Canadian Nuclear Society
Education and Communications Committee
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Chairman
Dr. Wm. (Bill) Garland
McMaster University
Hamilton, Ontario
CANADA L8S 4L8
Phone (905) 525-9140
garlandw@mcmaster.ca

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Nuclear Experiments for the Class Room

Hands-on Workshop on Ionizing Radiation
1998 April 16
1998 AECL Science for Educators Seminar
Chalk River Laboratories, Chalk River, Ontario
(Jeremy Whitlock[1])

Workshop

Hands-on workshop to demonstrate the properties and applications of ionizing radiation. Participants will conduct simple experiments with radiation sources and apparatus to demonstrate:

1. Alpha, beta and gamma-ray tracks in a cloud Chamber
2. Alpha, beta and gamma-ray attenuation in various materials
3. Half-life of radionuclide ^{137}Ba
4. Application of alpha radiation in Smoke Detector
5. Radiation Detectors **(INFORMATION ONLY – NOT OFFERED AT 1998 WORKSHOP)**

Equipment

1. Cloud chambers, dry ice, alcohol, flashlights, sources, rock samples
2. Radiation sources (^{90}Sr – β and ^{137}Cs – γ), Geiger monitor, absorbers
3. ^{137}Ba iso-generator, Geiger monitors, chart recorder monitor or PC
4. Smoke detectors, smoke simulators,
5. Bubble detectors, gamma spectrometer, alarm dosimeters **(NOT REQUIRED AT 1998 WORKSHOP)**

[1] Address: Chalk River Laboratories, Chalk River, Ont., K0J 1J0 Email: whitlockj@aecl.ca

Objective of Workshop

Hands-on exercises to demonstrate the properties, applications and safeguards of ionizing radiation. This should provide teachers with experience and resources for a Nuclear Energy Science and Technology curriculum. Part of the material used in this workshop is from the Resource Center established by the Education and Communications Committee of CNS to support teachers in acquiring resources for Nuclear Energy Science and Technology curriculum.

Ionizing-Radiation

Radiation may be of two categories. *Non-Ionizing* radiation causes little or no change inside the atoms of the matter it encounters. For example, a carbon dioxide laser beam could cut sheet steel, but it would not leave steel radioactive. *Ionizing* radiation causes changes, either through collisions with atomic electrons or through nuclear reactions. Ionizing radiation can be obtained from the decay of unstable radionuclides, or can be generated by nuclear reactions. Ionizing radiation may be either particles or electromagnetic waves of high energy. Particles and waves of the same energy behave differently, however.

Alpha Particles

Alpha particle (symbol: α) consist of two protons and two neutrons, and is equivalent to the nucleus of a Helium atom. Alpha particles have a positive electrical charge and are radiated by many radioactive substances such as Radium, Uranium, Thorium, and Americium 241. At sea level alpha particles from such sources travel only about 10 cm in air. They are also stopped by a sheet of paper or the outer layer of human skin.

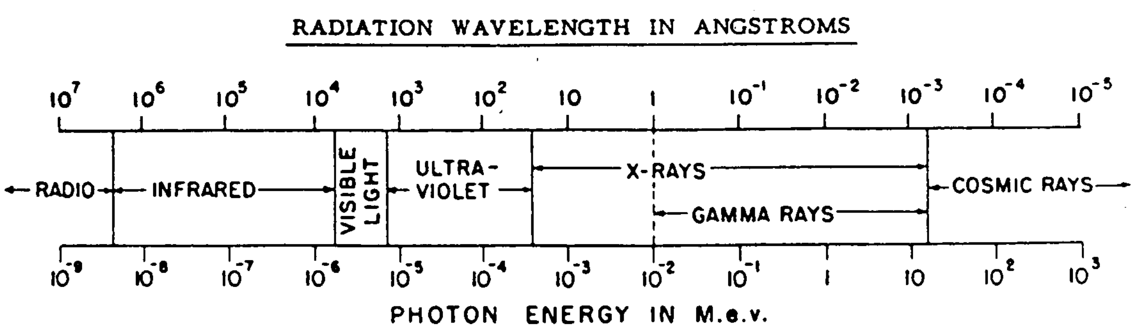
Beta Particles

Beta particles (symbol: β)are energetic electrons emitted by many radioactive substances such as Strontium-90. Beta particles travel through air easily and can damage living tissue if in sufficient quantity. They can be stopped by a sheet of aluminium.

X-Rays and Gamma-Rays

X-rays are energetic photons with no electrical charge or mass that travel at speed of light. X-rays range from "soft", or long-wavelength, types that are used for medical X-rays, to "hard", or short-wavelength, types that can pass through metal, and are frequently used for inspection of metal castings. Gamma-Rays (symbol: γ) are extremely energetic photons with no electrical charge or mass that travel at the speed of light. Gamma-rays are emitted by many radioactive substances (such as Cs-137, Co-60) and pass easily through materials. They are stopped easily by dense materials like lead, but water and concrete are also used.

The Electromagnetic Spectrum



Exercise 1 α, β, γ Tracks in a Cloud Chamber

Principle:

Radioactive elements continually undergo a process of radioactive decay during which their nuclei emit high speed particles and photons. These are much too small to be seen under a microscope. The Cloud Chamber is an instrument designed for study of the trails of these radioactive emissions, in the same manner that a passing jet can be identified by its condensation trail in the sky, although the jet itself may not be highly visible. In a Cloud Chamber the air must be super-saturated with water of alcohol vapor. When the high energy particle plow through the air, electrons are knocked loose from some of the atoms and form ions. Ions act as excellent centers for condensation. This condensation, however, must be stimulated by cooling air. The water vapor or alcohol condenses on the ions, leaving a vapor trail which clearly reveals the path of rays.

Procedure:

Saturate the felt band on the inside of the Cloud Chamber with alcohol. Quickly place the radioactive source (uranium ore) on the bottom of the chamber and cover the entire chamber. Place dry ice in paper dish and set the Cloud Chamber on its surface. Wait until the air becomes saturated. Viewing will be much better if the lights are turned off and a light is directed from the top at an angle onto the back surface of the Cloud Chamber.

What you will see:

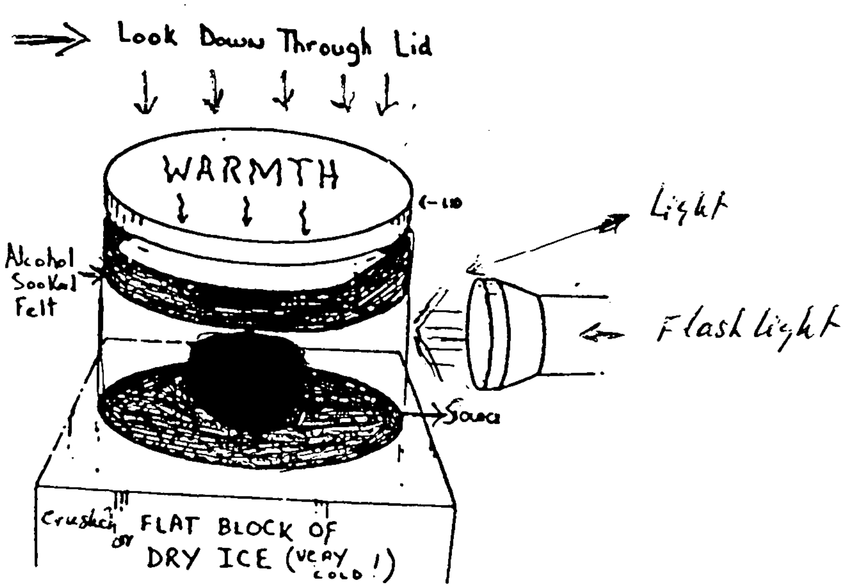
The tracks formed by the radiation appear to be white lines in the cloud. You may be able to find three kinds of tracks:

a) Most of the tracks will be about one-half inch long and quite sharp and dense. These are made by alpha radiation.

b) Sometimes you will see longer, thinner tracks. These are made by beta radiation.

c) Occasionally you will see some twisting, circling tracks that are so faint that they are difficult to see. These are caused by gamma radiation.

