Student's Guide to

Health and Physics

A Grade 12 Manitoba Resource for Health and Radiation Physics

Canadian Cancer Society | Société canadienne du cancer

Manitoba

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acknowledgements

The Manitoba Division of the Canadian Cancer Society and Manitoba Education, Citizenship and Youth gratefully acknowledges the contributions of the following individuals in the development of *Health and Physics: A Grade 12 Manitoba Physics Resource for Health and Radiation Physics.*

This resource, and its associated *Teacher Resource Guide,* were conceived and developed to assist students in achieving the learning outcomes for the "Medical Physics" topic in the Manitoba Grade 12 Physics curriculum. It provides a context for real-world applications of the fundamentals of radiation physics, with important connections to the health and well-being of the people of Manitoba.

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MINISTER OF EDUCATION, CITIZENSHIP AND YOUTH

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CANADA

To the Students of Manitoba:

It is with great pride that I announce the publication of *Health and Physics: A Grade 12 Manitoba Resource for Health and Radiation Physics* to support your learning experiences as physics students. This is an important and timely resource that will help you learn critical content within a meaningful context. It explores the safe and necessary applications of radiation to diagnostic imaging techniques, introduces you to the field of medical physics, and examines the treatment options used for various cancers. This resource constitutes the fruit of a long-standing and successful collaboration between the Manitoba Division of the Canadian Cancer Society and Manitoba Education, Citizenship and Youth (MECY).

Though great progress has been made in adopting early detection and prevention strategies, there is an expectation that most Canadians will directly deal with cancer and/or its treatment among family members at some point. This is why having an education about the technologies involved in the fight against cancer will provide a firmer basis for your healthcare decision-making down the road.

Manitoba families are encouraged by the prospects of better detection and improved outcomes for cancer patients, and we believe that a sound science education in this area contributes to wider understanding of the complex field of cancer research, diagnosis and treatment. This partnership with the Canadian Cancer Society demonstrates a commitment to relevant, high-impact science education here in Manitoba. My hope is that this new resource will improve your healthcare system awareness and decision-making capability as it increases your technical knowledge in applying science to vital human needs.

Sincerely,

Honourable Peter Bjornson

Canadian Cancer Society / Société canadienne du cancer
MANITOBA DIVISION

July 23, 2009

Dear Students and Teachers of Manitoba,

The Manitoba Division of the Canadian Cancer Society has been pleased to fund this interesting and informative curriculum guide in health physics – *Health and Physics: A Grade 12 Manitoba Resource for Health and Radiation Physics* and its associated Teacher Resource Guide. The project has been a partnership and fruitful collaboration among many individuals and organizations, including: students and teachers of physics who assisted in the pilot phases, the Department of Education, Citizenship and Youth's science consultants, medical physics expertise from CancerCare Manitoba and the St. Boniface Hospital Research Centre, and our staff here in the Manitoba Division of the Canadian Cancer Society.

The Canadian Cancer Society, Manitoba Division allocated donor dollars to this project as a demonstration of its commitments to public education in the sciences and to the well-being of all Manitobans. Our mandate is to serve all Manitobans who are at risk of developing cancer as well as those with cancer. We invested in this project as a meaningful connection to young adults, with the conviction that informed citizens are stronger advocates for their own health and the health of their families.

We believe that the information in the physics resource material will be of interest to students and their parents as the information is an excellent reference guide to imaging technology that is critical to much of health care. Imaging and radiation physics is also a core part of the cancer patient experience.

We are proud to have been associated with this project, and hope that students, teachers and families will find the material informative and useful for their future.

