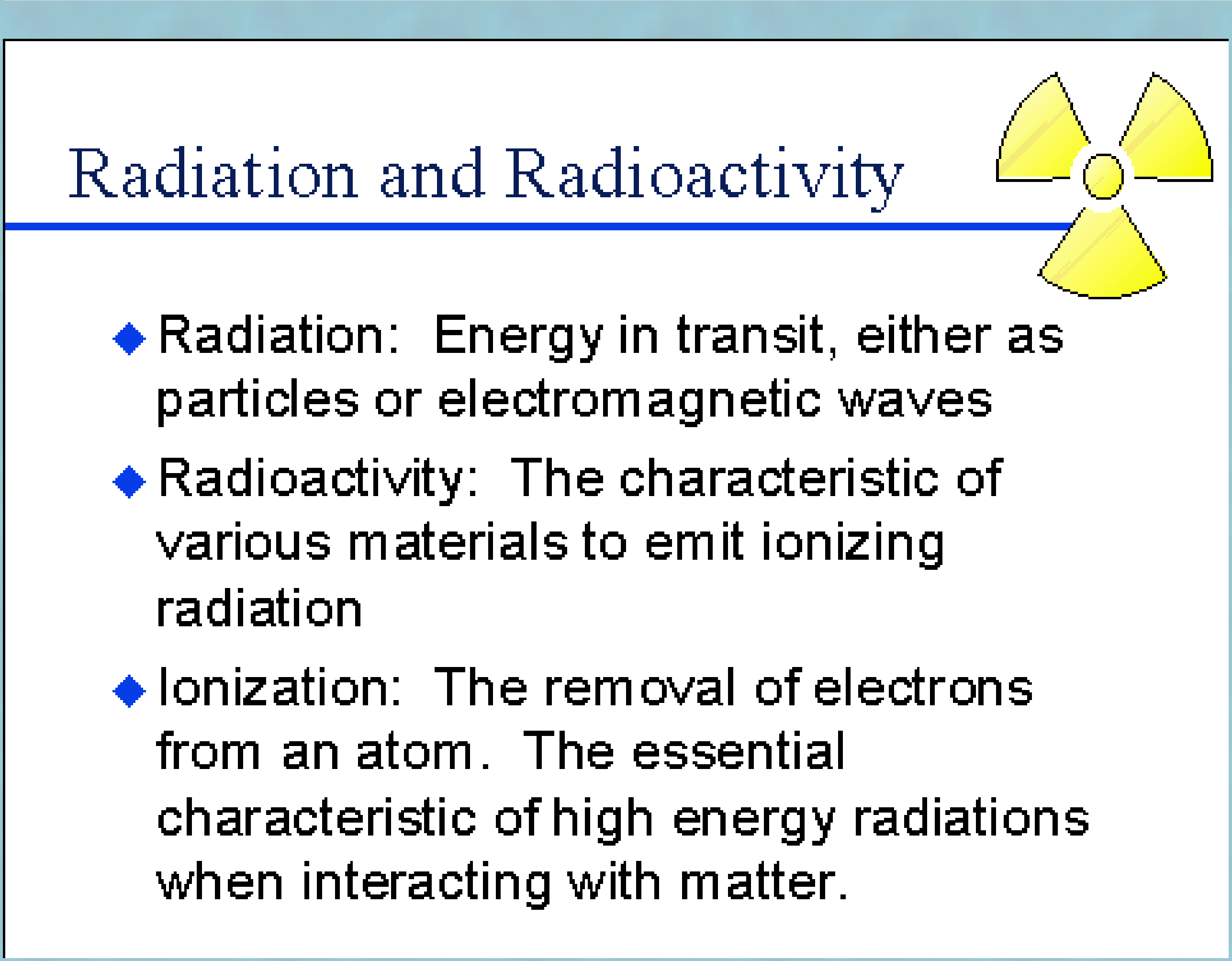
Radiation and Radioactivity



Radiation and Radioactivity

- Radiation: Energy in transit, either as particles or electromagnetic waves
- Radioactivity: The characteristic of various materials to emit ionizing radiation
- Ionization: The removal of electrons from an atom. The essential characteristic of high energy radiations when interacting with matter.

Radiation is energy traveling in the form of particles or waves in bundles of energy called photons. Some everyday examples are microwaves used to cook food, radio waves for radio and television, light, and x-rays used in medicine.

Radioactivity is a natural and spontaneous process by which the unstable atoms of an element emit or radiate excess energy in the form of particles or waves. These emissions are collectively called ionizing radiations. Depending on how the nucleus loses this excess energy either a lower energy atom of the same form will result, or a completely different nucleus and atom can be formed.

Ionization is a particular characteristic of the radiation produced when radioactive elements decay. These radiations are of such high energy that when they interact with materials, they can remove electrons from the atoms in the material. This effect is the reason why ionizing radiation is hazardous to health, and provides the means by which radiation can be detected.

Our glossary with definitions of more terms

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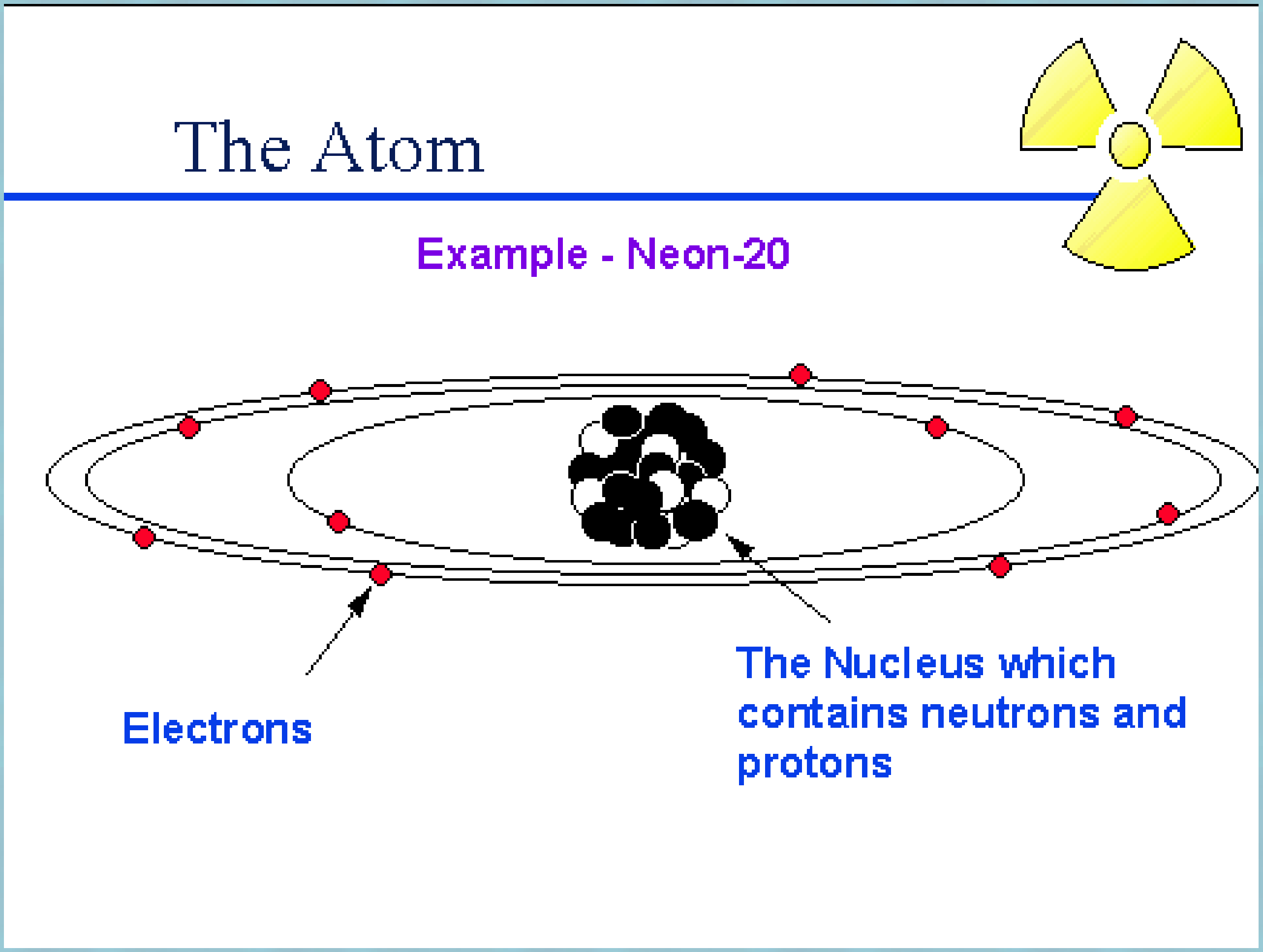
Page 2
The Atom



The Atom

Example - Neon-20

A typical model of the atom is called the Bohr Model, in honor of Niels Bohr who proposed the structure in 1913. The Bohr atom consists of a central nucleus composed of neutrons and protons, which is surrounded by electrons which "orbit" around the nucleus.

Protons carry a positive charge of one and have a mass of about 1 atomic mass unit or amu (1 amu $=1.7\text{x}10^{-27}$ kg, a very, very small number). Neutrons are electrically neutral and also have a mass of about 1 amu. In contrast, electrons carry a negative charge and have mass of only 0.00055 amu. The number of protons in a nucleus determines the element of the atom. For example, the number of protons in uranium is 92 and the number in neon is 10. The proton number is often referred to as Z.

Atoms with different numbers of protons are called elements, and are arranged in the periodic table with increasing Z.

Atoms in nature are electrically neutral so the number of electrons orbiting the nucleus equals the number of protons in the nucleus.

Neutrons make up the remaining mass of the nucleus and provide a means to "glue" the protons in place. Without neutrons, the nucleus would split apart because the positive protons would repel each other.

Elements can have nucleii with different numbers of neutrons in them. For example hydrogen, which normally only has one proton in the nucleus, can have a neutron added to its nucleus to from deuterium, or have two neutrons added to create tritium, which is radioactive. Atoms of the same element which vary in neutron number are called isotopes. Some elements have many stable isotopes (Tin has 10) while others have only one or two. We express isotopes with the nomenclature Neon-20 or $^{20}Ne_{10}$, with twenty representing the total number of neutrons and protons in the atom, often referred to as A, and 10 representing the number of protons (Z).

Radionuclides can be arranged by A and Z in the chart of the nuclides.

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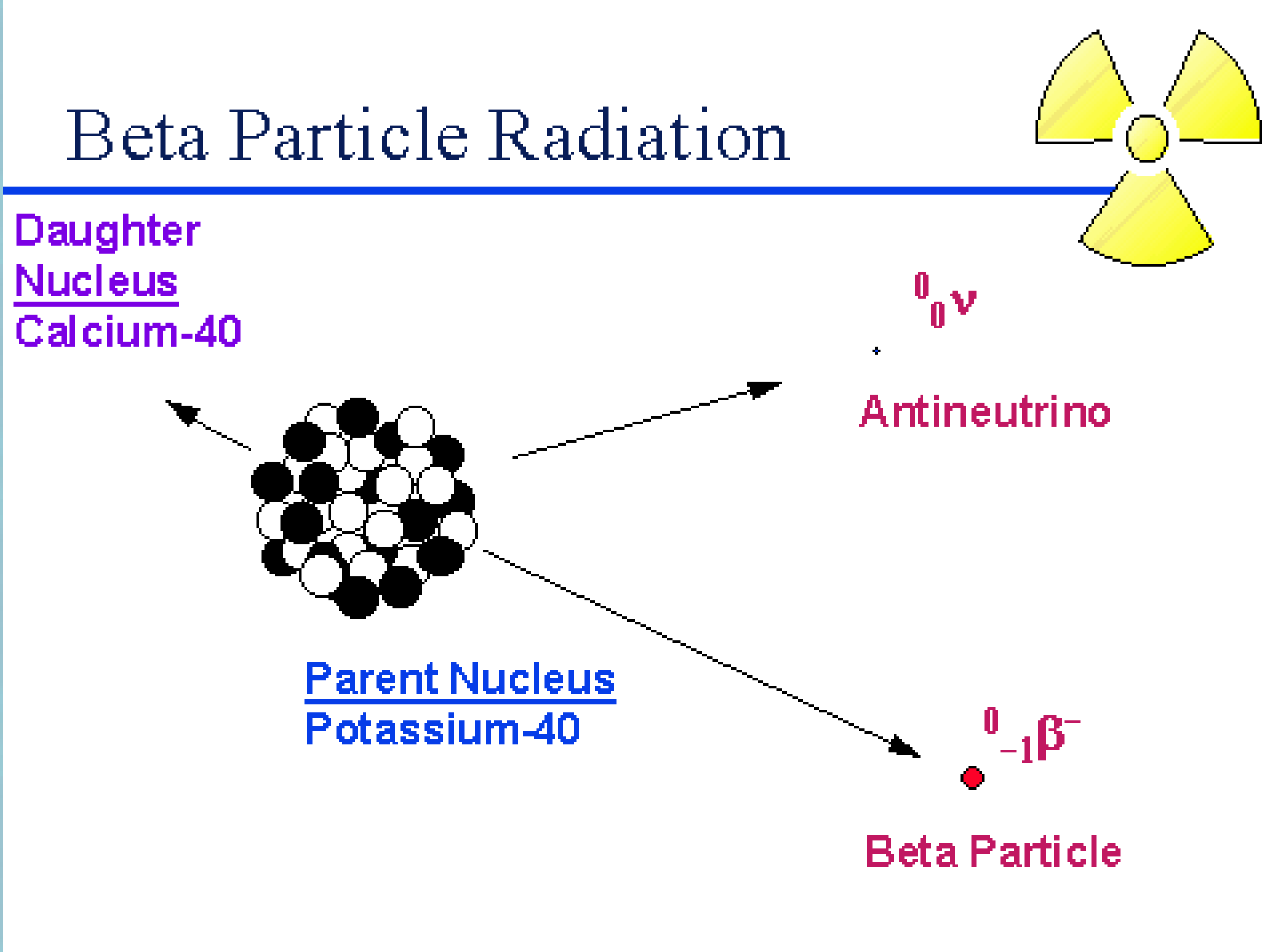
The Beta Particle



Beta decay is a radioactive process in which an electron is emitted from the nucleus of a radioactive atom, along with an unusual particle called an antineutrino. The neutrino is an almost massless particle that carries away some of the energy from the decay process. Because this electron is from the nucleus of the atom, it is called a beta particle to distinguish it from the electrons which orbit the atom.