After a while the tracks will become faint because the radiation has affected so many of the atoms in the chamber. When this happens, rub the top of the jar briskly with a cotton or silk cloth. The static electricity that is produced will clear the chamber and cause the tracks to become visible again.

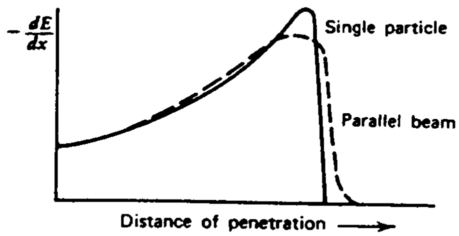


Exercise 2 α, β, γ Radiation Attenuation

Interaction of Radiation with matter:

Charged Particle:

Charged particulate radiation (electrons, protons, alphas and heavy ions), because of the electric charge carried by the particle, continuously interact through the Coulomb force with the electrons and the nuclei present in any medium through which they pass. The energy that is transferred to the electrons or ions must come from the kinetic energy of the charged particle, and its velocity is therefore decreased as a result of the encounter. This energy loss is expressed in terms of the linear stopping power S which is defined as the differential energy loss within the material divided by the corresponding differential path length: $S = -dE/dx$.

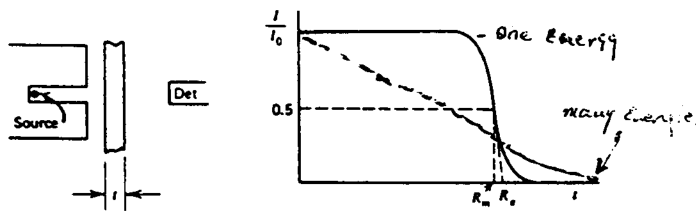


The specific energy loss along an alpha particle track.

Charged Particle Range:

The range of the charged particle is the distance the particle will penetrate a given medium, and is inversely proportional the linear stopping power. The range of a particle can be defined from the stopping power by direct integration as:

$$R = \int_0^{E_0} \frac{dE}{S(E)} R$$



An alpha particle transmission experiment. I is the detected number of alphas through an absorber thickness t, whereas I_0 is the number detected without the absorber. The mean range R_m and extrapolated range R_e are indicated.

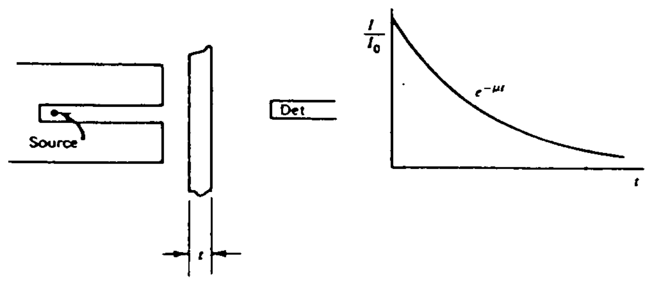
Due to the high values of S, the ranges of charged particles such as alpha rays are very small

Gamma-Rays:

Uncharged radiation (gamma-rays, neutrons) are not subject to the Coulomb force. They must first undergo a "catastrophic" interaction, which radically alters the properties of the incident radiation in a single encounter. If the interaction does not occur within the intercepting medium the uncharged radiation will pass completely through the medium. Since the number of uncharged photons or particles removed from the beam at a thickness x of the absorber is proportional to the intensity of the beam at that thickness $I(x)$, the number of medium atoms per cubic centimeter n, and the incremental thickness of material traversed dx, the change in beam intensity in dx mat be expressed in terms of the cross section σ and the intensity of the incident beam as

$$dI(x) = -I(x)\, n\sigma\, dx$$

$$I(x) = I_0\, e^{-n\sigma x}$$



The exponential transmission curve for gamma rays measured under "good geometry" conditions.

Exercise 3 Half-Life of the Radionuclide ^{137}Ba

Decay of a Radioactive Nuclide:

By laws of nature the decay of a radionuclide is a random process. Let the probability that any particular nuclide will disintegrate in unit time be λ (decay constant). Then the total number of disintegrations per unit time (shorter than 1/λ), will be $N\lambda$. The rate of depletion, will be, (because N decreases we insert a negative sign)

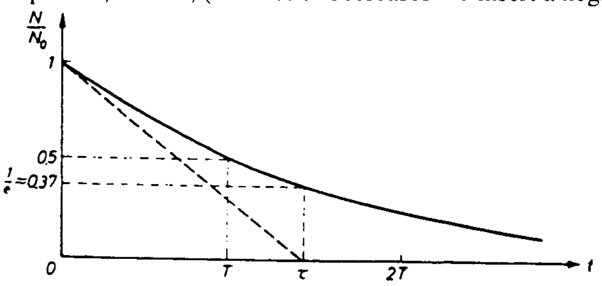
$$\frac{dN}{dt} = -\lambda N$$

which leads to

$$N = N_0 e^{-\lambda t}$$

or

$$N = N_0 e^{-t/\tau}$$

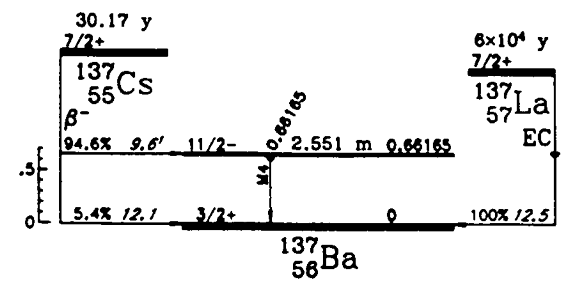


. Definition of parameters of the exponential function of a radioactive decay.

and the activity at time t is reduced by $e^{-\lambda t}$. The half-life is defined as time span in which the activity decreases by a factor of 2 from the activity at the start of time span. Thus half-life $T_{1/2} = 0.693/\lambda$

137Ba Radionuclide:

This 2.55 minute half-life radionuclide is formed by the beta decay of the 30 year half-life ^{137}Cs radionuclide. Ba can be separated cleanly from Cs by chemical process using an inexpensive ion exchange column. The 661 keV gamma-ray from ^{137}Ba are easily detected with a Geiger monitor.



Procedure:

Prepare a ^{137}Ba source by passing the EDTA solution through the Isogenerator™. Count the gamma-ray activity as a function of time with Geiger monitor/ chart recorder apparatus or with the RD-60 / IBM PC apparatus. Determine the half-life by calculating the time span in which the activity drops by a factor of two.