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chapter 1
Radiation-Based Diagnostic Technology

CASE STUDY: Francine Yellowquill - a Diagnosis

Francine Yellowquill was an active teenager, enjoying participating in all kinds of sports. Her favourite sport was gymnastics. She regularly practiced somersaults, handstands, and complicated jumps over sawhorses and on balance beams. One day she attempted a new manoeuvre upon dismounting from the balance beam, and ended up accidentally landing on her head. Excruciating pain shot through her back, as if thousands of hot needles were jabbing into her simultaneously. Instantly, her coach was at her side and called for an ambulance. The emergency doctor asked her some key questions and then promptly sent her for x-ray. “You might have a problem with trauma in two or three cervical vertebrae in your neck area,” it was explained following x-ray. The doctor then ordered a CT scan, which confirmed the initial diagnosis of broken vertebrae in Francine’s neck.

As she went for these tests, Francine (who always had an eye for technical explanations of things) began to ask some questions. What kinds of technologies are being used on me? How do these imaging machines actually work? Why did I need to go for more than one type of imaging? Could the doctor obtain the same diagnosis without resorting to a technology that uses ionizing radiation? *Fictitious patient (stock photo)*

X-Rays

In late 1895, Wilhelm Roentgen was working at Wuerzburg University in Germany with a cathode-ray tube in his laboratory. While conducting his experiments, he noticed that phosphorescent crystals glowed in the presence of the working tube. When Roentgen created a vacuum in the tube and applied a high voltage to the electrodes, a fluorescent glow appeared. Roentgen concluded that a new type of ray was being created by this apparatus. Through further experiments, he concluded that this ray could pass through most substances. What he discovered was what we know in a familiar fashion as the “x-ray.” The letter “x” in x-ray derives from the Greek “xenos” which means something “foreign” or “strange” to typical experience.

An x-ray is a photon, or bundle of energy, which is essentially without mass and has no charge. The typical wavelength for an x-ray is between 0.01 to 10 nanometres. Because x-rays are produced by accelerating electrons towards a target (a large potential difference), they are not a natural form of radiation. X-rays are used in both x-ray technology and CT (Computed Tomography) devices.

X-rays are a form of radiation that has shorter wavelengths than UV radiation. For most medical applications, x-rays have a short enough wavelength to demonstrate behaviour more like that of a particle than a wave. So, their particle-like qualities are favoured over their wave-like nature. In x-ray crystallography—where x-rays are used to help determine the structure of crystals—the opposite is the case.

In the decades following Roentgen’s discovery of x-rays, widespread and unrestrained experimentation with this new form of radiation followed. As a result, some excessive experimenters developed serious injury to the body from overexposure to this form of radiation. Typically, these injuries were not attributed to x-rays because the onset of the injuries was progressive over time. At one point, x-rays were used by assistants in shoe shops to determine children’s shoe sizes! Eventually, though, the field of health physics emerged that looked to manage the dangers of radiation technologies while still exploring their potential and real benefits.

Reality Check

Question | Can Sustaining a Physical Injury Cause Cancer?

Origin: In the late 1800s until the early 1920s, some scientists thought injuries (or trauma to the body) could cause cancer, despite the lack of any compelling experimental evidence. Many patients who came in with physical injuries had x-ray imaging performed on them, and in the process tumours were discovered.

Reality Check: A fall, a bruise or any other injury is almost never the cause of cancer. Typically, a physician orders some sort of imaging for injuries incurred, and when images are analyzed a tumour may be found at the same time. This does not mean that the tumour stemmed from the injury, however. The tumour was already there. The diagnostic procedure merely located the tumour while the technologist was requested to take images looking for bone and tissue damage.

Terry Fox, a well-known Canadian who died in 1981, had been an active teenager involved in many sports until a knee injury sidelined him at age 18. During the diagnosis and treatment process, bone cancer was found and he was forced to have his right leg amputated above the knee. Terry is best remembered for his Marathon of Hope, which was a cross-country run to raise funds for cancer research. His legacy lives on through the Terry Fox Foundation.