Like alpha decay, beta decay occurs in isotopes which are "neutron rich" (i.e. have a lot more neutrons in their nucleus than they do protons). Atoms which undergo beta decay are located below the line of stable elements on the chart of the nuclides, and are typically produced in nuclear reactors and cyclotrons. When a nucleus ejects a beta particle, one of the neutrons in the nucleus is transformed into a proton. Since the number of protons in the nucleus has changed, a new daughter atom is formed which has one less neutron but one more proton than the parent. For example, when Rhenium-187 decays (which has a Z of 75) by beta decay, Osmium-187 is created (which has a Z of 76). Beta particles have a single negative charge and weigh only a small fraction of a neutron or proton. As a result, beta particles interact less readily with material than alpha particles. Depending on the beta particles energy (which depends on the radioactive atom and how much energy the antineutrino carries away), beta particles will travel up to several meters in air, and are stopped by thin layers of metal or plastic. Antineutrinos have very little mass and no charge. Its been said that a neutrino has more than a 50% chance of traveling through a light-year of solid Lead and not be stopped.

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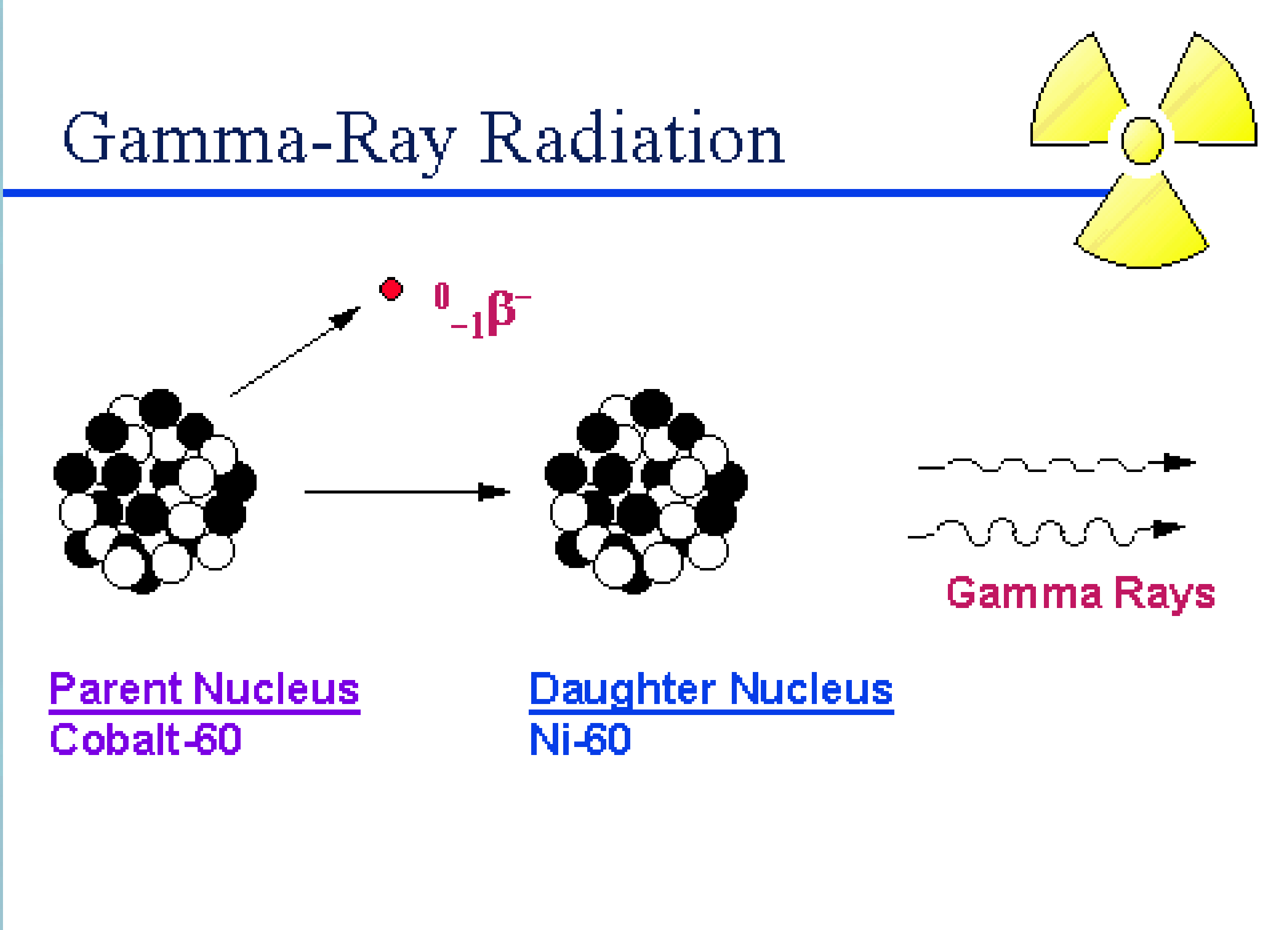
Gamma Radiation



After a decay reaction, the nucleus is often in an “excited” state. This means that the decay has resulted in producing a nucleus which still has excess energy to get rid of. Rather than emitting another beta or alpha particle, this energy is lost by emitting a pulse of electromagnetic radiation called a gamma ray. The gamma ray is identical in nature to light or microwaves, but of very high energy.

Like all forms of electromagnetic radiation, the gamma ray has no mass and no charge. Gamma rays interact with material by colliding with the electrons in the shells of atoms. They lose their energy slowly in material, being able to travel significant distances before stopping. Depending on their initial energy, gamma rays can travel from 1 to hundreds of meters in air and can easily go right through people.

It is important to note that most alpha and beta emitters also emit gamma rays as part of their decay process. However, there is no such thing as a “pure” gamma emitter. Important gamma emitters including Technetium-99^m which is used in nuclear medicine, and Cesium-137 which is used for calibration of nuclear instruments.

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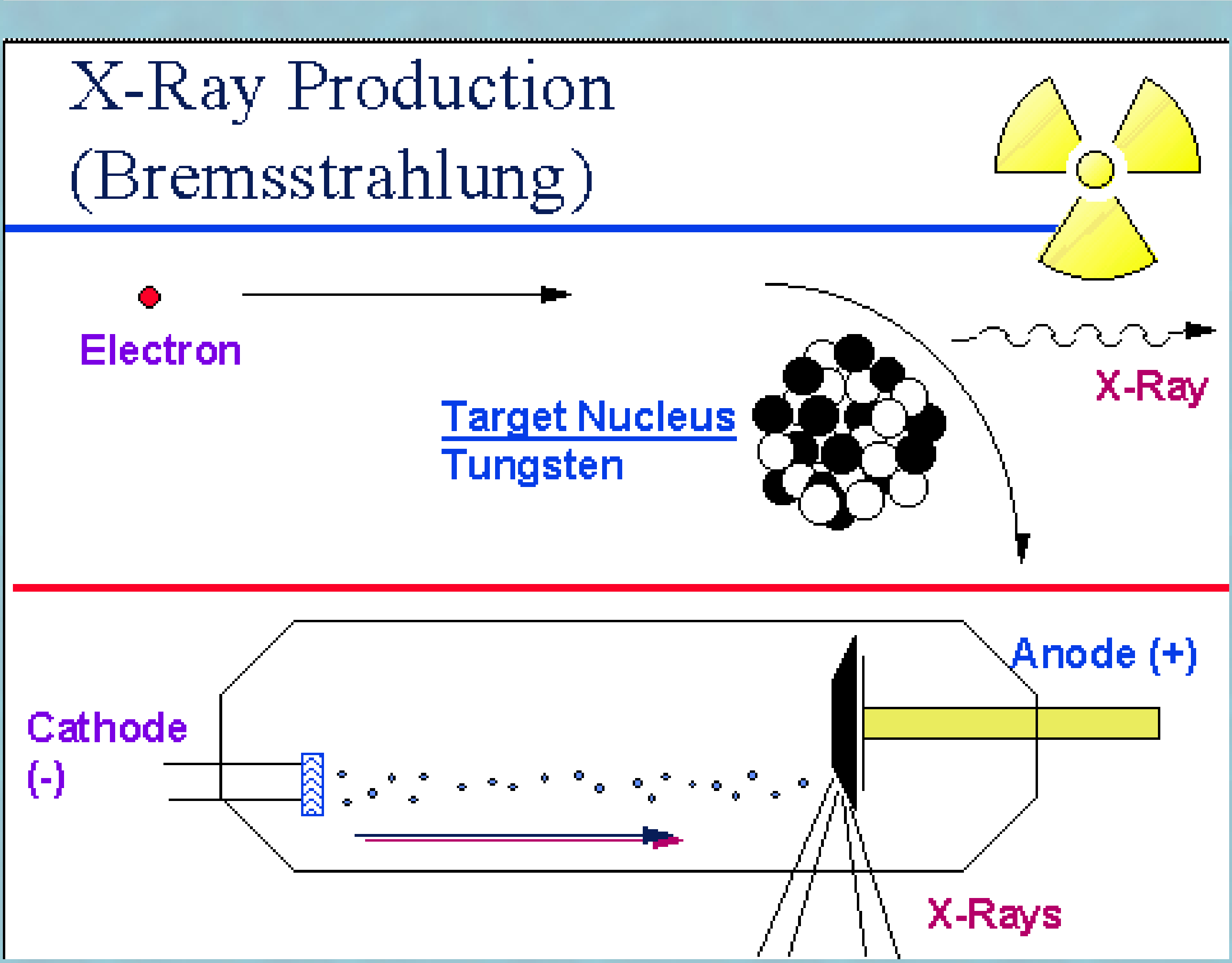
X-rays



Over a century ago in 1895, Roentgen discovered the first example of ionizing radiation, x-rays. The key to Roentgens discovery was a device called a Crooke's tube, which was a glass envelope under high vacuum, with a wire element at one end forming the cathode, and a heavy copper target at the other end forming the anode. When a high voltage was applied to the electrodes, electrons formed at the cathode would be pulled towards the anode and strike the copper with very high energy. Roentgen discovered that very penetrating radiations were produced from the anode, which he called x rays.

X-ray production occurs whenever electrons of high energy strike a heavy metal target, like tungsten or copper. When electrons hit this material, some of the electrons will approach the nucleus of the metal atoms where they are deflected because of their opposite charges (electrons are negative and the nucleus is positive, so the electrons are attracted to the nucleus). This deflection causes the energy of the electron to decrease, and this decrease in energy then results in forming an x ray.

Medical x-ray machines in hospitals use the same principle as the Crooke's Tube to produce x rays. The most common x-ray machines use tungsten as their cathode, and have very precise electronics so the amount and energy of the x-ray produced is optimum for making images of bones and tissues in the body.