From the Hospital to the Classroom

Radioisotope generators have long been routinely used in diagnostic medicine. Now, the Isogenerator™ is available for classroom use in teaching the fundamentals of radiation detection, radioactive decay, and similar basic principles. Isogenerators are miniaturized radioisotope generators which provide instant short half life nuclides for student experiments.

Each Isogenerator contains a long-lived radionuclide (Cs-137) that decays to a short-lived radionuclide (Ba-137). The original nuclide or "parent" is kept permanently fixed within the isogenerator. By passing a solution (EDTA) through the parent, the short-lived "daughter" is selectively removed. Isogenerators may be used over and over throughout the school year. Every Isogenerator contains an amount of parent activity which is exempt from state and federal licensing requirements.

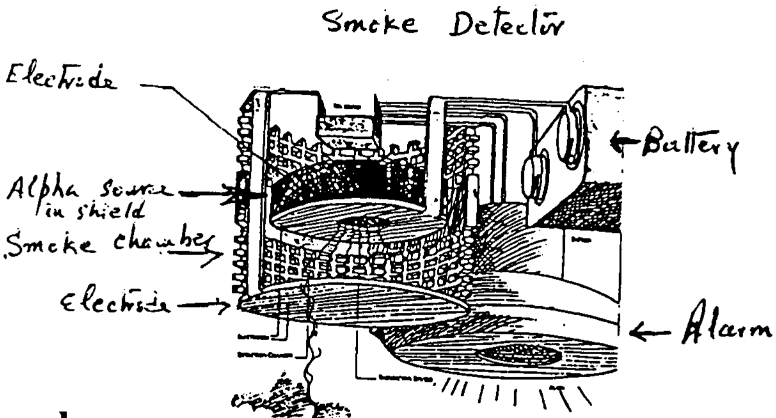
Exercise 4 Applications of Ionizing Radiation (Smoke Detector)

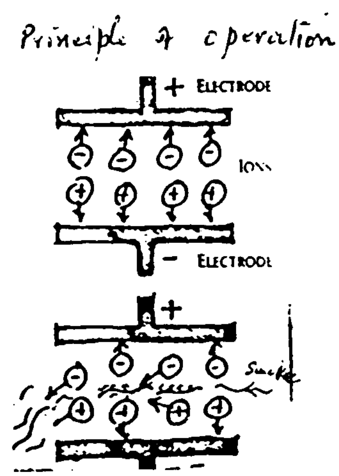
Applications of Ionizing Radiation:

Radioactive substances are used commonly in many industrial and medical applications. For example: **homes:** in smoke detectors; **hospital and medical labs:** for diagnosing and treating disease, radiation sterilization; **office:** to eliminate static in photocopying machines; **manufacturing plants:** for thickness gauging and product testing, radiation curing, paint curing, coating non stick frying pans, crosslinking of polymers; **processing plants:** to measure liquid levels in cans, irradiation of food for preservation; **police labs:** crime detection, civil defense training; **city water departments and large oil companies:** to detect pipe leaks or determine flow; **nuclear power plants:** to generate electricity; **highway construction companies:** to measure density and moisture in soils for road building: **airports:** detection of explosives; **Laboratories in universities or elsewhere:** for research and archaeological dating.

Smoke Detector:

Two types of smoke detectors are currently available in the market. One type uses a beam of light passing through a chamber for detection of presence of light attenuating smoke in the chamber. The other type uses a radioactive alpha source for detection of smoke in the chamber. This type is much more sensitive and inexpensive.





Smoke:

Fumes and smoke are dispersions of finely divided solids or liquids in a gaseous medium. The particle size range is from 0.01 to 5.0 micrometers. Typical dispersions are smokes from incomplete combustion of organic matter such as tobacco, wood, and coal; soot or carbon black; oil-vapor mists; chemical fumes such as sulfur trioxide (SO_3) and phosphorus pentoxide (P_2O_5) mists, ammonium chloride (NH_4Cl), and metal oxides; and the products of hydrolysis of metal chlorides by moist air. Oil-vapor and P_2O_5 mists (formed by burning phosphorus in moist air) have been extensively used in military operations to produce screening smokes.

Detection of Smoke:

Rays from the radioactive source (Am α source) ionize the atoms in the air of the detection chamber, giving them positive and negative electric charges. The charged atoms r ions carry an electric current between the charged electrodes. Smoke particles entering the chamber attract the ions and reduce the current. This change in the current triggers the alarm.

Exercise:

Test the sensitivity of the smoke detectors to various forms of mists and smoke.

Exercise 5 Radiation Detectors

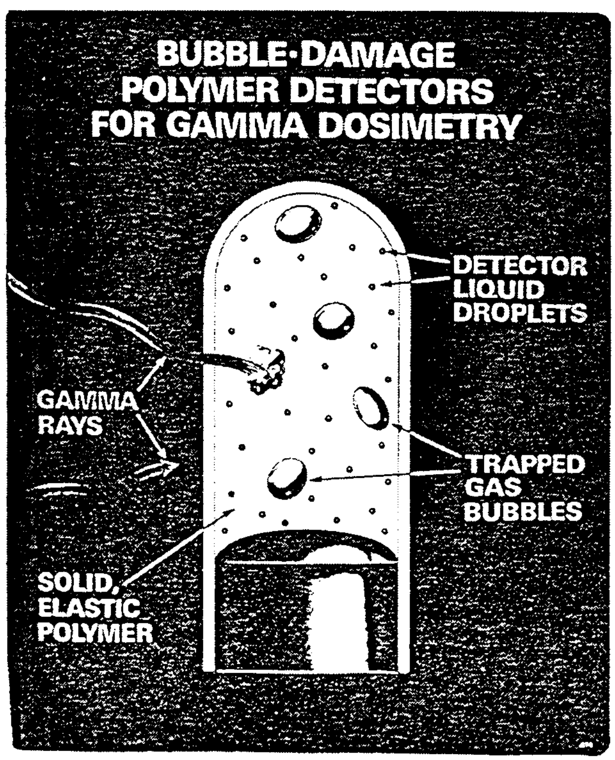
(INFORMATION ONLY - NOT OFFERED AT 1998 WORKSHOP)

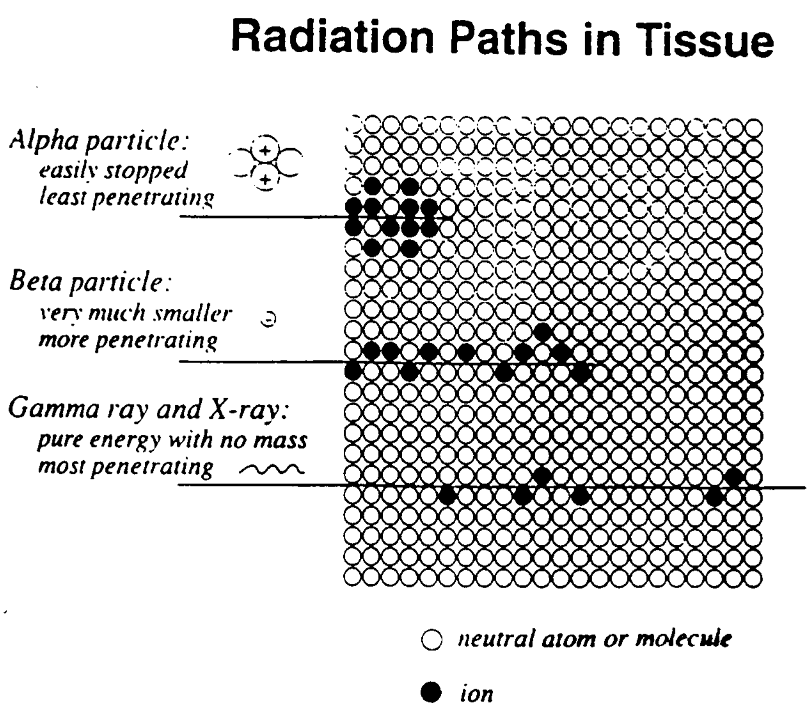
Radiation Protection:

Although no evidence exists of a health effect due to "low levels" of radiation (i.e. below levels that are hundreds of times the natural background exposure), an accepted principle of health physics, from the point of view of conservative safety, is to assume that all exposures produce some biological damage. Regulations governing handling of radiation sources and industrial establishments require that licensees demonstrate that doses received by workers and members of the public as a result of their operations are "as low as reasonably achievable" (the ALARA principle). Doses to individuals must therefore be kept as low as possible. Lower dose limits increase the need to be sure that the number quoted for a dose can be relied on. A reliable measure of doses in various operating circumstances is important and there is a steady development in improvements of radiation dosimeter.

Radiation Detectors:

A radiation detector is an instrument that determines the level of radiation present, and in some cases converts this to the biological dose received. The detector is more precisely called a "dosimeter" in this latter case. The measurement stems from induced reaction that the radiation undergoes within the detection medium; the effect could be physical, chemical or nuclear in nature. Applications of radiation in various disciplines require dosimeters that can operate over a wide range of radiation intensity and operating conditions. High resolution spectrometer type instruments can determine the dose as well as identify the type of radiation. Some examples of modern detectors used for radiation protection are: **Geiger tube monitors, ion chambers, scintillation spectrometers, CR-39, bubble detector.**





Ionization Workshop Resource Kits

Cloud chambers:

Plastic containers (cover R DT-15C clear, box R DT-15B clear) from Durphy Packaging company 47 Richard Road, Ivyland PA 18974. Phone (215) 674-1260, Fax (215) 674-3051. Painted black on bottom and glued felt on the inside top rim. Complete **Cloud chamber with source (Cat #. S52008 price $39.05)** available from **Fisher Scientific 112 Colonnade Road, Nepean, ON K2E 7L6. Phone 613-228-0542 / 800-267-3556. Fax 613-226-1658.**

Uranium rock samples from **Sargent Welch (1-800-727-4368 $2.40 per sample)** or from **Minerals Unlimited P.O.Box.877 Ridgecrist California USA 93556-0877 Phone (619)-375-5279 (about US$10 for a bagful of ore rocks.)**

PC computer based-α, β, γ Geiger probes:

AWARE Electronics manufactures Geiger counters which plugs into the RS232 communication channel of an IBM compatible computer and makes a complete counting system. The software included with the package gathers radiation data from the probe and stores the data to disk and allows the user to display the data in graphical form on the screen. Prices (in US $) of complete systems with ,data acquisition and analysis software, cable assembly, documentation, exercises

RM-60: $149.50, RM-70: $240.00, RM-80: $319.00
AWARE Electronics corporation P.O. Box 4299 Wilmington, DE, USA 19807
Phone/Fax: (302)-655-3800. Internet: http://www.aw-el.com Email: Aware@aw-el.com

^{137}Ba source generator:

Generator purchase from PASCO Phone 800-772-8700
Eluent to milk ^{137}Ba from the generator Ethylene Diamine Tetra Acetic (EDTA)
EDT chemical formula ($C_{10}H_{16}N_2O_8$) composition (0.1M PH 9).

To make EDTA mix:

Tetra sodium salt ($C_{10}H_{12}N_2Na_4O_8$)	10.4g
Pure water (H_2O)	250 mL

Dissolve salt in water. The pH of this solution will be about 11. It is crucial to adjust this pH to 9. In order to do this, add few drops of high purity nitric acid. Measure pH with meter.

For videos or equipment for school projects please contact:

Dr. Aslam Lone
Address: P.O. Box 1413, Deep River, Ont. Canada. K0J 1P0
Phone: work (613)-584-8811 Ext. 4007, **Fax:** (613)-584-1849; **Home:** (613)-584-9212
Email: lonea@aecl.ca
CNS Home Page: http://www.cns-snc.ca

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Nuclear Experiments for the Class Room

Instructions for use of equipment

A. Ba radionuclide Iso-generator

setup generatror

1. Install stopper valve on the iso-generator (One end of the valve fits on the thin tube of the generator
2. Mount generator on the metal laboratory stand with clamps provided
3. Identify ion-echange column end (raison - small dark portion on the bottom of the generator)
4. The generator is stored filled with de-ionized water to avoid letting raison part get dry
5. Drain water from the generator by opening the valve but keep raison in water
6. Elute Ba into a small plastic bottle placed under the generator by flushing the column with EDTA eluent (about 1 ml every time You can extract full strength Ba at 10 minute intervals. Ba has about 2.5 min half life so you can drain the solution into sinks after about 10 minutes
7. When finishe drain the column with de-ionized water. Flush it twice to remove all traces of EDTA. The fill the generator with de-ionized water for storage.
   Count radiation 661 KeV gamma rays with Geiger counter see section D
8. place Ba in small tube in front of the Geiger probe connected to the PC (section D) (keep away from generator to reduce ambient radiation level)
9. count for time base of 10 second
10. count number of bars (10 second interval) separating counts that differ by ½ , get half life by multiplying this number of bars by 10. Can start from any bar and count until the following bar that has half the count. (If we plotted the counts with the plotter program on the disk then we could show a straight line on a semi-log and evaluate half life from slope of the plot)

B. Cloud Chambers

1. Put about one cup of crushed ice in the styrofoam plate
2. Put methnol alcohol drops (ethyle alcohol works as well) on the felt inside the cloud chamber cup (don't soak the felt). Put alcohol in plastic bottle with thin snout and put a thin line of alcohol all along the felt belt
3. Rub the felt with hand to spread the alcohol on the felt
4. Put one rock source or metal uranium sample in the chamber
5. Close the lid
6. Put the chamber on the dry ice
7. **Rub the top of the chamber with palm to create a temperature gradient between the top and the bottom of the chamber**
8. Shine light from the side of the chamber and see downward from the top, or shine light at an angle from the top while looking down towards the dark bottom of the chamber
9. You should see radiation tracks like northern lights.
10. The bright thick tracks are from alpha rays
11. The thin wavy tracks are electrons or low energy gamma rays
12. Some tracks appear to drift like white vapour trails behind a high flying jet.

