Radiation Encounter!

Seeing and understanding the radiation around us

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presented by:

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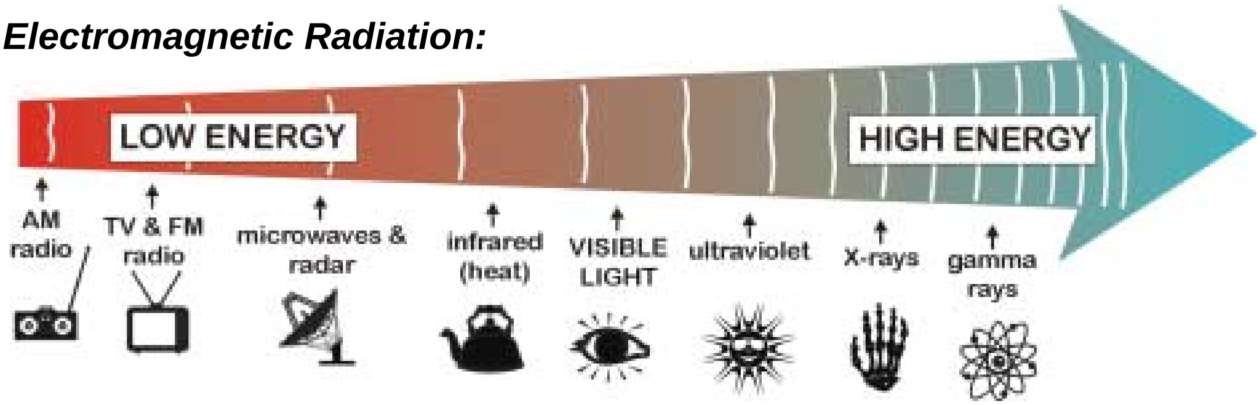
The Invisible World

Radiation is the energy around us, moving through the air, space, rocks soil … and ourselves. Most of it is invisible, but a very small portion we do see ("visible" light), while other portions we sense as heat (infrared radiation), or when the sun burns our skin (ultraviolet radiation).

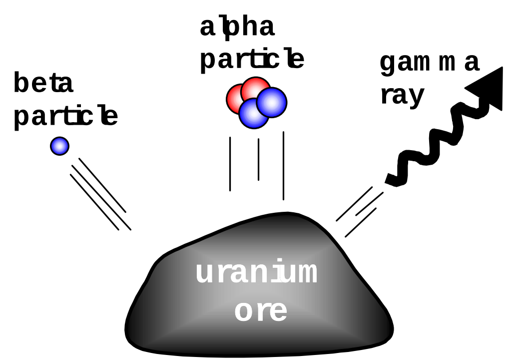
Much of the radiation around us is called **electromagnetic radiation**, or "EM radiation", and covers a vast energy range. TV signals are an example of low-energy EM radiation, while X-rays are an example of high-energy EM radiation. Somewhere in the middle we find visible light, infrared, and ultraviolet radiation:

Electromagnetic Radiation:



Although our bodies sense only a small portion of this invisible world around us, we can build devices (such as radios, TVs, X-ray machines) that "see" other types of the EM radiation.

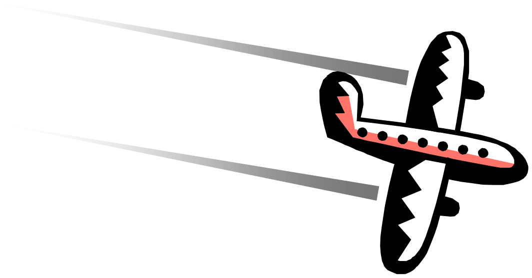
Another form of radiation in our environment is emitted by **radioactive sources**. Some rocks, like uranium ore, are **naturally radioactive**. The energy they emit is in the form of **alpha particles** and **beta particles**, as well as a high-energy form of EM radiation called **gamma rays** (see above diagram).