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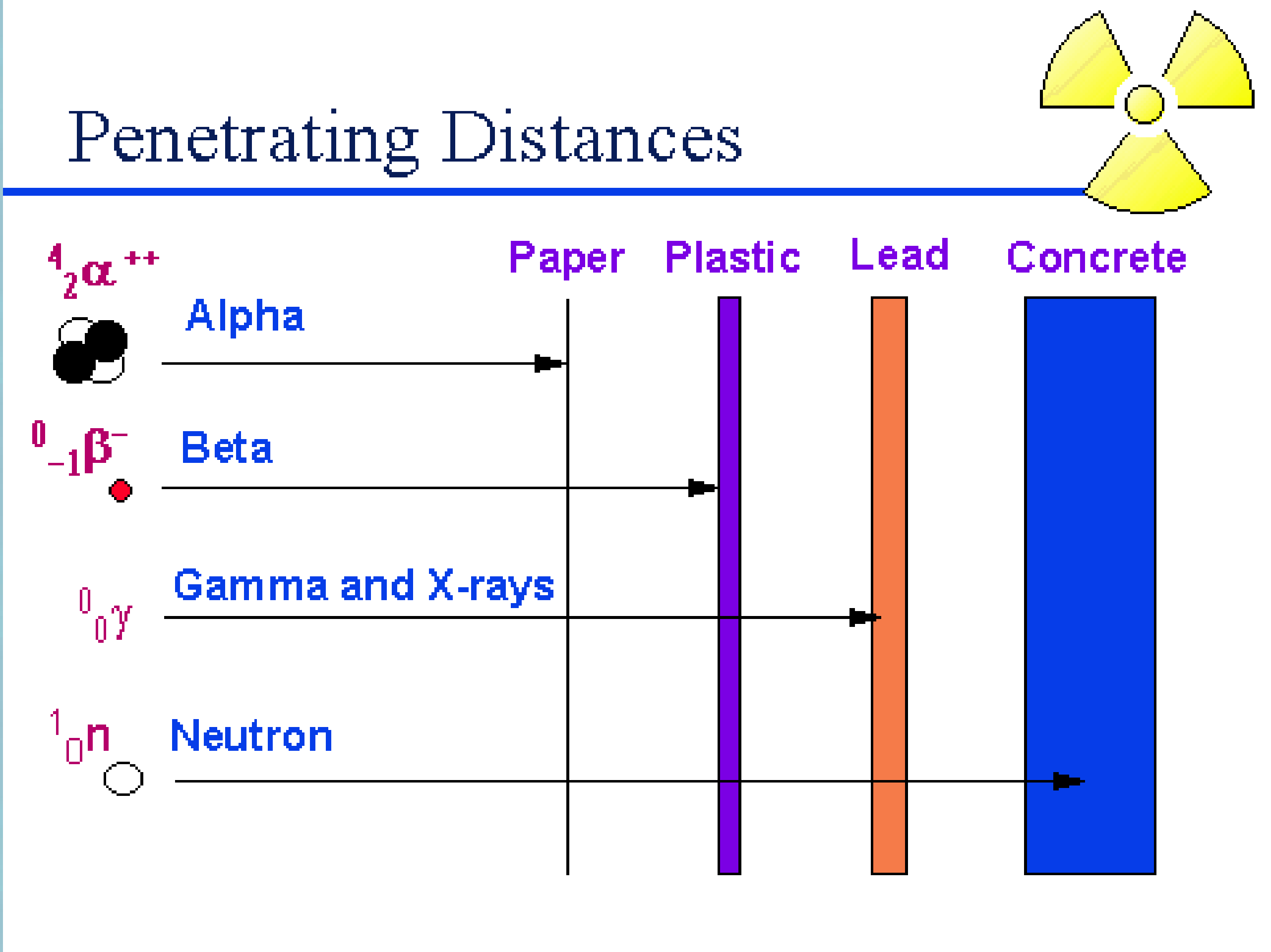
Page 7
Properties of Radiation

Different radiations have different properties, as summarized below:

Radiation	Type of Radiation	Mass (AMU)	Charge	Shielding material
Alpha	Particle	4	+2	Paper, skin, clothes
Beta	Particle	1/1836	±1	Plastic, glass, light metals
Gamma	Electromagnetic Wave	0	0	Dense metal, concrete, Earth
Neutrons	Particle	1	0	Water, concrete, polyethylene, oil



In summary, the most common types of radiation include alpha particles, beta and positron particles, gamma and x-rays, and neutrons. Alpha particles are heavy and doubly charged which cause them to lose their energy very quickly in matter. They can be shielded by a sheet of paper or the surface layer of our skin. Alpha particles are only considered hazardous to a person's health if an alpha emitting material is ingested or inhaled. Beta and positron particles are much smaller and only have one charge, which cause them to interact more slowly with material. They are effectively shielded by thin layers of metal or plastic and are again only considered hazardous if a beta emitter is ingested or inhaled.

Gamma emitters are associated with alpha, beta, and positron decay. X-Rays are produced either when electrons change orbits within an atom, or electrons from an external source are deflected around the nucleus of an atom. Both are forms of high energy electromagnetic radiation which interact lightly with matter. X-rays and gamma rays are best shielded by thick layers of lead or other dense material and are hazardous to people when they are external to the body.

Neutrons are neutral particles with approximately the same mass as a proton. Because they are neutral they react only weakly with material. They are an external hazard best shielded by thick layers of concrete. Neutron radiation will be discussed in more detail in the discussion of nuclear power.

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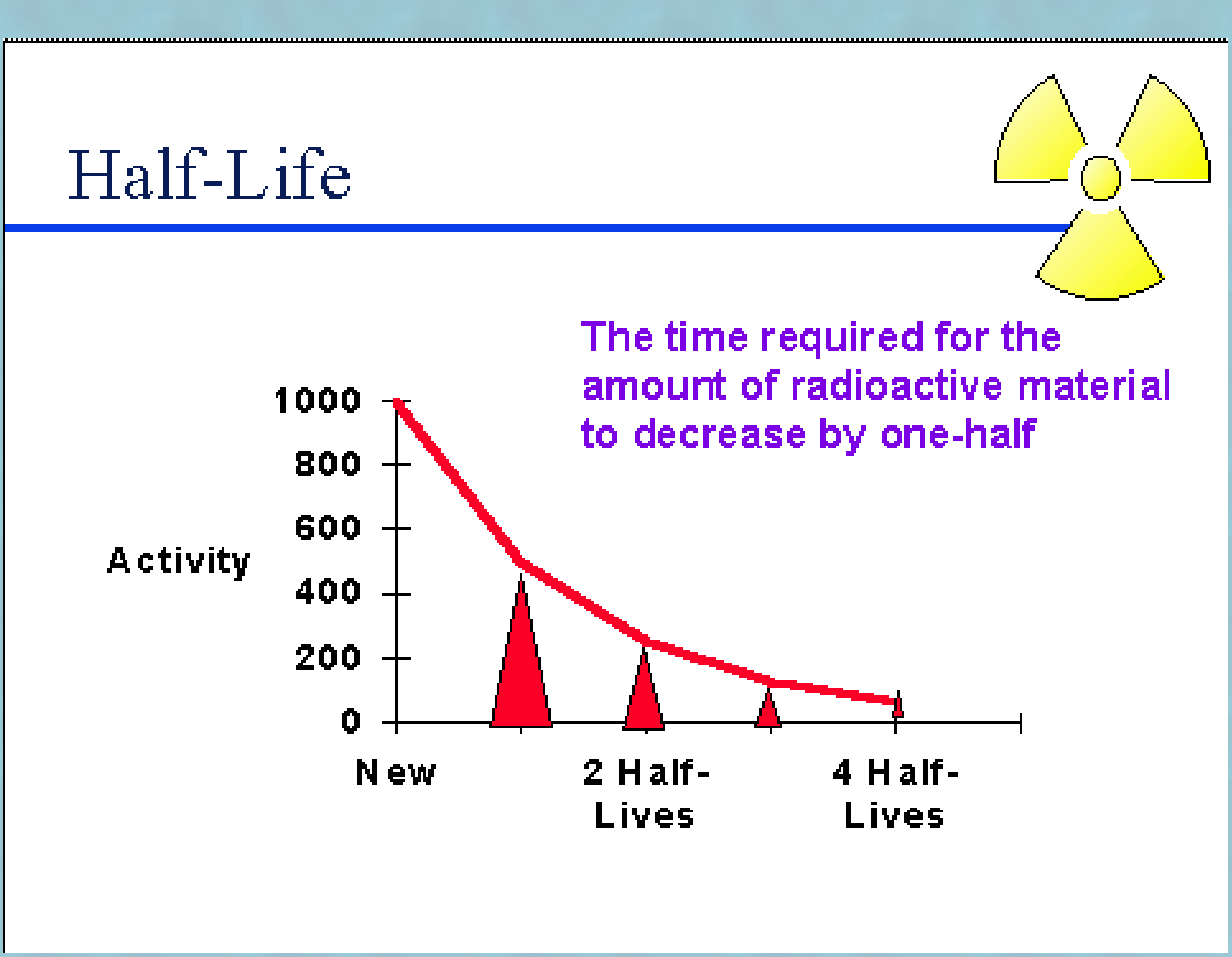
Half-life



Half-Life

The time required for the amount of radioactive material to decrease by one-half

Half-life is the time required for the quantity of a radioactive material to be reduced to one-half its original value.

All radionuclides have a particular half-life, some of which a very long, while other are extremely short. For example, uranium-238 has such a long half life, 4.5x10^{9} years, that only a small fraction has decayed since the earth was formed. In contrast, carbon-11 has a half-life of only 20 minutes. Since this nuclide has medical applications, it has to be created where it is being used so that enough will be present to conduct medical studies.

Here is a on-line calculator that will calculate the activity of some radionuclides at some time after it is formed.

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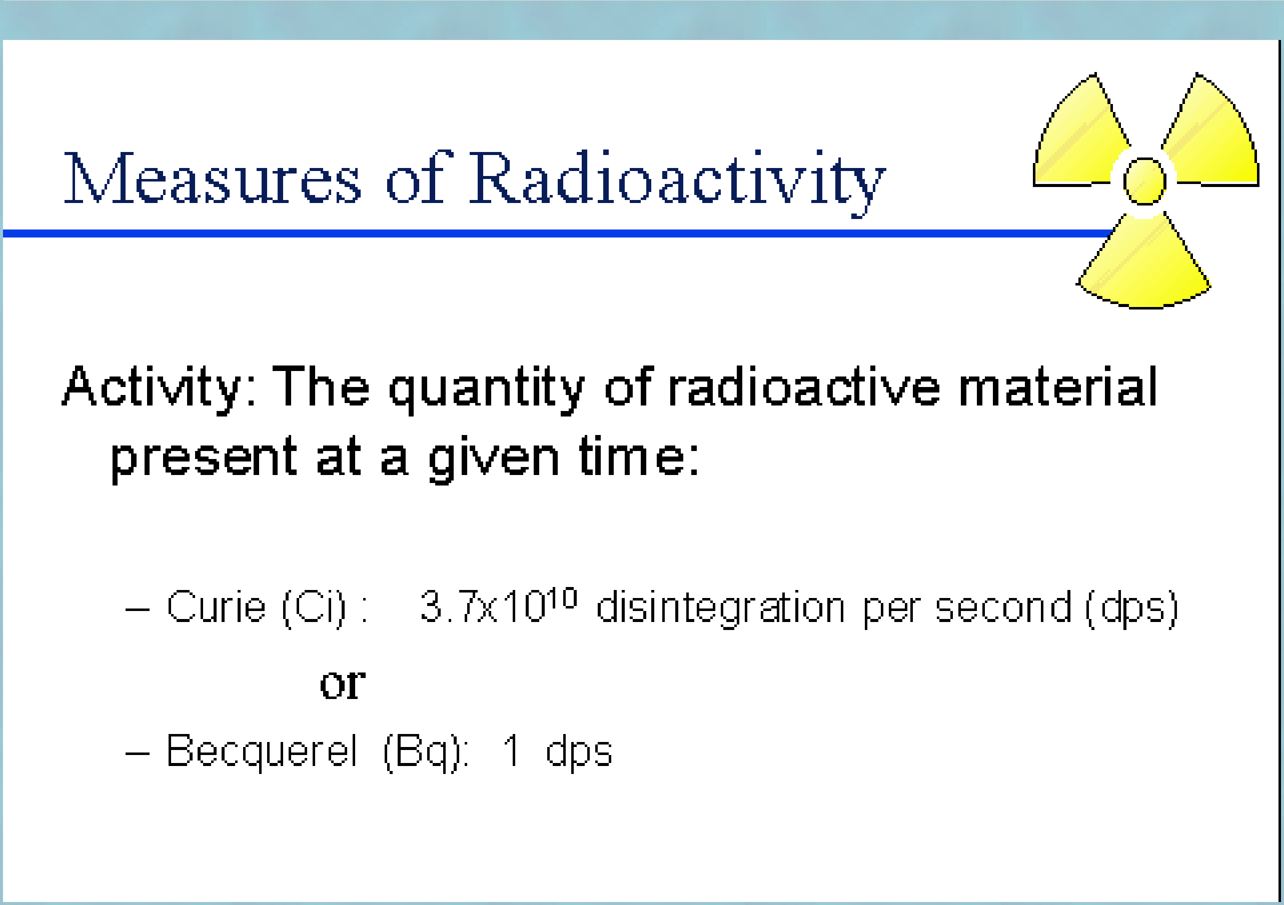
Radiation Measurement