13. Eventually decrease in temperature gradient reduces track formation. Rub the top again the tracks will start again. (This may also be due to other causes such as positive ion accumulation ?)
14. After use please dry out rock sample for storage

C. Smoke Detectors

1. One is battery operated. The Americium source is in the ionization chamber (SQUARE cage with perforated walls)
2. light one of the smoke making insect repellent stick
3. Put smoke detector with face downward
4. Place the smoke stick underneath the smoke detector.
5. (You could demonstrate that the detector can trigger with artificial smoke (I am out of it) or wet steam)
6. Second detector uses 110 volt house power. Connect AC three pin end to detector and other end to AC outlet

D Geiger Detector Probe and Pocket Radiation Monitor

1. The radiation monitor is self supporting and you can either use it as a rate meter of scaling unit
2. The Geiger Counter RM80 Probe can be used with an accompanying scaling unit
3. For use with scaling unit, plug the telephone end of the cable from RM 80 (it may be connedted to 9 pin connector - unplug from it) to the scaling unit.
4. Set the three buttons on the scaling unit , one is for use as rate meter, the other for scaling unit and the third is power
5. To use RM80 with a PC computer follow the instruction below

Use Geiger Probe with PC
Download Program

1. Create a director Aware on your portable PC hard drive
2. copy from **Aw-srad.exe** form the accompanying 3 ½ disk to this director (You could copy all of Aware directory from the floppy onto the Aware directory
3. **Connect Geiger Detector to computer**
4. Power down computer
5. connect the detector on the back of the computer to the 9 or 25 pin RS 232 outlet connector (use 9 pin or 25 pin adapter to the phone connector on the end of the cable from the detector
6. turn on the computer
7. **Execute program**
8. execute program **aw-srad.exe**
9. the screen will show a page with tool bars and key words on the tool bar
10. **SET UP software parameters**
11. **(You can go to previous stage by hitting esc key any time)**
12. hit S on key board or click Setup with mouse
13. hit I or click Input on the drop down menu
14. **Identify Comm Port of the connector to which detector is connected**
15. hit A or click Automatic search with mouse on drop down sub menu shown by step 12
16. after some time computer will respond (identified comm port) . It is now set automatically
17. **select time base for counting interval (MCI) multi-channel integration with time base**
18. hit T or click TBU with mouse
19. hit 1 for 10 second count period
20. **Finish setup**
21. hit **Esc** key
22. **Ready for Data collection**
23. hit C or click Capture on tool bar
24. **Collect Data**
25. hit D or click Display current data
26. **Save data (computer will show current directory and ask for file name)**

27. hit return to disregard data save (it is needed if you want to plot data for further analysis - with program on the disk)
28. **Data will appear as a vertical bar ever 10 seconds (TBU in step 18)**
29. **Manipulate data display and view options**
30. hit f1 for help on how to change display options (dropdown help appears)
31. hit ALT f3 to set vertical scale maximum counts automatically (Good option)
32. or hit ALT f4 to suppress auto vertical scale count
33. **Sound**
34. hit B to toggle counting beep on and off
35. hit A to toggle alarm on and off (alarm threshold can be set)
36. **to stop counting**
37. hit F2 function menu goes back to step 9. For restart hit C if you do not want to change anything else repeat from step 10
38. **Use detector as rate meter**
39. hit C in step 23 instead of D
40. program will show a horizontal rate meter scale after a short set up period. The horizontal bar shows count rate
41. **Termination**
42. Stop program , Power down computer and unplug probe from back of the computer

E, F Radiation Attenuation through Materials

1. Use plates, Al, Cu, Pb and backelite separately with Sr, Cs source or uranium rock source to demonstrate attenuation use radiation monitor or Geiger Probe Detector with computer for counting
2. Place source and detector apart at some distance such that materials can be placed in between without changing distance
3. start counting with rate meter or scalar (check count rate, with computer count fixed time)
4. repeat count after placing a number of Al or backelite sheet
5. repeat by replacing Al with Cu
6. repeat by replacing Cu with Pb
7. explain reason for attenuation differences Z and density dependence)
8. go back to 3 and increase distance between source and probe
9. show that radiation level decrease with distance ($1/R^2$ dependence)
10. Can demonstrate counting statistics by choosing difference counting time (analogy with spreads in count rate per min of cars passing on a street with count period) Importance of statistics in evaluation and understanding of low level radiation effects

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Dr. Wm. (Bill) Garland
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Hamilton, Ontario
CANADA L8S 4L8
Phone (905) 525-9140
garlandw@mcmaster.ca

Common radioisotopes and their everyday uses

There are a large number of radioisotopes found in nature. Many of these are now being used commonly in both the home and the workplace. This list is taken from Nuclear Energy, 2nd Qtr. 1993 published by USCEA.

Americium-241	Used in many smoke detectors for home and business - to measure levels of lead in dried paint - to ensure uniform thickness in rolling processes for steel and paper - to determine optimum locations for oil well drilling.
Cadmium-109	Used to analyze metal alloys for checking stock or sorting scrap.
Calcium-47	Important aid for biomedical researchers studying cell formation and bone structure in mammals.
Californium-252	Used to inspect airline baggage for hidden explosives - to gauge the moisture content of soil in construction activities - to measure moisture in material stored in silos.
Carbon-14	Used to ensure that new drugs under development are metabolized without forming harmful byproducts - used by archaeology and paleontology for dating historical artifacts.
Cesium-137	Used to treat cancer tumors - to measure correct patient dosages of radioactive pharmaceuticals - to measure and control liquid flow in pipelines - to tell researchers whether oil wells are plugged with sand - to ensure that containers are filled to the proper level with food, drugs or other consumables. other consumables.
Chromium-51	Used in research in red blood cell studies.
Cobalt-57	Used in nuclear medicine to help doctors interpret diagnostic scans of patients' organs.
Cobalt-58	Used as a tracer to diagnose pernicious anaemia.
Cobalt-60	Used to sterilize surgical instruments - used to improve safety of industrial fuel oil burners.
Copper-67	Helps antibodies to bind with and destroy cancer tumors.
Curium-244	Used in mining to analyze material excavated from pits or slurries taken from drilling operations.
Iodine-123	Used to diagnose thyroid disorders.
Iodine-129	Used to check radioactivity counters in in-vitro diagnostic testing laboratories.
Iodine-131	Used to test the integrity of pipe welds, boilers and aircraft parts.

Iron-55	Used to analyze electroplating solutions.
Krypton-85	Used in indicator lights in appliances such as washing machines, dryers, stereos and coffeemakers - used to gauge the thickness of thin plastics, sheet metal, rubber, textiles and paper - used to measure dust and pollutant levels.
Nickel-63	Used to detect explosives - used in voltage regulators and current surge protectors in electronic devices.
Phosporus-32	Used in molecular biology and genetics research.
Plutonium-238	Has been used to power NASA spacecraft since 1972.
Polonium-210	Reduces static discharge in the making of photographic film and phonograph records.
Promethium-147	Used in electric blanket thermostats - used to gauge thickness of metals, plastics, textiles and paper.
Radium-226	Makes lighting rods more effective.
Selenium-75	Used in protein studies for life science research
Sodium-24	Used to locate leaks in pipelines.
Strontium-85	Used to study bone formation and metabolism.
Strontium-90	Used in metering applications.
Technetium-99M	Widely used in radiopharmaceutical studies - many different chemical forms used for organ imaging and blood flow studies.
Thallium-204	Measures pollutant levels on filter paper - used to measure thickness of metal, rubber, textiles and paper.
Thorium-229	Used to make fluorescent lights last longer.
Thorium-230	Provides colour and fluorescence in glazes and glassware.
Tritium	Used for medical studies - used for self-luminous watch dials and commercial and aircraft exit signs - used to make luminous paint.
Uranium-234	Used in dental fixtures such as crowns and dentures to provide natural colour.
Uranium-235	Fuel for nuclear power plants - used to produc fluorescent glassware and coloured glazes.
Xenon-133	Used in nuclear medicine for lung ventilation and blood flow studies.