Source: Gansler, Dr. Ted. "Discovery Health: Top 10 Cancer Myths: Myth 7." Discovery Health n.d.. 29 July 2008 http://health.discovery.com/centers/cancer/top10myths/myth7.html

The Electromagnetic Spectrum

When you listen to the radio, watch television, cook food in the microwave, use a tanning bed, or go to the doctor to get an x-ray, you are using electromagnetic waves. A wave is simply a vibration that is propagated through a medium such as air. An electromagnetic wave is a vibration produced by the acceleration of an electric charge. Though we cannot actually "hear" sound waves, our ears are designed to respond to these mechanical waves and it is via this response that we hear. Visible light, as part of the electromagnetic spectrum, helps us to "see" colours because photons from light sources fall within the range of wavelengths that the receptors in our eyes can translate into red, blue, green and other variations. Other types of waves are not registered by the human body through sound or sight. Microwaves and x-rays are two examples of such waves.

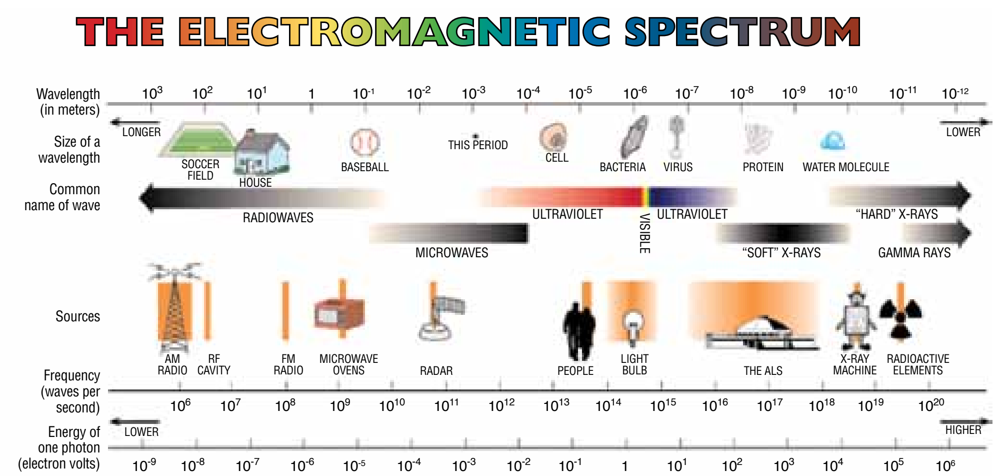


***Figure 1-2** shows the different wavelengths, frequencies, and energies that waves in the electromagnetic spectrum have. Note that radio frequency waves are among the largest in wavelength, with x-rays having incredibly small wavelengths. As wavelength decreases, the frequency of the wave (and the amount of energy the wave carries) increases.*

The chart shows the relative sizes, frequencies, and wavelengths of the different types of electromagnetic waves. The visible portion of the electromagnetic spectrum (light) is a small portion of the chart. UV, x-ray, and gamma rays all have shorter wavelengths and higher frequencies than the visible spectrum. By contrast, ultrasound—which is commonly used in medical imaging—is not an electromagnetic wave at all. Rather, it is a very high frequency sound wave beyond what our auditory systems are capable of hearing.

Questions: Electromagnetic Spectrum

1. Calculate the wavelength of radiofrequency waves that an FM radio station emits when broadcasting at 88MHz. (Use $v = f\lambda$, and find the speed of sound in air at 20 degrees C from your physics tables)
2. What is the difference between “soft” and “hard” x-rays (mentioned in Figure 1-2)?
3. What is the wavelength used by cell phones compared to the wavelength of the gamma rays used in PET scans? Which carries more energy?
4. What is the difference between UV-A and UV-B ultraviolet light?
5. What is the difference between sound waves we hear and ultrasound? Are sound waves considered part of the electromagnetic spectrum?

X-Ray Diagnosis

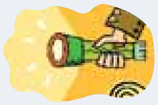
The use of “x” in the phrase “x-ray” is similar to when mathematicians use the symbol “x” to represent the “unknown.” When x-rays were first discovered, there were many things that were “unknown” about them. Recall the connection to the Greek word “xenos”, meaning ‘foreign’.