Measures of Radioactivity

Activity: The quantity of radioactive material present at a given time:

- Curie (Ci) : $3.7\text{x}10^{10}$ disintegration per second (dps)

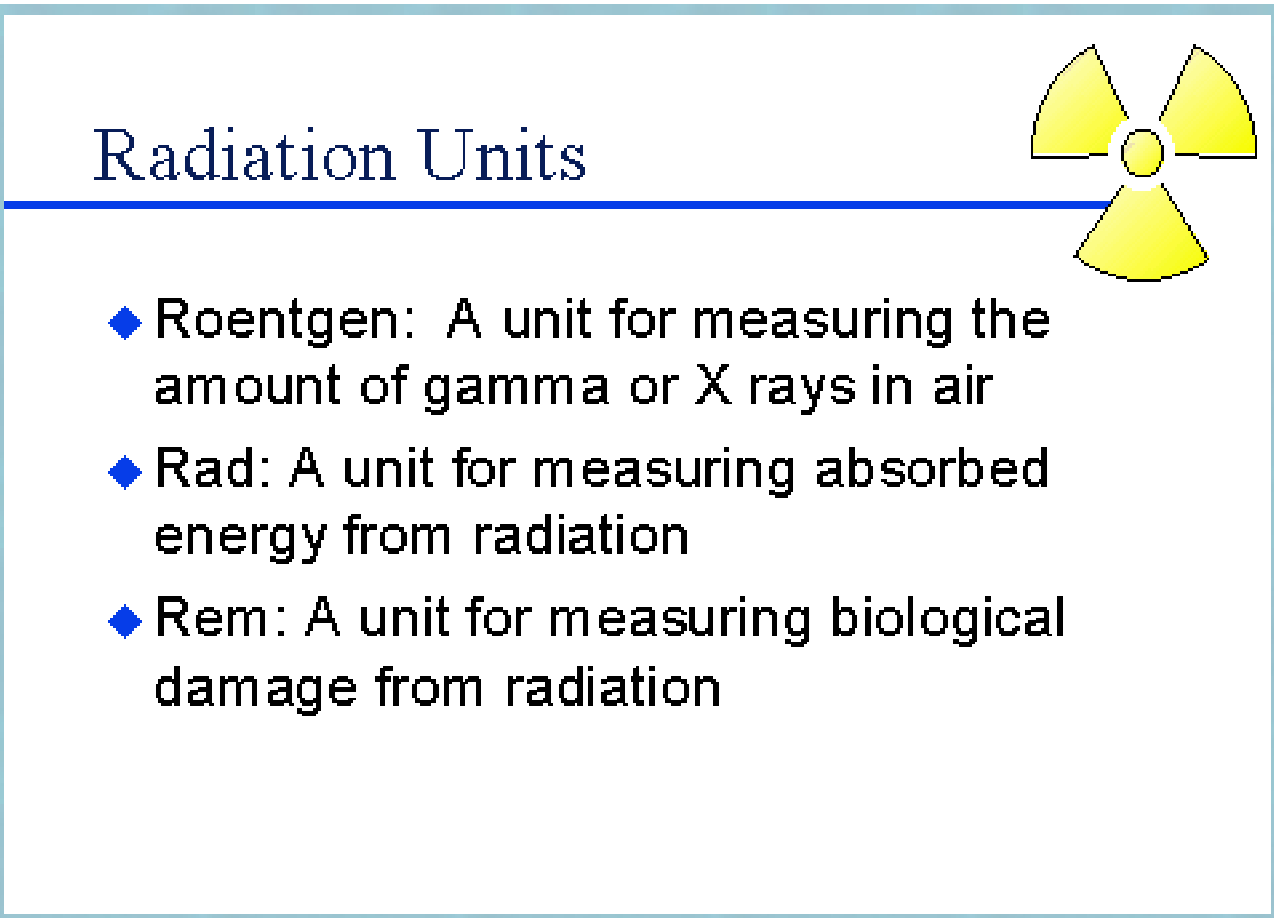
or

- Becquerel (Bq): 1 dps

When given a certain amount of radioactive material, it is customary to refer to the quantity based on its activity rather than its mass. The activity is simply the number of disintegrations or transformations the quantity of material undergoes in a given period of time.

The two most common units of activity are the Curie and the Becquerel. The Curie is named after Pierre Curie for his and his wife Marie's discovery of radium. One Curie is equal to $3.7\text{x}10^{10}$ disintegrations per second. A newer unit of activity if the Becquerel named for Henry Becquerel who is credited with the discovery of radioactivity. One Becquerel is equal to one disintegration per second.

It is obvious that the Curie is a very large amount of activity and the Becquerel is a very small amount. To make discussion of common amounts of radioactivity more convenient, we often talk in terms of milli and microCuries or kilo and MegaBecquerels.



Radiation Units

- Roentgen: A unit for measuring the amount of gamma or X rays in air
- Rad: A unit for measuring absorbed energy from radiation
- Rem: A unit for measuring biological damage from radiation

Radiation is often measured in one of these three units, depending on what is being measured and why. In international units, these would be Coulombs/kg for roentgen, Grays for rads and Seiverts for rem.

Pictures of the Curies and of Becquerel.

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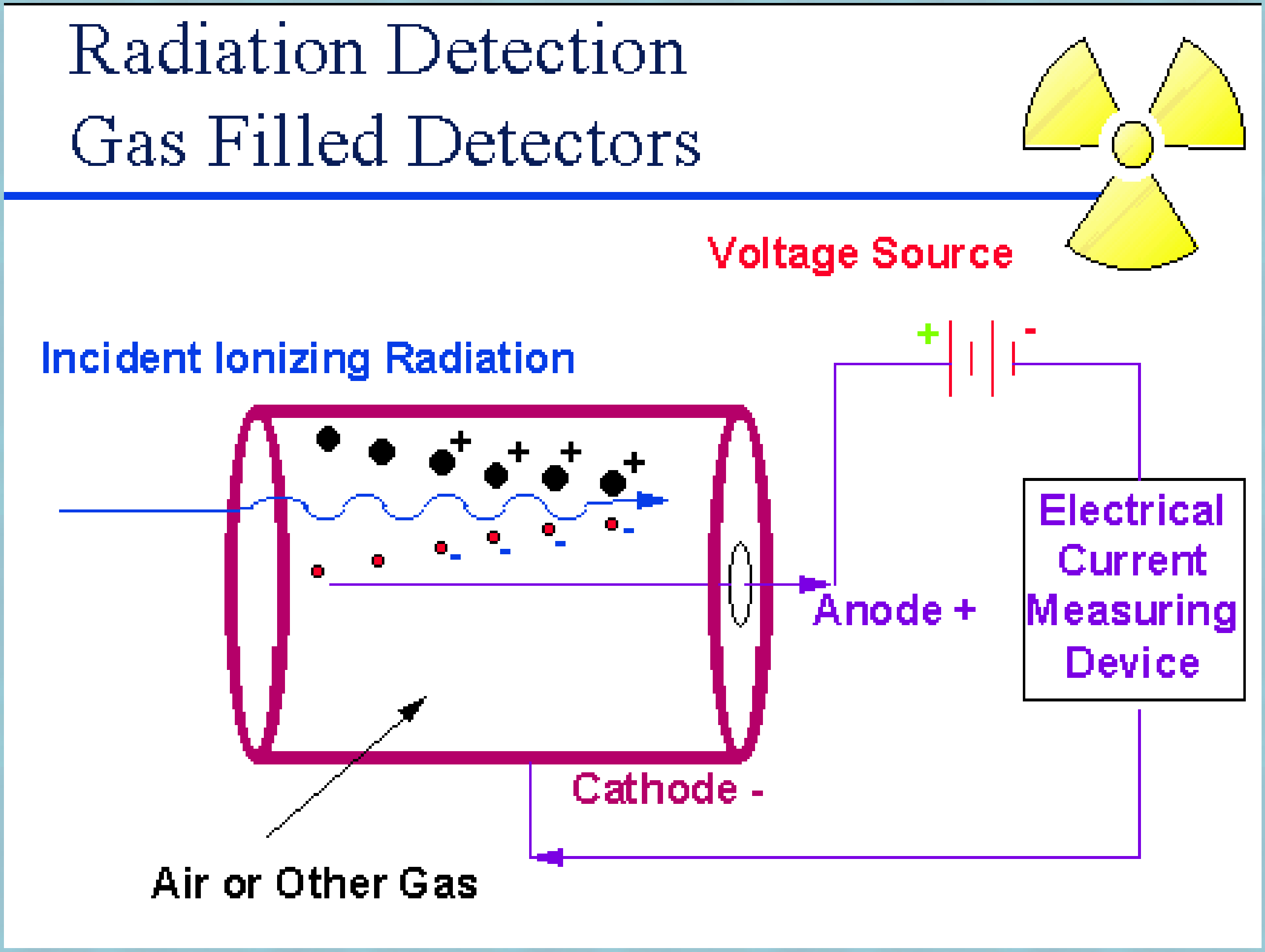
Measurement of Radiation, Gas Filled Detector



Since we cannot see, smell or taste radiation, we are dependent on instruments to indicate the presence of ionizing radiation.

The most common type of instrument is a gas filled radiation detector. This instrument works on the principle that as radiation passes through air or a specific gas, ionization of the molecules in the air occur. When a high voltage is placed between two areas of the gas filled space, the positive ions will be attracted to the negative side of the detector (the cathode) and the free electrons will travel to the positive side (the anode). These charges are collected by the anode and cathode which then form a very small current in the wires going to the detector. By placing a very sensitive current measuring device between the wires from the cathode and anode, the small current measured and displayed as a signal. The more radiation which enters the chamber, the more current displayed by the instrument.

Many types of gas-filled detectors exist, but the two most common are the ion chamber used for measuring large amounts of radiation and the Geiger-Muller or GM detector used to measure very small amounts of radiation.

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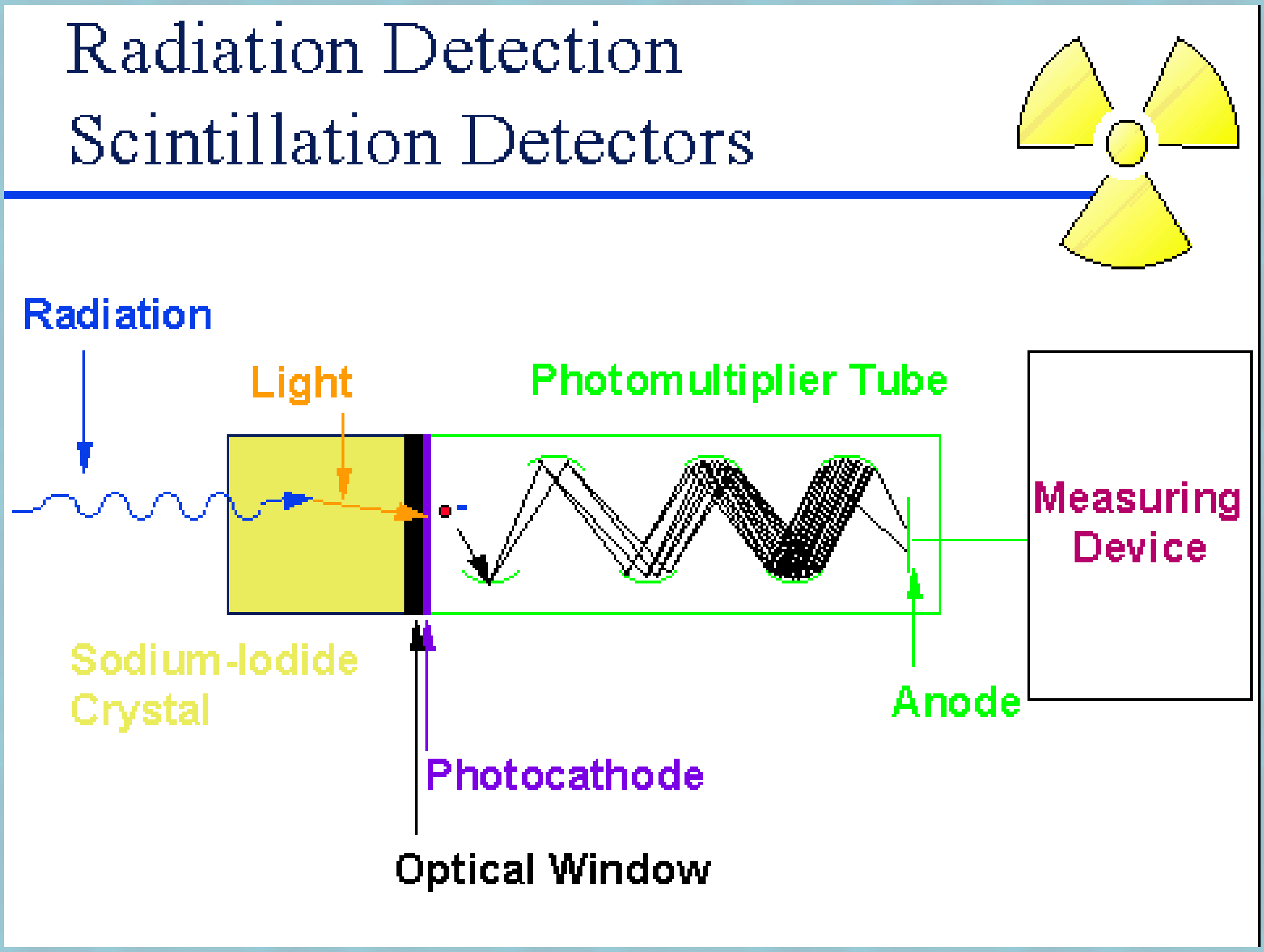
Measurement of Radiation, Sodium Iodide Detector



The second most common type of radiation detecting instrument is the scintillation detector. The basic principle behind this instrument is the use of a special material which glows or “scintillates” when radiation interacts with it. The most common type of material is a type of salt called sodium-iodide. The light produced from the scintillation process is reflected through a clear window where it interacts with device called a photomultiplier tube.