Canadian Nuclear Society
Education and Communications Committee
Visit our website: http://www.cns-snc.ca

Chairman
Dr. Wm. (Bill) Garland
McMaster University
Hamilton, Ontario
CANADA L8S 4L8
Phone (905) 525-9140
garlandw@mcmaster.ca

Smoke Detectors and Americium-241 Fact Sheet

$_{95}Am^{241}$

For more than 25 years, Canadians have used ionization chamber-based smoke detectors to warn them of possible fires in their homes. Most of these detectors use a small quantity (approximately 0.2 mg) of americium-241 (Am-241) in the form of americium dioxide (AmO_2). This small quantity of Am-241 corresponds to 0.8 microcuries (μCi) or 30 kilobecquerel (kBq) of radioactive material. The alpha radiation emitted by the Am-241 ionizes oxygen and nitrogen in the air in the sensing chamber. The electric potential from a battery causes a small current to flow. Smoke particles (or aerosols, or mists from the bathroom shower) that enter the chamber absorb alpha particles. This reduces the ionization of the air, and hence reduces the electric current in the chamber. The reduction in the current is detected and the alarm is triggered.

Am-241 emits both alpha radiation and low-energy gamma rays. The alpha particles are absorbed within the detector, while most of the gamma rays escape.

Americium has atomic number 95 and an average atomic mass of 243. Metallic americium is a silvery metal, which tarnishes slowly in air and is soluble in acid. There are no stable isotopes of americium, and hence it is extremely scarce in nature. The first sample of americium was produced by bombarding plutonium with neutrons in a nuclear reactor at the University of Chicago. The discovery of element number 95 was announced on an American children's radio program called "Quiz Kids" in November 1945 by Glenn Seaborg, a chemist who worked on the Manhattan Project and co-discovered 10 elements, including plutonium.

The name americium, chosen by Seaborg in honour of the continent where it was discovered, was given to the new element in 1946. Of its 13 isotopes, Am-243 is the most stable, with a half-life of over 7500 years, although Am-241, with a half-life of 470 years, was the first isotope to be isolated. (After one half-life, half of the original quantity of a radioactive isotope would have decayed, and half would remain.)

Source

Plutonium-241 (Pu-241), which forms about 12% of the one percent plutonium content of typical spent fuel from a light-water power reactor, has a half-life of 14 years, decaying to Am-241 through beta emission. (These proportions are different in a CANDU® heavy water reactor.) Pu-241 is formed in any nuclear reactor by neutron capture starting from uranium-238 (U-238). The steps are:

U-238 + neutron => U-239,
U-239 by beta decay => Np-239, Np = neptunium
Np-239 by beta decay =>Pu-239,
Pu-239 + neutron => Pu-240,
Pu-240 + neutron => Pu-241.

The Pu-241 decays (emitting a beta particle) both in the reactor and subsequently to form Am-241.

It is of interest (and some significance in recycling spent fuel) that if too much Am-241 builds up in plutonium separated from spent fuel, it cannot readily be used for mixed oxide (MOX) fuel because it is too radioactive for handling in the normal MOX plant. For instance, British Nuclear Fuels Limited at Sellafield, UK, can handle plutonium with up to 3% Am-241, hence up to 6 years old (higher concentrations would need additional measures to control the dose to workers).

Hazards

The radiation dose to the occupants of a house from a domestic smoke detector is very small, very much less than that from natural background radiation due to cosmic rays, naturally occurring radioactive elements such as potassium, or radon. The small amount of radioactive material that is used in these detectors is not considered to be a health hazard. When smoke detectors using americium were first introduced, they were labelled as requiring return to the supplier or shipment to the Atomic Energy Control Board for disposal in Canada. This requirement was later withdrawn, although some jurisdictions (e.g., Australia) require special disposal. There is probably some "spent fuel waste" in your local land fill in the guise of defunct smoke detectors.

Am-241 is a potentially hazardous isotope, decaying by both alpha activity and gamma emissions. If it enters the body in a chemically available form, it would concentrate in the skeleton. However, swallowing the radioactive material from a smoke detector would not lead to significant internal absorption of Am-241. Since the dioxide is insoluble, it will pass through the digestive tract, without delivering a significant radiation dose. Inhaling AmO_2 as dust particles could lead to it residing in the lungs. Alpha particle emitters present a biological hazard when inside the body, since the alpha particles are absorbed in a small volume near the source, increasing the risk of cell damage that may result in cancer. The low gamma rays are less hazardous as they interact over a larger volume.

Am-241 decays to an isotope of neptunium (Np-237) emitting an alpha particle with an energy of approximately 5.5 MeV and gamma rays, with the majority having an energy of 60 keV. Np-237 has a half-life of 2.14 million years, and also decays by alpha emission (4.9 MeV). Because of its long half-life, Np-237 is less hazardous than Am-241. (Very rarely, Am-241 undergoes spontaneous fission.)

Cost

Americium dioxide was first offered for sale by the US Atomic Energy Commission in 1962 and the price of $1500 US per gram has remained virtually unchanged to the present day. Since one gram of americium dioxide provides enough active material for more than 5000 smoke detectors, the AmO_2 accounts for less than 5% of the retail price of a smoke detector.

Other uses

Americium (in combination with beryllium) is also used as a neutron source in non-destructive testing of machinery and equipment, and as a thickness gauge in the glass industry. However, its most common application is as an ionization source in smoke detectors, and most of the several kilograms of americium made each year is used in this way.

Alternative Smoke Detectors

Photoelectric smoke detectors sense smoke in the air by detecting changes in the transmission of light due to absorption and scattering by smoke particles. These devices require more electrical power than the ionization detectors, are usually connected to the house wiring, and hence are more costly to purchase and install. For some types of fires, photoelectric detectors perform better than ionization chambers, but they are considered to be less effective, in general. Some manufacturers are now offering smoke detectors that use both technologies.

References

The Uranium Institute, London, UK: **http://www.uilondon.org/**
Uranium Information Centre Limited, Melbourne, Australia: **http://www.uic.com.au/**
Handbook of Physics and Chemistry, 60th Edition, Chemical Rubber Company, 1979.

CANADIAN NUCLEAR WEBSITES

(updated 98/04/13)