X-ray machines use a form of electromagnetic radiation produced when electrons are exposed to a large potential difference, or voltage. The electrons gain so much extra energy that this potential energy becomes kinetic energy and the electrons move quickly, colliding with the metal target plate. The rapid change in velocity causes the release of x-rays. This burst of radiation is aimed by the machine at the patient through positioning an extendable arm over the area of the body to be studied (see Figure 1-3). The x-rays pass through the body and an image of what they pass through is recorded on photographic film or is digitally generated. Because different parts of the body have different densities, the image will show lighter sections (indicating greater density and passage of fewer x-rays through the substance) and darker sections (lesser density and more x-rays traveling through). The picture obtained by this method is called a radiograph. Radiographs show clear images of bones and potential damage to them; however, they are limited in their ability to produce images of soft tissues that have clarity for diagnostic purposes. The reduction in the number of x-rays traveling through dense material is called attenuation, or ‘loss’.

Arthrography is a procedure where a substance such as iodine (mixed with water) is injected into the space between joints so that an x-ray can be taken to study how the joint is functioning and to study its structural anatomy.

activity

Tissue Attenuation



Tissue attenuation is an important concept in our understanding of x-rays and how their penetration into tissues affects image quality.

Shine a flashlight on a piece of tissue paper that someone is holding up in a darkened room. How much light goes through the tissue paper?

Now fold over one corner of the paper so there is a double layer of tissue paper. How much light goes through the double layer compared to the single layer? How do these results help in the understanding of radiographs?

Figure 1-3

Figure 1-3 *This x-ray machine has a bed for the patient to lie on and a tray underneath the bed to hold the radiographic film. The source of x-rays comes from the arm extended above the bed. Note that if a patient was lying on the bed, the arm would be rotated to aim the x-rays downward rather than towards the left wall (as is shown on the picture).*

Mammography is a specialized field of x-ray technology, where low energy x-rays are used to produce images of breast tissue. Radiologists use these images to detect differences in density, mass, or to spot calcifications that may indicate the presence of tumours. Low energy x-rays provide greater definition in the images. Higher energy x-rays travel fast and the result is an indistinct radiograph with lower contrast due to lower attenuation by the tissues involved.

activity

X-Ray analysis

Below are nine different x-rays of various parts of the human body. Imagine you are the x-ray technician asked to analyze each radiograph, or to guide the attending physician. Do you see something that is unusual in any of these images? What do the unusual sections potentially indicate? Why are some areas of the x-rays brighter? For each image, discuss in small groups whether the differences in brightness are more likely due to density, thickness, or the nature of the material (attenuation coefficient).

Figure 1-5 chest

Figure 1-6 molars

Figure 1-7 panoramic dental

Figure 1-8 forearm

Figure 1-9 knees

Figure 1-10 forearm

Figure 1-11 colon

Figure 1-12 skull

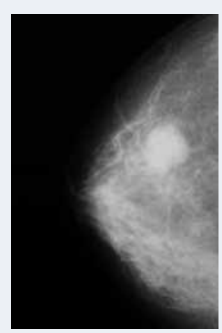


Figure 1-13 breast

Research Questions:

Why use iodine in arthrography and not other elements? What does calcification refer to?

Question:

Note that the wrist joint of Figure 1-4 is brighter than the finger joints. What does this tell you about comparative bone densities or thicknesses of the bone tissues?

Figure 1-4

This is an x-ray image of a person's hand. Note the detailed, high contrast image of the bones, including brighter and darker areas. X-rays can be used to determine whether an individual has osteoporosis by studying the comparative densities of bone areas and noting potential damage.