The first part of the photomultiplier tube is made of another special material called a photocathode. The photocathode has the unique characteristic of producing electrons when light strikes its surface. These electrons are then pulled towards a series of plates called dynodes through the application of a positive high voltage. When electrons from the photocathode hit the first dynode, several electrons are produced for each initial electron hitting its surface. This “bunch” of electrons is then pulled towards the next dynode, where more electron “multiplication” occurs. The sequence continues until the last dynode is reached, where the electron pulse is now millions of times larger then it was at the beginning of the tube. At this point the electrons are collected by an anode at the end of the tube forming an electronic pulse. The pulse is then detected and displayed by a special instrument.

Scintillation detectors are very sensitive radiation instruments and are used for special environmental surveys and as laboratory instruments.

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Basic Terms

Radiation

Radiation is energy in transit in the form of high speed particles and electromagnetic waves. We encounter electromagnetic waves every day. They make up our visible light, radio and television waves, ultra violet (UV), and microwaves with a spectrum of energies. These examples of electromagnetic waves do not cause ionizations of atoms because they do not carry enough energy to separate molecules or remove electrons from atoms.

Ionizing radiation

Ionizing radiation is radiation with enough energy so that during an interaction with an atom, it can remove tightly bound electrons from their orbits, causing the atom to become charged or ionized. Examples are gamma rays and neutrons. Radiation is measured in many ways, and commonly expressed in units of RAD.

Non-ionizing radiation

Non-ionizing radiation is radiation without enough energy to remove tightly bound electrons from their orbits around atoms. Examples are microwaves and visible light.

Health Physics

Health Physics is an interdisciplinary science and its application, for the radiation protection of humans and the environment. Health Physics combines the elements of physics, biology, chemistry, statistics and electronic instrumentation to provide information that can be used to protect individuals from the effects of radiation.

Radioactivity

Radioactivity is the spontaneous transformation of an unstable atom and often results in the emission of radiation. This process is referred to as a transformation, a decay or a disintegration of an atom.

Radioactive Material

Radioactive Material is any material that contains radioactive atoms.

Radioactive Contamination

Radioactive contamination is radioactive material distributed over some area, equipment or person. It tends to be unwanted in the location where it is, and has to be cleaned up or decontaminated.

Dose

In a general sense, dose is a measure of the amount of energy from an ionizing radiation deposited in a mass of some material. Dose is affected by the TYPE of radiation, the amount of radiation and the physical properties of the material itself. Specifically, we can talk about absorbed dose in tissue, or a material like silicon. Other common doses are the effective and equivalent doses, which are adjusted to allow the comparison of different tissues or types of radiation. Absorbed doses are normally measured in units of Gray (RAD), and effective and equivalent doses in Sievert (Rem).

Common Types of Radiation

Gamma Rays

Gamma rays are electromagnetic waves or photons emitted from the nucleus (center) of an atom.

Betas

A beta is a high speed particle, identical to an electron, that is emitted from the nucleus of an atom. It has an anti-matter counter part, sometimes called a Beta+, called a positron. A positron has the same mass and size as an electron but has a positive (+) charge versus the electron's negative (-) charge.

Alphas

An alpha is a particle emitted from the nucleus of an atom, that contains two protons and two neutrons. It is identical to the nucleus of a Helium atom, without the electrons.

Neutrons

Neutrons are neutral particles that are normally contained in the nucleus of all atoms and may be removed by various interactions or processes like collision and fission.

X rays

X Rays are electromagnetic waves or photons not emitted from the nucleus, but normally emitted by energy changes in electrons. These energy changes are either in electron orbital shells that surround an atom or in the process of slowing down such as in an X-ray machine.

Common Units - USA

These are the common units used in the United States in health physics.

Roentgen (R)

The Roentgen is a unit used to measure a quantity called exposure. This can only be used to describe an amount of gamma and X-rays, and only in air. One Roentgen is equal depositing to 2.58×10^{-4} coulombs per kg of dry air. It is a measure of the ionizations of the molecules in a mass of air. The main advantage of this unit is that it is easy to measure directly, but it is limited because it is only for deposition in air, and only for gamma and x rays.

RAD (Radiation Absorbed Dose)

The RAD is a unit used to measure a quantity called absorbed dose. This relates to the amount of energy actually absorbed in some material, and is used for any of radiation and any material. One RAD is defined as the absorption of 100 ergs per gram of material. The unit RAD can be used for any of radiation, but it does not describe the biological effects of the different radiations.

REM (Roentgen Equivalent Man)

The rem is a unit used to derive a quantity called equivalent dose. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of thousandths of a rem, or millirem. To determine equivalent dose (rem), you multiply absorbed dose (RAD) by a quality factor (Q) that is unique to the of incident radiation.

Curie (Ci)

The curie is a unit used to measure a radioactivity. One curie is the amount of radioactivity in one gram of the element first discovered by Madame Curie, Radium. It is also the quantity of a radioactive material that will have 37,000,000,000 transformations in one second. Often radioactivity is expressed in smaller units like: thousandths (mCi), one millionths (uCi) or even billionths (nCi) of a curie. The relationship between Becquerel and curie is: 3.7×10^{10} Bq in one curie.

Common Units - SI - International Standard

Note: These are the common units used throughout the world in health physics.

Gray (Gy)

The gray is a unit used to measure a quantity called absorbed dose. This relates to the amount of energy actually absorbed in some material, and is used for any of radiation and any material. One gray is equal to one joule of energy deposited in one kg of a material. The unit gray can be used for any of radiation, but it does not describe the biological effects of the different radiations. Absorbed dose is often expressed in terms of hundredths of a gray, or centi-grays. One gray is equivalent to 100 RAD.

Sievert (Sv)

The Sievert is a unit used to derive a quantity called equivalent dose. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of millionths of a Sievert, or micro-Sievert. To determine equivalent dose (Sv), you multiply absorbed dose (Gy) by a quality factor (Q) that is unique to the of incident radiation. One Sievert is equivalent to 100 rem.

Becquerel (Bq)

The Becquerel is a unit used to measure a radioactivity. One Becquerel is that quantity of a radioactive material that will have 1 transformation in one second. Often radioactivity is expressed in larger units like: thousands (kBq), millions (MBq) or even billions (GBq) of a Becquerel. As a result of having one Becquerel being equal to one transformation per second, there are 3.7 x 10^{10} Bq in one curie.

SI Prefixes

Many units are broken down into smaller units or expressed as multiples, using standard metric prefixes. As examples, a kilobecquerel (kBq) is 1000 Becquerel, a millirad (mrad) is 10^{-3} RAD, a microrem (μrem) is 10^{-6} rem, a nanogram is 10^{-9} grams, and a picocurie is a 10^{-12} curies.

SI Prefixes

Factor	Prefix	Symbols	Factor	Prefix	Symbols
10^{18}	exa	E	**10^{-1}**	deci	d
10^{15}	peta	P	**10^{-2}**	centi	c
10^{12}	tera	T	**10^{-3}**	milli	m
10^{9}	giga	G	**10^{-6}**	micro	μ
10^{6}	mega	M	**10^{-9}**	nano	n
10^{3}	kilo	k	**10^{-12}**	pico	p
10^{2}	hecto	h	**10^{-15}**	femto	f
10^{1}	deka	da	**10^{-18}**	atto	a

Terms Related to Radiation Dose

Chronic dose

A chronic dose means a person received a radiation dose over a long period of time.

Acute dose

An acute dose means a person received a radiation dose over a short period of time.

Somatic effects

Somatic effects are effects from some agent, like radiation that are seen in the individual who receives the agent.

Genetic effects

Genetic effects are effects from some agent, that are seen in the offspring of the individual who received the agent. The agent must be encountered pre-conception.

Teratogenic effects

Teratogenic effects are effects from some agent, that are seen in the offspring of the individual who received the agent. The agent must be encountered during the gestation period.

Stochastic effects

Stochastic effects are effects that occur on a random basis with its effect being independent of the size of dose. The effect typically has no threshold and is based on probabilities, with the chances of seeing the effect increasing with dose. Cancer is thought to be a stochastic effect.

Non-stochastic effect

Non-stochastic effects are effects that can be related directly to the dose received. The effect is more severe with a higher dose, i.e., the burn gets worse as dose increases. It typically has a threshold, below which the effect will not occur. A skin burn from radiation is a non-stochastic effect.

For additional definitions, try:

NRC's Nuclear Related Terms

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Radiation and Risk

How much radiation do we get?

The average person in the United States receives about 360 mrem every year whole body equivalent dose. This is mostly from natural sources of radiation, such as radon. (See Radiation and Us).

In 1992, the average dose received by nuclear power workers in the United States was 3 mSv whole body equivalent in addition to their background dose.

What is the effect of radiation?

Radiation causes ionizations in the molecules of living cells. These ionizations result in the removal of electrons from the atoms, forming ions or charged atoms. The ions formed then can go on to react with other atoms in the cell, causing damage. An example of this would be if a gamma ray passes through a cell, the water molecules near the DNA might be ionized and the ions might react with the DNA causing it to break.

At low doses, such as what we receive every day from background radiation, the cells repair the damage rapidly. At higher doses (up to 1 Sv), the cells might not be able to repair the damage, and the cells may either be changed permanently or die. Most cells that die are of little consequence, the body can just replace them. Cells changed permanently may go on to produce abnormal cells when they divide. In the right circumstance, these cells may become cancerous. This is the origin of our increased risk in cancer, as a result of radiation exposure.

At even higher doses, the cells cannot be replaced fast enough and tissues fail to function. An example of this would be "radiation sickness." This is a condition that results after high acute doses to the whole body (>2 Gy), the body's immune system is damaged and cannot fight off infection and disease. Several hours after exposure nausea and vomiting occur. This leads to nausea, diarrhea and general weakness. With higher whole body doses (>10 Gy), the intestinal lining is damaged to the point that it cannot perform its functions of intake of water and nutrients, and protecting the body against infection. At whole body doses near 7 Gy, if no medical attention is given, about 50% of the people are expected to die within 60 days of the exposure, due mostly from infections.

If someone receives a whole body dose more than 20 Gy, they will suffer vascular damage of vital blood providing systems for nervous tissue, such as the brain. It is likely at doses this high, 100% of the people will die, from a combination of all the reasons associated with lower doses and the vascular damage.

There a large difference between whole body dose, and doses to only part of the body. Most cases we will consider will be for doses to the whole body.

For more information on Acute radiation doses and its effects, check here

What needs to be remembered is that very few people have **ever** received doses more than 2 Gy. With the current safety measures in place, it is not expected that anyone will receive greater than 0.05 Gy in one year where these sicknesses are for sudden doses delivered all at once. Radiation risk estimates, therefore, are based on the increased rates of cancer, not on death directly from the radiation.

Non-Ionizing radiation does not cause damage the same way that ionizing radiation does. It tends to cause chemical changes (UV) or heating (Visible light, Microwaves) and other molecular changes (EMF). Further information on EMF that may be of interest.

- FAQ on Power lines and Cancer (John Moulder)
- FAQs about Cell Phone Base Antennas and Human Health (John Moulder)
- Static fields and Cancer FAQ (John Moulder)

Further information on the biological effects can be found in our FAQ.

Risk

How is risk determined?