The Canadian Nuclear FAQ (an unofficial information resource)	http://www.ncf.carleton.ca/~cz725
AECL's Homepage (designer and vendor of CANDU reactor product)	http://www.aecl.ca
Ontario Hydro's Homepage (one of North America's largest nuclear utilities)	http://www.hydro.on.ca
New Brunswick Power Commission (operates one CANDU reactor at Pt. Lepreau, N.B.)	http://www.gov.nb.ca/cnb/news/nbp
Hydro Québec (operates one CANDU reactor at Gentilly, P.Q.)	http://www.hydro.qc.ca
The Canadian Nuclear Association (CNA) (representing the Canadian nuclear industry)	http://www.cna.ca
The Canadian Nuclear Society (CNS) (representing Canadian nuclear science & technology)	http://www.cns-snc.ca
Atomic Energy Control Board (Canada's federal nuclear regulator)	http://www.gc.ca/aecb/docs/ar95/eng/menu.htm
Heavy Water (good fact sheet from Queen's University)	http://snodaq.phy.queensu.ca/SNO/D2O.html
HANARO (Canada's MAPLE technology in South Korea)	http://hpngp01.kaeri.re.kr/hanaro
MDS Nordion (global radiopharmaceutical distributor, in Kanata, Ont.)	http://www.mds.nordion.com
Cernavoda site (CANDU project in Romania)	http://www.uilondon.org/uiabs95/glod.html
B. N. Brockhouse (Canada's 1994 Nobel Physics Laureate)	http://www.physics.mcmaster.ca/Brockhouse.html
The Sudbury Neutrino Observatory (built onto a nickel mine, uses heavy water)	http://snodaq.phy.queensu.ca/SNO/sno.html
Bubble Technology Industries (BTI) Inc. (neutron dosimeter and spectrometer R&D and marketing)	http://intranet.on.ca/~bubble
Atlantic Nuclear Services Ltd. (nuclear engineering consultant company, N.B.)	http://ctca.unb.ca/GFEDC/eng/firms/atlantic.htm
Stern Laboratories Inc. (private nuclear testing laboratory, Hamilton, Ont.)	http://www.netaccess.on.ca/~sternlab
Nray Services (commercial neutron radiography, Petawawa, Ont.)	http://www.nray.com
Canada as host to ITER fusion project (ITER – planned prototype fusion reactor)	http://www.hookup.net/~itercan
The NRC's "Neutron Program for Materials Research" (using the neutron beams from the NRU reactor)	http://www.sims.nrc.ca/sims/neutrn_e.html

NON-CANADIAN NUCLEAR WEBSITES

(updated 98/04/13)

The American Nuclear Society (the CNS' counterpart south of the border)	http://www.ans.org
Todd's Atomic Homepage (a thorough resource)	http://neutrino.nuc.berkeley.edu/neutronics/todd.html
Uranium Information Centre (good nuclear information site, from Australia)	http://www.uic.com.au
Uranium Institute (good nuclear information site, from England)	http://www.uilondon.org
"Chernobyl – Ten Years On" (1996 summary of Chernobyl's health effects)	http://www.uilondon.org/chernidx.html
Nuclear Energy FAQ (John McCarthy's unofficial information site)	http://www-formal.stanford.edu/jmc/progress/nuclear-faq.html
IAEA World Atom (UN's International Atomic Energy Agency)	http://www.iaea.or.at/worldatom
The Virtual Nuclear Tourist (an unofficial guide to nuclear reactors worldwide)	http://www.cannon.net/~gonyeau/nuclear

CANADIAN NUCLEAR ASSOCIATION · ASSOCIATION NUCLÉAIRE CANADIENNE

Nuclear*Facts*

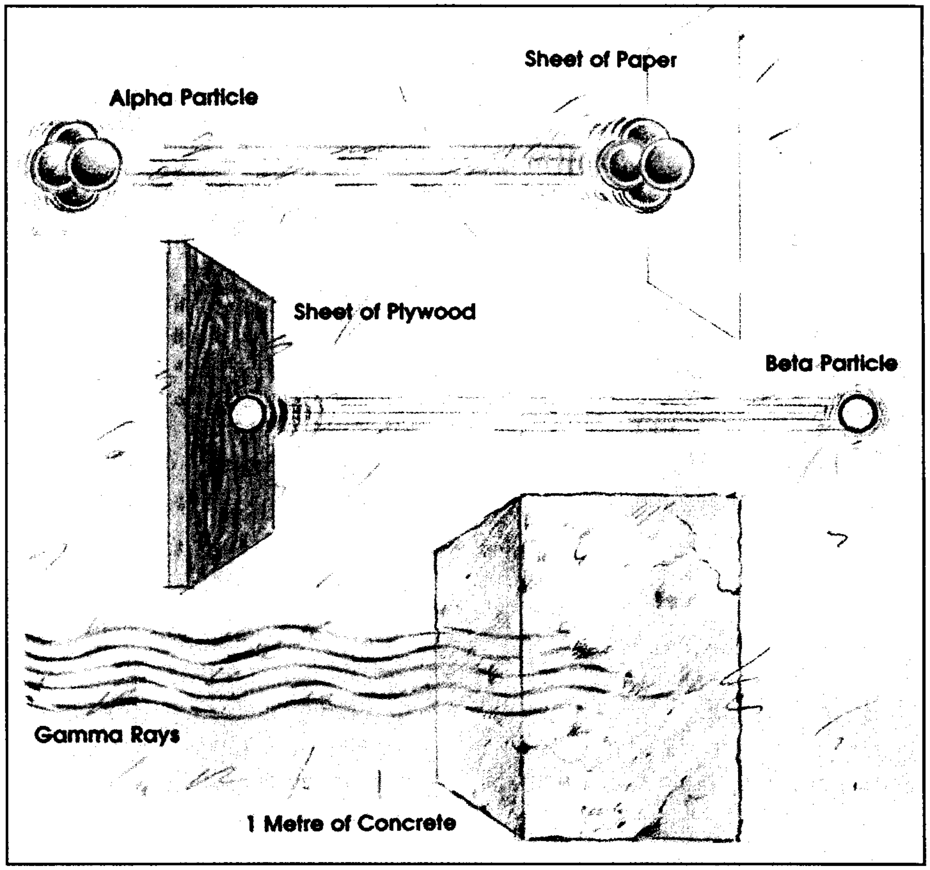
Seeking to generate a better understanding

What is Radiation?

There are millions of different kinds of materials in the world, yet these basic materials are made up of only about 100 basic substances, known as elements. Most of the atoms that make up these basic elements are stable, yet there are several which are unstable. These atoms, such as uranium, radium and thorium, are found everywhere. When atoms are unstable, they constantly attempt to become stable by emitting energy. This is radiation. Radiation is a form of energy which travels through space, giving up all or part of its energy on contact with matter. It sometimes takes the form of "alpha" or "beta" or "gamma" rays. These kinds of radiation are commonly referred to as "ionizing radiation".

The penetrating ability of ionizing radiation varies. Alpha particles cannot penetrate very far. In fact, they can be stopped by a sheet of paper, or several centimetres of air. Beta particles have a higher penetration capability but can be stopped by several millimetres of aluminium or wood. Gamma rays, on the other hand, are highly penetrating, although an appropriate thickness of concrete, water or other material can protect people from them.

Substances which emit gamma radiation could be hazardous inside or outside the body; beta particles would be most harmful inside the body; while those substances which emit only pure alpha particles could only be hazardous if swallowed or inhaled.