Want to learn more about the nuclear model of the atom? ***Check out Chapter Five!***

In The Media

Airport x-ray scanning devices are used around the world as a vital component of airport security measures. The devices are used to scan luggage and carry-on items to ensure that accelerants, weapons, and other dangerous goods are not taken onto the plane. In the United States, the National Council on Radiation Protection continues to perform research on the general public to track radiation exposure from every-day devices such as these machines. To date, their studies continue to show that there is only very low radiation exposure from these devices. You can read their most recent findings on their website: www.ncrponline.org

Figure 1-14

Natural Forms of Radiation

The nucleus of an unstable atom can decay, or transform, releasing energy in the form of either particles or waves. There are many types of natural radiation, including exposure to naturally occurring stratospheric radiation when in an airplane and radon exposure from the earth in the form of radon gas. We will focus on the following three forms: alpha, beta, and gamma radiation.

Alpha decay occurs when the nucleus of an unstable atom releases an alpha particle. An alpha particle is positively charged, and is essentially indistinguishable from a helium nucleus. The reason why scientists do not refer to it as a helium nucleus is because at the time alpha particles were discovered, they were not fully understood. It was only much later that it was determined that they were two protons plus two neutrons traveling together. Isotopes of elements that release alpha particles are known as alpha emitters.

Alpha particles carry high amounts of energy, but have low ability to penetrate through substances. In fact, substances as thin as a piece of paper can prevent alpha particles from penetrating through to the other side. Though alpha particles can be stopped by mere paper, if humans inhale or ingest them they can cause enormous amounts of damage.

Uranium-238 is an example of a substance that undergoes alpha decay. Its nucleus is left with two less protons and two less neutrons, so a daughter nucleus is produced. This nucleus forms the centre of the thorium-234 atom. A subatomic change, or transmutation, occurred in the uranium to become a completely different chemical element. You may recall from earlier science courses that it is the number of protons in the nucleus that uniquely defines which element we are referring to.

Beta decay occurs when a beta particle is released from an unstable atom. A beta particle can be either a high speed electron or a proton. If the process of beta decay releases an electron, it is referred to as beta-minus (β -)decay. Release of a proton is called beta-plus (β +) decay.

When beta particles enter a substance, they cause a physical/chemical change. Glass, for instance, becomes darker after being exposed to beta radiation. Most beta particles do not have the energy to penetrate the skin, but constant bombardment of one area of skin with these particles can eventually cause damage. One common form of beta decay is when carbon-14 releases a beta particle and becomes nitrogen-14. Because a nuclear change took place, **transmutation** occurred.

Unstable atoms, as mentioned previously, may have an excess of subatomic particles. However, sometimes there is simply an excess of energy rather than an excess of particles. This is when gamma rays are emitted. A **gamma** ray is a high energy photon with a wavelength of less than 0.1 nanometres. Typically, gamma rays are emitted by the nucleus whereas x-rays are emitted from the electron cloud in an atom.

Gamma rays are often produced alongside the release of alpha or beta particles, especially if the substance emitting the particles is in an excited state. Gamma rays are high energy electromagnetic waves, and as such cause serious damage when in contact with living cells.

When a gamma ray is emitted, the nucleus changes from a higher-level energy state to a lower level. Just as electrons in an atom have energy levels, the nucleus has energy levels. When electrons are in a higher energy level (or state), they release usually a few electron-volts (eV) of energy in the form of visible or ultraviolet light. When a nucleus is in a higher energy state and wants to return to a lower and more stable energy level, it releases energy in the range of a few hundred kiloelectron-volts (keV). The chemical makeup of the atom emitting a gamma ray does not change. The chemical makeup of the atom does change if it emits either an alpha or beta particle. (Note: an **electron-volt** is defined as the energy gained by an electron when it travels through a potential of one volt.)

Figure 1-15

Research Questions: Mammography & Alternatives

Mammograms are not able to confirm the absence or presence of cancer, although mammography combined with pathology confirms or denies the existance of cancer. However mammography is a significant tool in finding abnormal growths that are not at the palpable (sensed by touch examination) stage. What could a doctor, attempting to provide an accurate diagnosis, suggest to a patient who has just received positive test results on her mammogram?