Alpha and beta particles, like EM radiation, are invisible to us, but we can build devices that let us "see" them. One relatively simple device is called a **cloud chamber**.

Seeing the Invisible

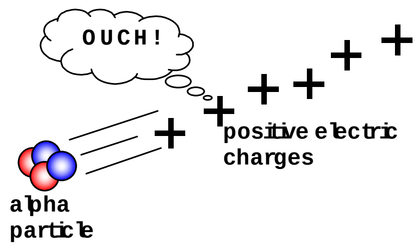
When you look up on a clear day, you often see **condensation trails** from jets passing overhead, even when it's difficult to see the jets themselves.



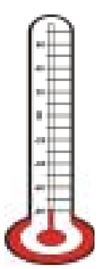
A condensation trail is actually billions of droplets of water from jet engine's exhaust, condensing in the frigid, high-altitude air and forming long, thin clouds. **Condensation** – when vapour turns to water – works best around small dust particles and other impurities in the air.

In a **cloud chamber** we "see" alpha and beta radiation the same way you "see" the invisible jet – by the condensation (cloud) trails left behind.

How do alpha and beta particles make their condensation trails? As these particles move through the air they bump into air molecules, knock off electrons, and leave the air electrically charged – we call this **ionizing the air**. High-energy EM radiation, like X-rays and gamma rays, can also ionize air and other materials.



Ions, or electric charges, act like dust particles and impurities – they are favourite spots for condensation to occur. Thus, in a cloud chamber we see thin "cloud trails" emanating from a **radioactive source**, unmistakably marking the electrically charged trails left by alpha and beta particles.



Now, instead of water vapour, we use **alcohol vapour**, since it condenses more easily. We need a way to cool the alcohol vapour, just as the water vapour was cooled when it left the jet's engines, to get it to condense around ions in the chamber. For this, we use **"dry ice"**, or solid carbon dioxide (CO_2), at –78 °C.

Finally, we need to illuminate the condensation trails so we can see them easily. As anyone who's turned on headlights in the fog might guess, the best way for us to see the condensation is with a **flashlight**!

Making Clouds

A simple **cloud chamber** starts with a transparent container and lid, about 4" in diameter. A narrow **felt strip** is glued around the top of the inside wall, and the bottom surface of the container is **painted black**.

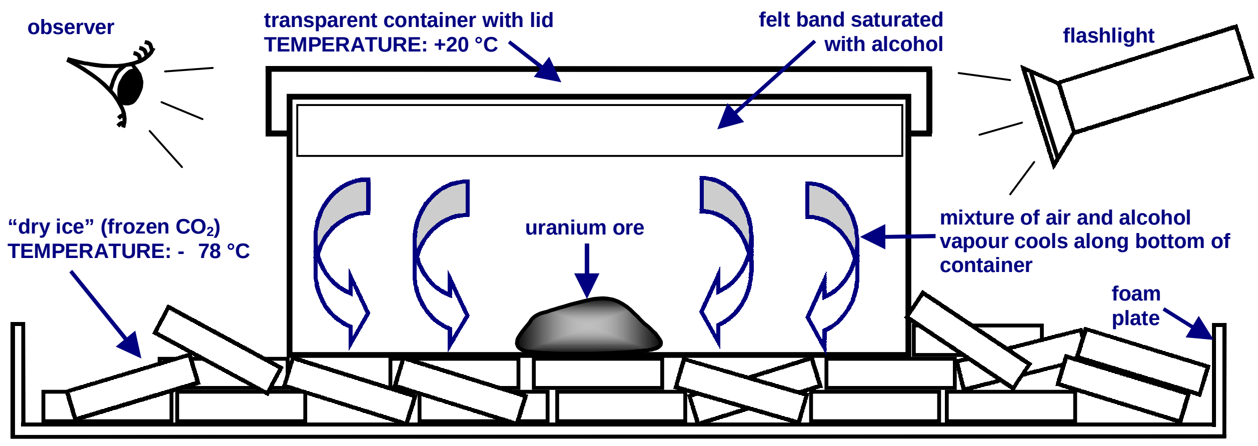
Saturate the felt strip with **alcohol** (ethanol, methanol, or a mixture of both), place a **radioactive source** (usually uranium ore) in the centre, and put the lid on. Place the container on a **Styrofoam plate** filled with **dry ice**.