Risk estimates for radiation were first evaluated by scientific committees in the starting in the 1950s. The most recent of these committees was the Biological Effects of Ionizing Radiation committee five (BEIR V). Like previous committees, this one was charged with estimating the risk associated with radiation exposure. They published their findings in 1990. The BEIR IV committee established risks exclusively for radon and other internally alpha emitting radiation, while BEIR V concentrated primarily on external radiation exposure data.

It is difficult to estimate risks from radiation, for most of the radiation exposures that humans receive are very close to background levels. In most cases, the effects from radiation are not distinguishable from normal levels of those same effects. With the beginning of radiation use in the early part of the century, the early researchers and users of radiation were not as careful as we are today though. The information from medical uses and from the survivors of the atomic bombs (ABS) in Japan, have given us most of what we know about radiation and its effects on humans. Risk estimates have their limitations,

1. The doses from which risk estimates are derived were much higher than the regulated dose levels of today;
2. The dose rates were much higher than normally received;
3. The actual doses received by the ABS group and some of the medical treatment cases have had to be estimated and are not known precisely;
4. Many other factors like ethnic origin, natural levels of cancers, diet, smoking, stress and bias effect the estimates.

What is the risk estimate?

According to the Biological Effects of Ionizing Radiation committee V (BEIR V), the risk of cancer death is 0.08% per rem for doses received rapidly (acute) and might be 2-4 times (0.04% per rem) less than that for doses received over a long period of time (chronic). These risk estimates are an average for all ages, males and females, and all forms of cancer. There is a great deal of uncertainty associated with the estimate.

Risk from radiation exposure has been estimated by other scientific groups. The other estimates are not the exact same as the BEIR V estimates, due to differing methods of risk and assumptions used in the calculations, but all are close.

Risk comparison

The real question is: how much will radiation exposure increase my chances of cancer death over my lifetime.

To answer this, we need to make a few general statements of understanding. One is that in the US, the current death rate from cancer is approximately 20 percent, so out of any group of 10,000 United States citizens, about 2,000 of them will die of cancer. Second, that contracting cancer is a random process, where given a set population, we can estimate that about 20 percent will die from cancer, but we cannot say *which* individuals will die. Finally, that a conservative estimate of risk from low doses of radiation is thought to be one in which the risk is linear with dose. That is, that the risk increases with a subsequent increase in dose. Most scientists believe that this is a conservative model of the risk.

So, now the risk estimates. If you were to take a large population, such as 10,000 people and expose them to one rem (to their whole body), you would expect approximately eight additional deaths (0.08%*10,000*1 rem). So, instead of the 2,000 people expected to die from cancer naturally, you would now have 2,008. This small increase in the expected number of deaths would not be seen in this group, due to natural fluctuations in the rate of cancer.

What needs to be remembered it is not known that 8 people will die, but that there is a risk of 8 additional deaths in a group of 10,000 people if they would all receive one rem instantaneously.

If they would receive the 1 rem over a long period of time, such as a year, the risk would be less than half this (<4 expected fatal cancers).

Risks can be looked at in many ways, here are a few ways to help visualize risk.

One way often used is to look at the number of "days lost" out of a population due to early death from separate causes, then dividing those days lost between the population to get an "Average Life expectancy lost" due to those causes. The following is a table of life expectancy lost for several causes:

Health Risk	**Est. life expectancy lost**

Smoking 20 cigs a day	6 years
Overweight (15%)	2 years
Alcohol (US Ave)	1 year
All Accidents	207 days
All Natural Hazards	7 days
Occupational dose (300 mrem/yr)	15 days
Occupational dose (1 rem/yr)	51 days

You can also use the same approach to looking at risks on the job:

Industry type	**Est. life expectancy lost**
All Industries	60 days
Agriculture	320 days
Construction	227 days
Mining and quarrying	167 days
Manufacturing	40 days
Occupational dose (300 mrem/yr)	15 days
Occupational dose (1 rem/yr)	51 days

These are estimates taken from the NRC Draft guide DG-8012 and were adapted from B.L Cohen and I.S. Lee, "Catalogue of Risks Extended and Updates", Health Physics, Vol. 61, September 1991.

Another way of looking at risk, is to look at the Relative Risk of 1 in a million chances of dying of activities common to our society.

- Smoking 1.4 cigarettes (lung cancer)
- Eating 40 tablespoons of peanut butter
- Spending 2 days in New York City (air pollution)
- Driving 40 miles in a car (accident)
- Flying 2500 miles in a jet (accident)
- Canoeing for 6 minutes
- Receiving 10 mrem of radiation (cancer)

Adapted from DOE Radiation Worker Training, based on work by B.L Cohen, Sc.D.

The following is a comparison of the risks of some medical exams and is based on the following information:

- **Cigarette Smoking -** 50,000 lung cancer deaths each year per 50 million smokers consuming 20 cigarettes a day, or one death per 7.3 million cigarettes smoked or 1.37 x 10^{-7} deaths per cigarette

- **Highway Driving -** 56,000 deaths each year per 100 million drivers, each covering 10,000 miles or one death per 18 million miles driving, or 5.6 x 10^{-8} deaths per mile driven
- **Radiation Induced Fatal Cancer -** 4% per Sv (100 rem) for exposure to low doses and dose rates

Procedure	Effective Dose (Sv)	Effective Dose (mrem)	Risk of Fatal Cancer	Equivalent to Number of Cigarettes Smoked	Equivalent to Number of Highway Miles Driven
Chest Radiograph	3.2 x 10^{-5}	3.2	1.3 x 10^{-6}	9	23
Skull Exam	1.5 x 10^{-4}	15	6 x 10^{-6}	44	104
Barium Enema	5.4 x 10^{-4}	54	2 x 10^{-5}	148	357
Bone Scan	4.4 x 10^{-3}	440	1.8 x 10^{-4}	1300	3200

Adapted from information in *Radiobiology for the Radiologist*, Forth Edition; Eric Hall 1994, J.B. Lippincott Company

So, in summary, we must balance the risks with the benefit. It is something we do often. We want to go somewhere in a hurry, we accept the risks of driving for that benefit. We want to eat fat foods, we accept the risks of heart disease. Radiation is another risk which we must balance with the benefit. The benefit is that we can have a source of power, or we can do scientific research, or receive medical treatments. The risks are a small increase in cancer. Risk comparisons show that radiation is a small risk, when compared to risks we take every day. We have studied radiation for nearly 100 years now. It is not a mysterious source of disease, but a well-understood phenomenon, better understood than almost any other cancer causing agent to which we are exposed.

Doses

The following is a comparison of limits, doses and dose rates from many different sources. Most of this data came from Radiobiology for the Radiologist, by Eric Hall or BEIR V, National Academy of Science. Ranges have been given if known. All doses are TEDE (whole body total) unless otherwise noted. Units are defined on our Terms Page. The doses for x-rays are for the years 1980-1985 and could be lower today. Any correction or comments can be sent to us at the University of Michigan using our comment form.

Doses from various sources

Limits for Exposures	**Exposure**	**Range**
Occupational Dose limit (US - NRC)	50 mSv/year	
Occupational Exposure Limits for Minors	5 mSv/year	
Occupational Exposure Limits for Fetus	5 mSv	
Public dose limits due to licensed activities (NRC)	1 mSv/year	
Occupational Limits (eye)	150 mSv/year	
Occupational Limits (skin)	500 mSv/year	
Occupational Limits (extremities)	500 mSv/year	
Source of Exposure		
Average Dose to US public from All sources	3.6 mSv/year	
Average Dose to US Public From Natural Sources	3.0 mSv/year	
Average Dose to US Public From Medical Sources	530 microSv/year	
Average dose to US Public from Weapons Fallout	< 10 microSv/year	
Average Dose to US Public From Nuclear Power	< 1 microSv/year	
Coal Burning Power Plant	1.65 microSv/year	
X-rays from old TV set (1 inch)	5 microSv/hour	
Airplane ride (39,000 ft.)	5 microSv/hour	
Nuclear Power Plant (normal operation at plant boundary)	6 microSv/year	
Natural gas in home	90 microSv/year	
Average Natural Background	0.008 mR/hour	0.006-0.015 mR/hour
Average US Cosmic Radiation	270 microSv/year	
Average US Terrestrial Radiation	280 microSv/year	
Terrestrial background (Atlantic coast)	160 microSv/year	
Terrestrial background (Rocky Mountains)	400 microSv/year	
Cosmic Radiation (Sea level)	260 microSv/year	
Cosmic Radiation (Denver)	500 microSv/year	
Background Radiation Total (East, West, Central US)	460 microSv/year	350-750 microSv/year
Background Radiation Total (Colorado Plateau)	900 microSv/year	750-1400 microSv/year
Background Radiation Total (Atlantic and Gulf in US)	230 microSv/year	150-350 microSv/year

Radionuclides in the body (i.e., potassium)	390 microSv/year	
Building materials (concrete)	30 microSv/year	
Drinking Water	50 microSv/year	
Pocket watch (radium dial)	60 microSv/year	
Eyeglasses (containing thorium)	60 - 110 microSv/year	
Coast to coast Airplane roundtrip	50 microSv	
Chest x-ray	80 microSv	50 - 200 microSv
Extemities x-ray	10 microSv	
Dental x-ray	100 microSv	
Head/neck x-ray	200 microSv	
Cervical Spine x-ray	220 microSv	
Lumbar spinal x-rays	1.30 mSv	
Pelvis x-ray	440 microSv	
Hip x-ray	830 microSv	
Shoe Fitting Fluroscope (not in use now)	1.70 mSv	
Upper GI series	2.45 mSv	
Lower GI series	4.05 mSv	
Diagnostic thyroid exam (to the thyroid)	0.5 Gy	
Diagnostic thyroid exam (to the Whole Body)	0.35 mGy	
CT (head and body)	11 mSv	
Therapeutic thyroid treatment (dose to the thyroid)		50-100 Gy
Therapeutic thyroid treatment (dose to the whole body)	7 cSv	5-15 cGy
Earliest Onset of Radiation Sickness	0.75 Gy	
Onset of hematopoietic syndrome	3 Gy	1 to 8 Gy
Onset of gastrointestinal syndrome	10 Gy	5 - 12 Gy
Onset of cerebrovacular syndrome	100 Gy	>500 Gy
Thershold for cataracts (dose to the eye)	2 Gy	
Expected 50% death without medical attention	4 Gy	3 to 5 Gy
Doubling dose for genetic effects	1 Gy	
Doubling dose for cancer	5 Gy	(8% per Sv, natural level at 20%)
Dose for increase cancer risk of 1 in a 1,000	1.250 cSv	(8% per Sv)
Consideration of theraputic abortion threshold (dose in utero)	10 cSv	
SL1 Reactor Accident highest dose to survivor	27 cSv	
Three Mile Island (dose at plant duration of the accident)	0.80 mSv	

For additional information on risk and low level radiation:

Radiation Effects Study (Diane LaMacchia)

Health Physics Society Position Statement on Risk from Ionizing Radiation (PDF Version, html)

Radiation and Us

Radiation all around us

Humans have been exposed to radiation from natural sources since the dawn of time. The sources include the ground we walk on, the air we breath, the food we eat and the solar system on the whole. Everything in our world contains small amounts of radioactive atoms like Potassium 40, Radium 226 and Radon 222. These are either left over from the creation of the world (like Uranium and Radium) or made by interactions with cosmic radiation (like Carbon 14 and Tritium). The Earth is constantly receiving cosmic radiation from outer space. These natural sources of radiation make up approximately 82 percent of the average annual dose to the US public.

The following was developed by the National Council on Radiation Protection and Measurement (NCRP 93) and is a breakdown of the sources of radiation for the population of the United States. These numbers are averages and were obtained by estimating the total dose for the US, and dividing by the number of people in the US.

Annual Effective Dose Equivalent

SOURCE	DOSE (mrem/yr)	DOSE (mSv/yr)	PERCENT OF TOTAL
Natural			
Radon	200	2.0	55%
Cosmic	27	0.27	8%
Terrestrial	28	0.28	8%
Internal	39	0.39	11%
Total Natural	**300**	**3**	**82%**
Artificial			
Medical X ray	39	0.39	11%
Nuclear medicine	14	0.14	4%
Consumer products	10	0.1	3%
Other			
Occupational	0.9	<0.01	<0.3

Nuclear Fuel Cycle	<1	<0.01	<0.03
Fallout	<1	<0.01	<0.03
Miscellaneous	<1	<0.01	<0.03
Total Artificial	**63**	**0.63**	**18%**
Total Artificial and Natural	360	3.6	100%

Or, this can perhaps be more easily seen with a graph (6K)

Further more, we also have a list of doses from other sources for comparison.