What does a positive test result mean for a mammogram? (Cancer? A calcium deposit? A benign tumour? (What does benign mean?) Something else? All of the above?)

What other types of diagnostic technologies could be used to confirm or nullify the positive test results?

Research and compare rates of breast cancer in males and females of similar ages. Are they the same or different? What have you found?

The Canadian Cancer Society has a particular set of positions with respect to breast cancer screening through mammography. It is important that you become familiar with these positions and talk about these with family members who are among the risk groups for developing breast cancer.

Benefits and risks of screening

Almost every test or procedure carries benefits and risks. The important thing is to be aware of them so that you can make an informed decision that is right for you.

No screening test is 100% accurate but a good screening test is one that results in a decrease in death rates in people with cancer.

Researchers also look for other benefits of screening including improved quality of life or less harmful treatments as a result of finding the cancer early.

Benefits of regular screening

- **Earlier detection of cancer**: In most cases, the earlier a cancer is detected, the better your chance of survival. Early detection may also mean less treatment and less time spent recovering.
- **Reducing the anxiety of "not knowing"**: Many people prefer to have 'check-ups', just like a physical exam with your family doctor.

Risks of regular screening

- **False positive results**: When test results suggest cancer even though cancer is not present. False positives can result in anxiety, stress and possibly painful and unnecessary tests to rule out cancer (that is, to make sure you don't have cancer when the screening test has suggested you might).
- **False negative results**: When cancer not detected by the test even though it is present. False negative results can cause you or your physician to ignore other symptoms that indicate the presence of cancer, causing a delay in diagnosis and treatment.
- **Over-diagnosis**: Some cancers would not necessarily lead to death or decreased quality of life. For example, some prostate cancers never become clinically apparent, meaning that they do not cause any symptoms, nor do they affect life expectancy or quality of life. Men with these tumours may not ever develop symptoms or need treatment for cancer.
- **Increased exposure to harmful procedures**: for example very low doses of radiation from x-ray tests.

What makes a good screening test

The World Health Organization (WHO) suggests reviewing several factors before introducing a test as a screening tool for the general population. These include:

- **Sensitivity**: How effectively the test identifies people who actually have cancer?
- **Specificity**: How often a test gives negative (normal) results for people who do not have cancer?
- **Acceptability**: Will the population who will benefit the most from the test (the "target population") agree to be tested by this method?

Tests that can be used for diagnosis and screening

Some tests that are used for screening can also be used to diagnose or rule out cancer in people who have reported symptoms to their doctors. For example, mammograms can be used for both screening and diagnostic purposes:

- To screen women with no signs of breast cancer, or
- To help diagnose women who do have signs of breast cancer (or rule out cancer in women who have signs of breast cancer)

Your doctor will be able to explain what type of test you are having and why you are having the test.

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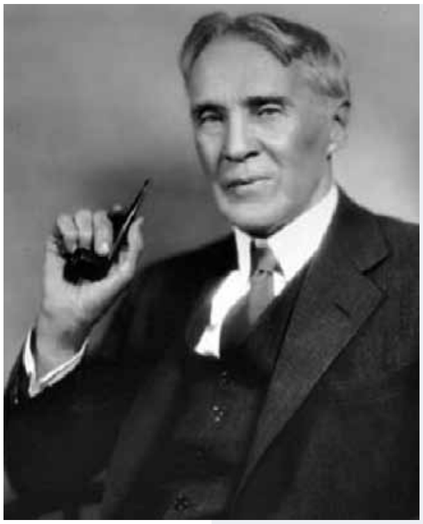
You can find much more information from the Canadian Cancer Society's online information pages found at: www.cancer.ca



Did You Know

N-Rays…Debunked!

Figure 1-16

In the spring of 1903, French researcher Rene Blondlot published a paper explaining the purported discovery of a new type of radiation called N-rays (N for Nancy, his hometown in France). This caused excitement among the scientific community, as the discovery followed closely after x-ray discoveries in 1895. Many scientists published research papers on N-rays in the most prestigious scientific journals in France, and all claimed to have confirmed the existence of the new N-ray experimentally.