Wait a few minutes. Alcohol vapour from the felt strip fills the container, while the bottom cools to –78 °C. Since the lid is at +20 °C (room temperature), there is a **100 °C temperature drop** from top to bottom!

Warm top air **holds more vapour** than the cold bottom air. Therefore, just as when a jet engine's warm exhaust hits cold high-altitude air, the alcohol vapour condenses along the container bottom. It does this first around the **ionized air molecules** (electric charges), created by our radioactive source.

It takes a few moments for this situation to get going (you can speed things along by warming the lid with the palm of your hand), but shortly you should see narrow cloud trails emanating from the radioactive source. Shine a flashlight at an angle, and look from the opposite side (see diagram). Move the light around and change the angle. Be patient, and stay alert – the cloud tracks don't stick around very long.

Simple Cloud Chamber:



A Closer Look

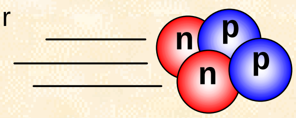
You will probably see two types of cloud tracks in this kind of cloud chamber. The most common tracks are made by **alpha particles**, and are short and "fuzzy". Alpha particles are the bulldozers of the radiation world – they are relatively large, slow-moving particles with lots of electric charge. This makes them lose energy in a shorter distance than other forms of radiation, leading to **more intense ionization**, and thicker condensation trails. However, alpha particles can be stopped by a mere sheet of paper, your skin, or a few centimetres of air.

Name: Alpha Particle

Electric charge: positive

Constituents: 2 protons + 2 neutrons

Stopped by: sheet of paper, skin, few cm of air



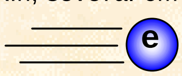
Less prevalent are the thinner, longer tracks made by **beta particles** – speed demons of the radiation world. These very small particles travel at high velocities, and lose energy over a longer distance than alpha particles. Their condensation trails are thinner because they cause **less ionization**. Still, beta particles can be stopped by a sheet of aluminium foil, or several centimetres of air.

Name: Beta Particle

Electric charge: negative

Constituents: 1 electron

Stopped by: aluminium foil, skin, several cm of air

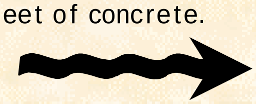


Occasionally faint, twisting tracks are observed (more common in larger cloud chambers). These are caused by **gamma rays**, a high-energy form of electromagnetic radiation (see page 1). Gamma rays lose energy over very long distances, and are stopped most efficiently by dense, heavy materials like lead. In many ways gamma rays are similar to *X-rays*, including an ability to pass through many everyday materials made of metal and wood.

Name: Gamma Ray

Electric charge: none

Stopped by: several inches of lead, several feet of concrete.



Each of these forms of **ionizing radiation** can be detected by a variety of methods, including our cloud chambers, which take advantage of the electric charges they leave behind. The knowledge of how to do this has been around for about 100 years. The cloud chamber was invented in 1911, earning Sir Charles T.R. Wilson the 1927 Nobel Prize in Physics.

Energy for Change

What causes some materials to be radioactive? In simple terms: **Excess energy**.