Natural Radiation

Everyone by now has probably heard of radon. Radon comes from the decay (change) of Uranium, a natural element. Uranium decays through a long chain of radionuclides that includes radon. Radon is a noble gas, not chemically active so it migrates through porous materials like the ground and your house's foundation. The radon itself has a small chance of decay as you breath it in and out. Most of our actual dose comes from the decay products of radon, sometimes called radon daughters or radon progeny. These radon progeny are particles not gases, and can be deposited in your lungs as you breath. There they have some chance of decaying before your body can get rid of them, resulting in a radioactive dose.

There are several other naturally occurring radioactive nuclides. Most notable are Carbon-14 (C-14) and Potassium 40 (K-40). They are made by cosmic ray interactions and eventually make there way into our food chain. Once ingested, they can decay and give us an internal dose. All living organic material has a constant ratio of carbon 14 to non-radioactive carbon 12. Once dead, the organic material stops taking in carbon. Therefore, by measuring that ratio of C-14 to C-12 found in organic archeological items, the appropriate time since death can be determined. This is what is known as carbon dating.

For more on Natural Radioactivity, see the Radioactivity in Nature page.

Here's just a sampling of radioactive materials...and the many ways they improve lives.

Radiation in the home

There are some small sources of radiation in the home. Your television set accelerates electrons to make the picture on the screen, and produces a few low energy x-rays. Smoke detectors contain small sources in them. These sources emit radiation that are easily stopped even by smoke, and that way detect the presence of smoke. The sources of radiation around the home, not counting natural sources like radon, tend to make up a small fraction of the background dose.

Radiation in the work place

Persons in many occupations encounter radiation above normal background as a natural part of their jobs. Some of these occupations include doctors, nurses, radiographers, astronauts, dental hygienists, researchers, pharmacists, welders, airplane and jet crews.. The doses received can be up to several rem of exposure over the course of a year.

Medical uses of radiation

Medical uses of radiation are roughly broken into therapy and diagnosis. Therapy is primarily used for tumor killing of cancer, but in the past has been used for other treatments. Most of the dose is received in a small area of the body. Diagnosis runs from fairly routine x rays to injections of radioactive material and imaging. These doses can be several hundred mrem for diagnosis and up to several hundred rem locally for treatments. The physician who prescribes radiation treatments and diagnosis weighs the risk of the radiation with the benefit of the treatment.

Who is in charge

Ultimately, you are. All of the sources of radiation, other than natural, are regulated by laws passed by Congress. Like any other law, you have your right to voice your views and opinions about it. The regulations that control the use of radioactivity in our country are based on recommendations of science organizations like the International Commission on Radiological Protection (ICRP), the National Council on Radiation Protection (NCRP), the International Atomic Energy Agency (IAEA), the United Nations (UN), and the Health Physics Society (HPS). Governing bodies like the Environmental Protection Agency (EPA), the Nuclear Regulatory Commission (NRC), the Department of Energy (DOE), and the Food and Drug Administration (FDA) review these recommendations and propose the regulations that industry and government must follow. These are then passed by Congress, if found to be acceptable, and published in the Code of Federal Regulations (CFRs).

To see some of the regulations, look at our Law, Orders and Directives page or our Federal agency page.

Additional Information

- NEA Radiation Protection Primer (France)
- Radiation Primer (MIT)
- Radiation Basics and information(Alan K. Stazer, Attorney at Law)
- ELF/EMF Papers (David Hafemeister - Cal Poly)
- Radiation and Risk (UofM)
- Health Physics Society Position Statement on Risk from Ionizing Radiation
- For more information on specific radiation sources like radon, UV, EMF,etc.
  try our Radiation and Radioactive Material Specific Information Section

Radioactivity in Nature

Our world is radioactive and has been since it was created. Over 60 radionuclides can be found in nature, and they can be placed in three general categories:

1. Primordial - been around since the creation of the Earth
2. Cosmogenic - formed as a result of cosmic ray interactions
3. Human produced - enhanced or formed due to human actions

Radionuclides are found in air, water and soil, and additionally in us, being that we are products of our environment. Every day, we ingest/inhale nuclides in the air we breathe, in the food we eat and the water we drink. Radioactivity is common in the rocks and soil that makes up our planet, in the water and oceans, and even in our building materials and homes. It is just everywhere. There is no where on Earth that you can get away from Natural Radioactivity.

Note: Many of the units used in science are broken down into smaller units or expressed as multiples, using standard metric prefixes. As examples, a kilobecquerel (kBq) in 1000 becquerels, a millirad (mrad) is 10^{-3} rad, a microrem (μrem) is 10^{-6} rem, a nanogram is 10^{-9} grams, and a picocurie is a 10^{-12} curies. These are examples of units used frequently throughout this short paper. To find definitions of terms you're not familiar with, look on our glossary page.

Common abbreviations used on this page are: **m** - meter, **m^3** - cubic meter, **g** - gram, **kg** - kilogram, **Bq** - becquerel, **Sv** - sievert, **Gy** - gray, **Ci** - curie, **ppm** - parts per million, **yr**- year, **hr** - hour, **L** - liter

Radioactive elements are often called radioactive isotopes or radionuclides. There are over 1,500 different radioactive nuclides. They can be labeled based on the element and on the atomic weight, as in radioactive hydrogen (tritium) or Hydrogen 3. Radionuclide names are often abbreviated using the chemical symbol and the atomic weight, so that Uranium 235 would be shortened to U-235 or ^{235}U.

Much of the information and many of tables found here are adapted from information found in *Environmental Radioactivity from Natural, Industrial and Military Sources* by Merril Eisenbud and Tom Gesell, Academic Press, Inc. 4th Edition. Other tables are adapted from the National Council on Radiation Protection reports 94 and 95. References are listed at the bottom of this page. Several of the tables below were made from calculation based on available data.

This page is best viewed with a browser that is capable of using **tables and superscripts**.

In the United States, the annual estimated average effective dose equivalent is 360 mrem per adult. This is broken down as:

Annual estimated average effective dose equivalent received by a member of the population of the United States.

Source	Average annual effective dose equivalent

	(μSv)	(mrem)
Inhaled (Radon and Decay Products)	2000	200
Other Internally Deposited Radionuclides	390	39
Terrestrial Radiation	280	28
Cosmic Radiation	270	27
Cosmogenic Radioactivity	10	1
Rounded total from natural source	3000	300
Rounded total from artificial Sources	600	60
Total	3600	360

Shown in the table above, 82% of the total average annual effective dose is from natural sources of radiation, and of that, most is from radon. Of the other 18%, the majority is from medical diagnosis and treatments, with <1% from nuclear power and fallout.

This can perhaps be more easily seen with a graph (6K)

See Radiation and Us for more info on average U.S. doses of radiation.

United States Geological Survey map of estimated total gamma exposure for the U.S. (78 k)

Primordial radionuclides

Primordial radionuclides are left over from when the world and the universe were created. They are typically long lived, with half-lives often on the order of hundreds of millions of years. Radionuclides that exist for more than 30 half-lives are not measurable. The progeny or decay products of the long lived radionuclides are also in this heading. Here are few of what we are talking about:

Primordial nuclides

Nuclide	Symbol	Half-life	Natural Activity
Uranium 235	^{235}U	7.04×10^{8} yr	0.72% of all natural uranium
Uranium 238	^{238}U	4.47×10^{9} yr	99.2745% of all natural uranium; 0.5 to 4.7 ppm total uranium in the common rock types
Thorium 232	^{232}Th	1.41×10^{10} yr	1.6 to 20 ppm in the common rock types with a crustal average of 10.7 ppm

Radium 226	^{226}Ra	1.60 x 10^3 yr	0.42 pCi/g (16 Bq/kg) in limestone and 1.3 pCi/g (48 Bq/kg) in igneous rock
Radon 222	^{222}Rn	3.82 days	Noble Gas; annual average air concentrations range in the US from 0.016 pCi/L (0.6 Bq/m^3) to 0.75 pCi/L (28 Bq/m^3)
Potassium 40	^{40}K	1.28 x 10^9 yr	soil - 1-30 pCi/g (0.037-1.1 Bq/g)

Some nuclides, like ^{232}Th have several members in their decay chains. You can roughly follow the chain starting with ^{232}Th

^{232}Th --> ^{228}Ra --> ^{228}Ac --> ^{228}Th --> ^{224}Ra -->
^{220}Rn --> ^{216}Po --> ^{212}Pb --> ^{212}Bi --> ^{212}Po --> ^{208}Pb (stable)

Some other primordial radionuclides are: ^{50}V, ^{87}Rb, ^{113}Cd, ^{115}In, ^{123}Te, ^{138}La, ^{142}Ce, ^{144}Nd, ^{147}Sm, ^{152}Gd, ^{174}Hf, ^{176}Lu, ^{187}Re, ^{190}Pt, ^{192}Pt, ^{209}Bi.

United States Geological Survey Digital maps of estimated potassium, equivalent uranium-238, equivalent thorium-232 concentrations for the U.S.

Cosmogenic

Cosmic radiation permeates all of space, the source being primarily outside of our solar system. The radiation is in many forms, from high speed heavy particles to high energy photons and muons. The upper atmosphere interacts with many of the cosmic radiations, and produces radioactive nuclides. They can have long half-lives, but the majority have shorter half-lives than the primordial nuclides. Here is an table with some common cosmogenic nuclides:

Cosmogenic Nuclides

Nuclide	Symbol	Half-life	Source	Natural Activity
Carbon 14	^{14}C	5730 yr	Cosmic-ray interactions, ^{14}N(n,p)^{14}C;	6 pCi/g (0.22 Bq/g)
Tritium 3	^{3}T	12.3 yr	Cosmic-ray interactions with N and O; spallation from cosmic-rays, ^{6}Li(n,alpha)^{3}H	0.032 pCi/kg (1.2 x 10^{-3} Bq/kg)
Beryllium 7	^{7}Be	53.28 days	Cosmic-ray interactions with N and O;	0.27 pCi/kg (0.01 Bq/kg)

Some other cosmogenic radionuclides are ^{10}Be, ^{26}Al, ^{36}Cl, ^{80}Kr, ^{14}C, ^{32}Si, ^{39}Ar, ^{22}Na, ^{35}S, ^{37}Ar, ^{33}P, ^{32}P, ^{38}Mg, ^{24}Na, ^{38}S, ^{31}Si, ^{18}F, ^{39}Cl, ^{38}Cl, ^{34m}Cl.

Human Produced

Humans have used radioactivity for one hundred years, and through its use, added to the natural inventories. The amounts are small compared to the natural amounts discussed above, and due to the shorter half-lives of many of the nuclides, have seen a marked decrease since the halting of above ground testing of nuclear weapons. Here are a few nuclides:

Human Produced Nuclides

Nuclide	Symbol	Half-life	Source
Tritium	^{3}H	12.3 yr	Produced from weapons testing and fission reactors; reprocessing facilities, nuclear weapons manufacturing
Iodine 131	^{131}I	8.04 days	Fission product produced from weapons testing and fission reactors, used in medical treatment of thyroid problems
Iodine 129	^{129}I	1.57 x 10^{7} yr	Fission product produced from weapons testing and fission reactors
Cesium 137	^{137}Cs	30.17 yr	Fission product produced from weapons testing and fission reactors
Strontium 90	^{90}Sr	28.78 yr	Fission product produced from weapons testing and fission reactors
Technetium 99m	^{99m}Tc	6.03 hr	Decay product of ^{99}Mo, used in medical diagnosis
Technetium 99	^{99}Tc	2.11 x 10^{5} yr	Decay product of ^{99m}Tc
Plutonium 239	^{239}Pu	2.41 x 10^{4} yr	Produced by neutron bombardment of ^{238}U (^{238}U + n--> ^{239}U--> ^{239}Np +ß--> ^{239}Pu+ß)

Other Interesting Aspects of Natural Radioactivity

Natural Radioactivity in soil

How much natural radioactivity is found in an area 1 square mile, by 1 foot deep? The following table is calculated for this volume (total volume is 7.894×10^5 m^3) and the listed activities. Activity levels vary greatly depending on soil type, mineral make-up and density (~1.58 g/cm^3). This table represents calculations using typical numbers.

Natural Radioactivity by the Mile

Nuclide	Activity used in calculation	Mass of Nuclide	Activity
Uranium	0.7 pCi/gm (25 Bq/kg)	2,200 kg	0.8 curies (31 GBq)
Thorium	1.1 pCi/g (40 Bq/kg)	12,000 kg	1.4 curies (52 GBq)
Potassium 40	11 pCi/g (400 Bq/kg)	2000 kg	13 curies (500 GBq)
Radium	1.3 pCi/g (48 Bq/kg)	1.7 g	1.7 curies (63 GBq)
Radon	0.17 pCi/gm (10 kBq/m^3) soil	11 µg	0.2 curies (7.4 GBq)

Natural Radioactivity in the Ocean

How much natural radioactivity is found in the world's oceans?