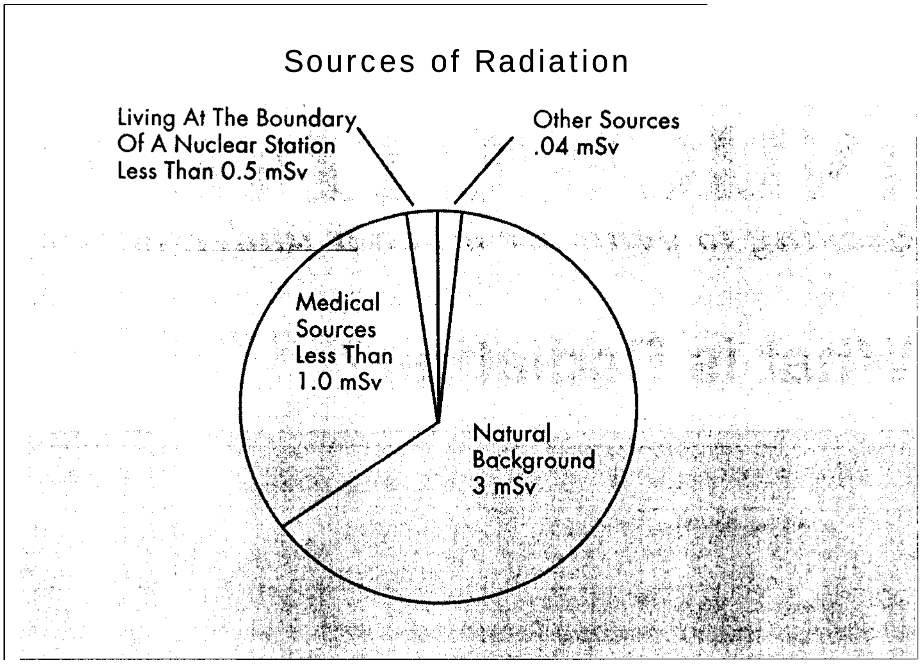
The penetrating ability of ionizing radiation varies. Alpha particles cannot penetrate very far; beta particles have a higher penetration capability; while gamma rays are highly penetrating.

What are the Sources of Radiation?

Everyone is constantly exposed to varying amounts of ionizing radiation. This comes from different sources, both natural and man-made. More than one-third of the radiation to which we are exposed exists naturally throughout the universe in the form of cosmic radiation. It is also emitted from naturally radioactive substances in the Earth's crust, in elements such as potassium and uranium. The human body is also mildly radioactive because it contains naturally occurring radioactive potassium.

Besides natural background radiation, there are many forms of man-made radiation. These are from medical applications, dental x-rays, nuclear reactors, and self-illuminating products such as signs.

Ionizing radiation is used to our advantage in medicine, industry, research and agriculture. Hospitals diagnose disease and carry out therapy with ionizing radiation. X-rays and gamma rays penetrate and view the interior of our bodies. More intense levels of ra-



The average Canadian receives an annual dose of 3.6 mSv of radiation. This exposure is from a number of sources, both natural and man-made.

diation from cobalt 60 or accelerators are used for cancer therapy.

Industry uses radioactive materials to improve the quality of products. For example, many medical products are sterilized using ionizing radiation.. Manufacturers of materials such as paper, plastic and metal, use ionizing radiation to continuously monitor product quality during production.

The preservation of food is a growing application of ionizing radiation; controlling the ripening of fruits and vegetables extends the shelf life of a variety of fresh foods. Ionizing radiation is used to inhibit sprouting in root crops such as potatoes and onions.

What are the Known Health Effects?

Radiation from the sun in the form of heat and light is essential for the growth and nourishment of all plants and animals. If wc arc not careful about how much sun wc are exposed to, the result can be a sunburn, or worse, skin cancer.

Similarly, ionizing radiation in large doses can cause serious injury, cancer or death. The degree or probability of harm depends on the size of the dose.

We measure biological exposure to radiation in units called sieverts.

It is known, for instance, that an acute does of 5 sieverts (Sv) received over a few hours would probably be lethal. In terms of relative toxicity, 100 aspirins taken over the same period of time may also be just as lethal. On the other hand, the same dose of radiation (5 Sv) spread over several decades would be considerably less harmful.

What are Common Exposure Levels?

The average Canadian receives an annual dose of about 3 millisieverts (mSv) from exposure to natural background radiation, depending on where he or she lives. Persons living at a higher elevation in mountainous areas would be exposed to more cosmic radiation than those who live at sea level. This is because the Earth's atmosphere at lower elevations provides more shielding protection from cosmic radiation than at higher elevations.

The average Canadian receives an exposure of less than 2 mSv each year from medical applications of radiation and dental x-rays.

The exposure during a return flight from Toronto to Vancouver is about 0.05 mSv, or slightly more than the radiation exposure from living at the boundary of a nuclear station for a full year.

Because we understand radiation today, we can USC and control it safely for the benefit of mankind.

Effects of Radiation at Various Dose Levels

0.05 mSv This amount, a fraction of natural background radiation, is the design target for maximum annual radiation at the perimeter of a nuclear generating station, or about the same exposure during a return flight from Toronto to Vancouver.

3 mSv This is the normal background radiation level from natural sources each year at sea level. This is also the average minimum dose received by most people on earth each year.

100 mSv If given instantaneously, this exposure would not cause obvious illness This dose might cause cancer many years later in one out of every 1,000 people exposed to this dose. (Average cancer deaths from all other sources is 160-200 per 1,000 people.)

Information from the Canadian Nuclear Association

This fact sheet is one of a number of fact sheets that are part of a public information program from the Canadian Nuclear Association.
For more information contact:

The Canadian Nuclear Association
144 Front St West, Suite 475
Toronto, Ontario
M5J 2L7
(416) 977-6152

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ACCESS THE CNS

A CONTACT SHEET FOR SCIENCE EDUCATORS

The Canadian Nuclear Society (CNS) provides Canadians interested in nuclear science and technology with a forum for technical and related discussion. The CNS endeavours to improve public knowledge in this area, through educational initiatives and by direct contact with CNS members. Many of our members are scientists and engineers working in the fields of nuclear science and technology. They comprise a valuable knowledge resource.

The following are three ways that you can access this resource:

1. CNS Education and Communication Committee

This committee exists to facilitate the exchange of information between CNS members and the public, and to develop educational programs in this regard. It administers the CNS Education Fund, which is used to improve communication and advance science and technology in Canadian schools. As a science educator, your input is important in ensuring that this resource is allocated where it is needed the most.

<u>Contact:</u> Dr. Bill Garland CNS-ECC, email: garlandw@mcmaster.ca, phone: (905)-525-9140
McMaster University, Hamilton, Ontario, CANADA L8S 4L8

2. CNS Internet Website

The CNS is on the Web. Our URL is **http://www.cns-snc.ca** From here you can find information on national and local programs, and read more about the objectives of the Society. The website is administered by the Internet committee of the CNS. The Webmaster is Peter Laughton, email: webmaster@lewis.cns-snc.ca

3. Local CNS Branches

There are twelve local branches of the CNS, in five provinces. Each branch holds meetings with interesting speakers, and the public is welcome to attend. These branches may also receive a portion of the CNS Education Fund, to be administered locally (for science fair prizes, assistance in obtaining special equipment for high school science experiments, scholarships). In addition, each branch represents a local wealth of expertise that can be drawn upon for classroom presentations, participation in science fairs and other community events, or simply to answer questions. Listed below are the contact persons for each branch (usually the chairperson of the branch executive), along with the branch's local website, if applicable.

Bruce
Eric Williams
519-361-2673

Chalk River
Jeremy Whitlock
613-584-3311
whitlockj@aecl.ca

Darlington
Richard Murphy
905-623-6670

Golden Horseshoe (Hamilton)
Dave Jackson
905-525-9140

Manitoba
Morgan Brown
204-753-2311
brownmj@eastman.freenet.mb.ca

New Brunswick
Dave Reeves
506-659-2200

Ottawa
Mohamed Lamari
613-788-2600

Pickering
Marc Paiment
905-839-1151

Québec
Willem Joubert
514-871-1116

Saskatchewan
Walter Keyes
306-586-9536

Sheridan Park (Mississauga)
Mac Tayal
905-823-9040

Toronto
Ross Rock
416-592-4930