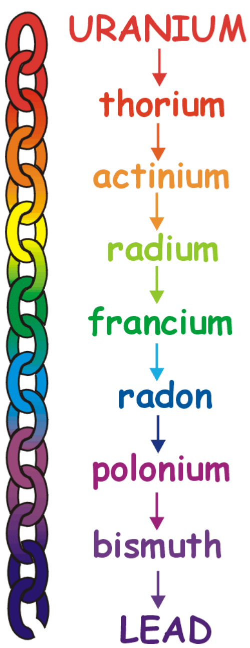
If we could peer inside a mineral like uranium, magnified a trillion times (that's a "one" with 12 zeroes after it!), we'd see individual uranium **atoms** brimming with excess energy. Every now and then, one of the uranium atoms would shed its excess energy by emitting an **alpha particle**. This is an example of **radioactive decay**.

As you may note in the cloud chamber, radioactive decay is a somewhat **random process** – cloud tracks appear at irregular time intervals. In fact, we have no way of predicting when an individual uranium atom will decay.

On the other hand, even knowing nothing about the fate of individual uranium atoms, we can predict with certainty that **half of the uranium atoms** in our sample will decay sometime in the next **4.5 billion years**. For this reason, this length of time is known as uranium's **half-life**.

All radioactive materials have a **unique**, **fixed** half-life. Half-lives range from fractions of a second for some materials, up to billions of years for materials like uranium. Whether short or long, the half-lives of radioactive materials are known to great accuracy.

As a radioactive material decays, it does more than just lose energy – it **turns into something else** (which may itself be radioactive). Thus, after enough half-lives have elapsed, the original radioactive material will have essentially disappeared. Uranium, for instance, decays through a series of other radioactive materials, until it becomes a **stable** (non-radioactive) form of **lead**, at which point the **decay chain** stops.



Uranium is not in danger of disappearing from the earth's crust, however, and is in fact one of our more abundant minerals. This is due to its long half-life – comparable to the age of the earth itself. All of the radioactive materials in uranium's decay chain are also found in nature, and contribute to the **natural background radiation** in our environment.

Natural, and Useful Too

Radiation is a natural part of our environment. Our world is filled with **electromagnetic radiation** of all energies, as well as materials emitting **alpha**, **beta** and **gamma radiation**. All life on this planet evolved in this environment, and is able to thrive in the presence of radiation.

Much of this **natural background radiation** comes from the rocks and soil – most importantly from uranium and its **radioactive decay** “progeny” (see figure on previous page). In fact, over half the **ionizing radiation** around us is due to **radon**, a gaseous product of uranium that enters our basements from the soil.

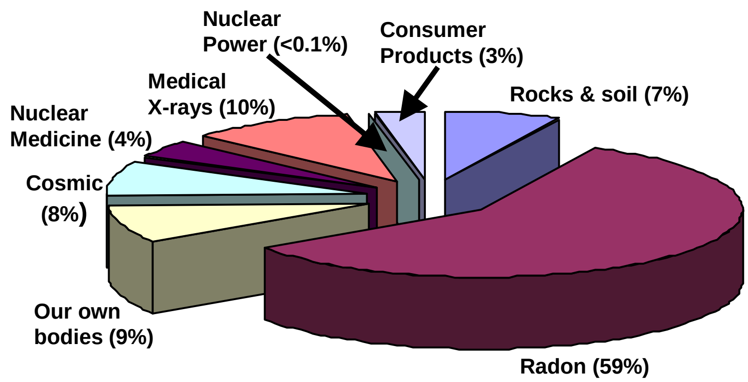
We are also exposed to radiation from the **cosmos** itself. Many billions of tiny, high-energy particles enter the earth’s atmosphere from space each year, accounting for another 8% of our background ionizing radiation.

In addition, we are each a source of ionizing radiation ourselves, since human bodies include many naturally radioactive materials, such as **potassium**. We are very much a part of the world around us, accounting for 9% of the background ionizing radiation we are exposed to.

In the last century we have learned to utilize ionizing radiation to improve our quality of life. We’re all aware of the beneficial diagnostic use of **X-rays**, and that **radiation therapy** is one of the most effective weapons against cancer. Another medical application, **nuclear medicine**, uses small internal doses of radiation for therapy and diagnosis – amounting to **50,000 procedures per day** around the world (over half using radioactive sources supplied by the Ottawa company **MDS Nordion**). We protect our homes with **ionization smoke detectors**, which use a tiny radioactive source to detect smoke particles.