All water on the Earth, including seawater, contains radionuclides in it. In the following table, the oceans' volumes were calculated from the *1990 World Almanac*:

- Pacific = 6.549×10^{17} m^3
- Atlantic = 3.095×10^{17} m^3
- Total = 1.3×10^{18} m^3

The activities used in the table below are from 1971 *Radioactivity in the Marine Environment*, National Academy of Sciences:

Natural Radioactivity by the Ocean

Nuclide	Activity used	Ocean

	in calculation	Pacific	Atlantic	All Oceans
Uranium	0.9 pCi/L (33 mBq/L)	6 x 10^8 Ci (22 EBq)	3 x 10^8 Ci (11 EBq)	1.1 x 10^9 Ci (41 EBq)
Potassium 40	300 pCi/L (11 Bq/L)	2 x 10^{11} Ci (7400 EBq)	9 x 10^{10} Ci (3300 EBq)	3.8 x 10^{11} Ci (14000 EBq)
Tritium	0.016 pCi/L (0.6 mBq/L)	1 x 10^7 Ci (370 PBq)	5 x 10^6 Ci (190 PBq)	2 x 10^7 Ci (740 PBq)
Carbon 14	0.135 pCi/L (5 mBq/L)	8 x 10^7 Ci (3 EBq)	4 x 10^7 Ci (1.5 EBq)	1.8 x 10^8 Ci (6.7 EBq)
Rubidium 87	28 pCi/L (1.1 Bq/L)	1.9 x 10^{10} Ci (700 EBq)	9 x 10^9 Ci (330 EBq)	3.6 x 10^{10} Ci (1300 EBq)

Human body

You are made up of chemicals, and it should be of no surprise that some of them are radionuclides, many of which you ingest daily in your water and food. Here are the estimated concentrations of radionuclides calculated for a 70,000 gram adult based ICRP 30 data:

Natural Radioactivity in your body

Nuclide	Total Mass of Nuclide Found in the Body	Total Activity of Nuclide Found in the Body	Daily Intake of Nuclides
Uranium	90 µg	30 pCi (1.1 Bq)	1.9 µg
Thorium	30 µg	3 pCi (0.11 Bq)	3 µg
Potassium 40	17 mg	120 nCi (4.4 kBq)	0.39 mg
Radium	31 pg	30 pCi (1.1 Bq)	2.3 pg
Carbon 14	95 µg	0.4 µCi (15 kBq)	1.8 µg
Tritium	0.06 pg	0.6 nCi (23 Bq)	0.003 pg
Polonium	0.2 pg	1 nCi (37 Bq)	~0.6 µg

It would be reasonable to assume that all of the radionuclides found in your environment would be in you in small amounts. The average annual dose equivalent from internally deposited radionuclides is given in the table at the top of this page.

Natural Radioactivity in Building Materials

As mentioned before, building materials have some radioactivity in them. Listed below are a few common building materials and their estimated levels of uranium, thorium and potassium.

Estimates of concentrations of uranium, thorium and potassium in building materials
(NCRP 94, 1987, except where noted)

Material	Uranium		Thorium		Potassium	
	ppm	mBq/g (pCi/g)	ppm	mBq/g (pCi/g)	ppm	mBq/g (pCi/g)
Granite	4.7	63 (1.7)	2	8 (0.22)	4.0	1184 (32)
Sandstone	0.45	6 (0.2)	1.7	7 (0.19)	1.4	414 (11.2)
Cement	3.4	46 (1.2)	5.1	21 (0.57)	0.8	237 (6.4)
Limestone concrete	2.3	31 (0.8)	2.1	8.5 (0.23)	0.3	89 (2.4)
Sandstone concrete	0.8	11 (0.3)	2.1	8.5 (0.23)	1.3	385 (10.4)
Dry wallboard	1.0	14 (0.4)	3	12 (0.32)	0.3	89 (2.4)
By-product gypsum	13.7	186 (5.0)	16.1	66 (1.78)	0.02	5.9 (0.2)
Natural gypsum'	1.1	15 (0.4)	1.8	7.4 (0.2)	0.5	148 (4)
Wood'	-	-	-	-	11.3	3330 (90)
Clay Brick"	8.2	111 (3)	10.8	44 (1.2)	2.3	666 (18)

' Chang et al, 1974 " Hamilton, 1970

Oklo Natural Reactor

Adapted from August 1976 Scientific American article on Oklo by Cowan.

In 1972, natural nuclear reactor was found in a Western Africa in the Republic of Gabon, at Oklo. While the reactor was critical, approximately 1.7 billion years ago, it released 15,000 megawatt-years of energy by consuming six tons of uranium. It operated over several hundred thousand years at low power.

It was discovered by a French mining geologist while assaying samples for the Oklo Uranium mine. Today, the fissionable Uranium 235 has an natural abundance of 0.7202%, but the scientist noticed some samples from Oklo to be 0.7171%. While this difference was small, it led the scientists to take a look closer at the Oklo site. Later, samples were found that were even more depleted, down to 0.44%. This difference could only be explained if some of the fuel, the ^{235}U, had been used up in a fission reaction. Upon further investigation, abnormally high amounts of fission products were found in six separate reactor zones.

Like present day power reactors, a natural reactor would require several special conditions, namely fuel, a moderator, a reflector, lack of neutron absorbing poisons and some way to remove the heat generated. At Oklo, the area was naturally loaded with uranium by water transport and deposition. The concentration of Uranium 235 is artificially enriched for most modern reactors, but at the time of the Oklo reactor it was naturally enriched with an abundance of approximately 3%. This is because when the world was formed, there was a certain amount of ^{235}U, and it has been decaying ever since. So, because ^{235}U has a shorter half-life than ^{238}U, one billion years ago ,^{235}U made up a larger percentage of the natural uranium. The 3% ^{235}U was enough for a sustained nuclear reaction. Oklo site was saturated with groundwater, which served as a moderator, reflector and cooling for the fission reaction. There was a lack of poisons before the reaction began, and fission products like xenon and neodymium serve as neutron absorbing poisons, absorbing neutrons, acting to limit the power.

To confirm that there was a natural fission reactor, the scientists started looking for other evidence. First they wanted to look for some element that might have been produced in a reactor, but would have little natural occurrence else where. They looked at several, and neodymium gave strong indications that the reactor had indeed operated. Neodymium has seven stable isotopes, but only six are fission products. The abundance of the neodymium at Oklo sites was compared to other areas and to the neodymium found in modern reactors. Once the samples were compared, the abundance of neodymium was found to be almost exactly that found in present day reactors. All in all, the fission products studied matched what would have been the result of a sustained nuclear reaction. There is even evidence that the reactor bread its own fuel, bombarding the ^{238}U with neutrons, making the easily fissionable ^{239}Pu.

Some other interesting information has come out of this, over half of the thirty fission products found there were confined to the reactor zones, with all plutonium immobilized. The strontium was mainly confined to the local zones, with some release to environment estimated from krypton 85 and cesium 137

One of the greatest works of the 20th century was the building of the first atomic pile (nuclear reactor) in Chicago in 1941 by Enrico Fermi. It took some of the brightest minds in modern physics and great engineering efforts to duplicate what nature did two billion years earlier.

For more information on the Oklo Reactor, try:

The a-recoil effects of uranium in the Oklo reactor. Nature 312:535-6 Dec 6 '84

Gabon's natural reactors: nature shows how to contain radioactive waste.
Nuclear-Engineering-International. vol.39, no.475; Feb. 1994; p.30-1

Organic matter and containment of uranium and fissiogenic isotopes at the Oklo natural reactors.
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Estimation of burnup in the Oklo natural nuclear reactor from ruthenium isotopic composition.
Journal of Radioanalytical and Nuclear Chemistry, Letters. vol.155, no.2; 16 Sept. 1991; p.107-13

The origin of the chemical elements and the Oklo phenomenon. Kuroda, P. K. Berlin ; New York :

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High Background Radiation Areas

Background radiation levels result from a combination of terrestrial (from the ^{40}K, ^{232}Th, ^{226}Ra, etc.) and cosmic radiation (photons, muons, etc.). The level is fairly constant over the world, being 8-15 μrad/hr. Here is a radiation detector in Pittsburgh, Penn, USA showing background radiation levels.

Around the world though, there are some areas with sizable populations that have high background radiation levels. The highest are found primarily in Brazil, India and China. The higher radiation levels are due to high concentrations of radioactive minerals in soil. One such mineral, Monazite, is a highly insoluble rare earth mineral that occurs in beach sand together with the mineral ilmenite, which gives the sands a characteristic black color. The principal radionuclides in monazite are from the ^{232}Th series, but there is also some uranium its progeny, ^{226}Ra.

In Brazil, the monazite sand deposits are found along certain beaches. The external radiation levels on these black sands range up to 5 mrad/hr (50 µGy/hr), which is almost 400 times normal background in the US. Some of the major streets of the surrounding cites have radiation levels as high as 0.13 mrad/hr (1.3 µGy/hr), which is more than 10 times the normal background. Another high background area in Brazil is the result of large rare earth ore deposits that form a hill that rises about 250 meters above the surrounding area. An ore body near the top of the hill is very near the surface, and contains an estimated 30,000 tons of thorium and 100,000 tons of rare earth elements. The radiation levels near the top of the hill are 1 to 2 mrad/hr (0.01 to 0.02 mGy/hr) over an area of about 30,000 m^2. The plants found there have absorbed so much ^{228}Ra that they will produce a self "x-ray" if placed on a sheet of photographic paper (an autoradiograph).

On the Southwest coast of India, the monazite deposits are larger than those in Brazil. The dose from external radiation is, on average, similar to the doses reported in Brazil, 500-600 mrad/yr (5 - 6 mGy/yr), but individual doses up to 3260 mrad/yr (32.6 mGy/yr) have been reported.

An area in China has does rates that is about 300-400 mrad/yr (3-4 mGy/yr). This is also from monazite that contains thorium, uranium and radium.

From BEIR V, National Research Council report on Health Effects of Low Levels of Ionizing Radiation:

> In areas of high natural background radiation, an increased frequency of chromosome aberrations has been noted repeatedly. The increases are consistent with those seen in radiation workers and in persons exposed at high dose levels, although the magnitudes of the increases are somewhat higher than predicted. No increase in the frequency of cancer has documented in populations residing in areas of high natural background radiation.

Cosmic Radiation

Cosmic radiation (as discussed above) interacts with our atmosphere to produce cosmogenic radionuclides. It also is responsible for a whole body doses.

Cosmic radiation is really divided into two types, primary and secondary. Primary cosmic radiation is made up of extremely high energy particles (up to 10^{18} eV), and are mostly protons or sometimes larger particles. A large percentage of it comes from outside of our solar system and is found throughout space. Some of the primary cosmic radiation is from our sun, produced during solar flares.

Little of the primary cosmic radiation penetrates to the Earth's surface, the vast majority of it interacts with the atmosphere. When it does interact, it produces the secondary cosmic radiation, or what we actually see here on Earth. These reactions produce other lower energy radiations in the form of photons, electrons, neutrons and muons that make it to the surface.

The atmosphere and the Earth's magnetic fields also act as shields against cosmic radiation, reducing the amount that reaches the Earth's surface. With that in mind, it is easy to see that the annual dose you get from cosmic radiation depends on what altitude you are at. From cosmic radiation, the average person in the U.S. will receive a dose of 27 mrem per year and this roughly doubles every 6,000 foot increase in elevation.

Typical Cosmic Radiation Dose rates:

4 μR/hr in the Northeastern US

20 μR/hr at 15,000 feet

300 μR/hr at 55,000 feet

There is only about a 10% decrease at sea level in cosmic radiation rates when going from pole to the equator, but at 55,000 feet the decrease is 75%. This is on account of the effect of the earth's and the Sun's geomagnetic fields on the primary cosmic radiations.

Flying can add a few extra mrem to your annual dose, depending on how often you fly, how high the plane flies, and how long you are in the air.

Calculated cosmic ray doses to a person flying in subsonic and supersonic aircraft under normal solar conditions

Route	Subsonic flight at 36,000 ft (11 km)			Supersonic flight at 62,000 (19 km)		
	Flight duration (hrs)	Dose per round trip		Flight duration (hrs)	Dose per round trip	
		(mrad)	(μGy)		(mrad)	(μGy)
Los Angeles-Paris	11.1	4.8	48	3.8	3.7	37

Chicago-Paris	8.3	3.6	36	2.8	2.6	26
New York-Paris	7.4	3.1	31	2.6	2.4	24
New York-London	7.0	2.9	29	2.4	2.2	22
Los Angeles-New York	5.2	1.9	19	1.9	1.3	13
Sydney-Acapulco	17.4	4.4	44	6.2	2.1	21

Astronauts are exposed to cosmic radiation, but they are also exposed to radiation as they pass through the Van Allen radiation belts that circle the Earth.

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