In total, man-made sources amount to 17% of background ionizing radiation – natural sources comprising 83%. This level of radiation is safe for humans and other life on this planet, and may even be beneficial.

Ionizing Radiation in our Environment:



Glossary

alpha particle – positively-charged particulate form of radiation

background radiation – radiation around us, natural and man-made

beta particle – negatively-charged particulate form of radiation

cloud chamber – a device for indirectly observing ionizing radiation

condensation – the conversion of a vapour to a liquid

dry ice – solid (frozen) carbon-dioxide, at -78°C

decay chain – materials linked by successive radioactive decay

electromagnetic (EM) radiation – a form of energy that includes radio waves, microwaves, visible light, ultraviolet and X-rays

gamma rays – a high-energy, ionizing form of EM radiation

half-life – the time for half a sample of radioactive atoms to decay

ionization – the imparting of electric charges to a material

ionizing radiation – radiation able to ionize material that it passes through

ionization smoke detector – a device using ionizing radiation to detect smoke particles in the air

natural background radiation – the contribution to background radiation (four-fifths) from rocks, soil, space, and ourselves

potassium – a necessary constituent of human bodies, partially radioactive

nuclear medicine – internal use of ionizing radiation for medical therapy and diagnosis

radiation – energy that transmits from one place to another

radioactive decay – the emission of excess energy by an atom, and subsequent change to another material

radioactive sources – material, natural or man-made, which radioactively decays

X-rays – a high-energy, ionizing form of EM radiation

Websites of Interest

Radiation:

"ABC's of Nuclear Science" – www.lbl.gov/abc
"The Particle Adventure" – particleadventure.org/particleadventure
Cloud chambers –
www.sciencenet.org.uk/database/Physics/Atomic/p00423c.html
The electromagnetic spectrum –
imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html
Background ionizing radiation – www.physics.isu.edu/radinf/natural.htm

Nuclear Medicine:

MDS Nordion (radiopharmaceuticals) – www.mds.nordion.com
Boron neutron capture therapy – www.bnct.net

Canadian nuclear science & technology:

"The Canadian Nuclear FAQ" – www.ncf.ca/~cz725
Atomic Energy of Canada Ltd. – www.aecl.ca
The Canadian Nuclear Society – www.cns-snc.ca

Other applications of ionizing radiation:

Ionizing-radiation smoke detectors – www.howstuffworks.com/smoke2.htm
Food irradiation – www.mds.nordion.com
Heart Pacemakers – www.icorp.net/cardio/articles/pacemakr.htm
Gamma Astronomy – people.ne.mediaone.net/roachke/sci99/sci06.html
Space travel (Cassini project to Saturn) – www.jpl.nasa.gov/cassini

Dr. Jeremy Whitlock is a reactor physicist for AECL (Atomic Energy of Canada Ltd.), and a vice-president of the Canadian Nuclear Society (CNS). He currently chairs the Education and Communication Committee of the CNS.

Dr. Whitlock has a PhD in Engineering Physics from McMaster University (Hamilton, Ontario), with a specialty in CANDU reactor physics. His current professional involvement is the physics analysis of MAPLE research reactors.

In his spare time Dr. Whitlock communicates with the public on nuclear issues, often with high-school science students. Since 1996 he has maintained a personal website of "frequently-asked questions" (FAQs) about nuclear technology, called *The Canadian Nuclear FAQ*, at www.ncf.ca/~cz725. Questions of all kinds are welcome by email.

In 1999 Dr. Whitlock received the *Education and Communication Award* from the Canadian Nuclear Society. He lives in Deep River, Ontario, and feels that canoes are the closest Mankind has come to inventing a perfect machine.