Not all physicists were confident in the existence of N-rays, however. One such physicist was Robert Wood (*Figure 1-16*) from Johns Hopkins University in Baltimore, Maryland. In the summer of 1904 he traveled to France to meet Blondlot and observe the experimental apparatus used to confirm the existence of N Rays.

Blondlot chose to show Wood his most well-known demonstration, where he claimed N-rays could be spread out into a spectrum by a prism. The spectrum could be detected by noting small increases in brightness along various points of a phosphorescent strip. Though many experimenters claimed to see these brighter points, others (including Wood) could see no evidence of this. While Blondlot was setting up his equipment to demonstrate the spectrum to Wood, Wood quietly removed the prism and waited for the experiment to be completed. Once again, Blondlot affirmed the existence of the spectrum, which could only be created in the presence of the now-missing prism, and claimed that Wood's eyesight was not good enough to see the results. After repeated demonstrations of this "spectrum," Wood became convinced that experimenters were imagining the results. Without the presence of the prism, a spectrum could not be created, yet experimenters claimed they saw one. Wood concluded N-rays did not exist.

In the end, many researchers reluctantly, and quietly, retracted their published results in what became a rather spectacular blunder in the history of modern physics. Was it a classic case of "believing is seeing"? In science, we often say that "extraordinary claims require the most extraordinary evidence to back them up." Maybe, in the N-ray affair, we learned that valuable lesson yet again. What you may want to do now is to turn up what you can on a very recent example of nuclear science controversy – the so-called "cold fusion" phenomenon. Access information online at: *http://freeenergynews.com/Directory/ColdFusion/* or a rather advanced level discussion at:

www.infinite-energy.com/iemagazine/issue1/colfusthe.html

For more information on Wood, Blondlot, and N-Rays, see the website of the American Physics Society at www.aps.org

Figure 1-17 *Similar to an x-ray machine, a CT scanner has a flat bed for the patient to lie on. The bed slides into the "donut hole," where one section of the ring contains a source of x-rays that radiate outwards in a fan shape. The other section of the ring contains a banana-shaped detector. This ring can rotate around the patient. One full rotation produces one cross-sectional slice or "profile."*

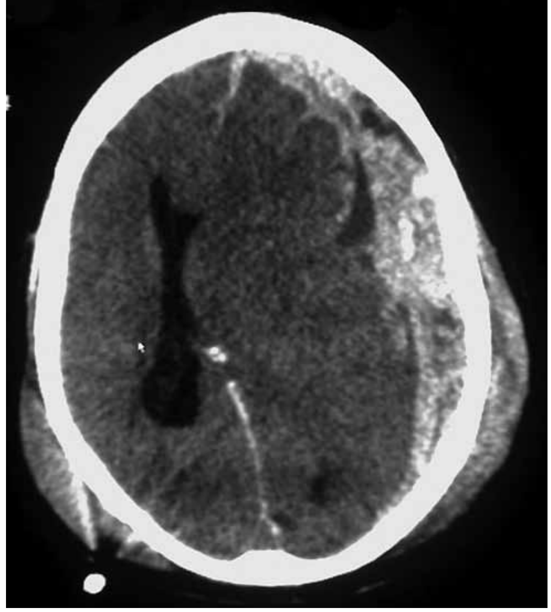


Figure 1-18 *Here is an example of a cross-section of a person's brain produced by a CT scanner. Note that the image is not in colour. Images can be checked by technicians for bone abnormalities, fluid retention, tumours, haemorrhages, trauma or skull fractures among other things. In this image, the darker areas in the upper right indicate the presence of subdural (beneath the skull) trauma or blood clotting.*

activity

X-RAYS and CT SCANS – the LINKS

One of the main differences between x-ray machines and CT scanners is that CT scanners are highly sensitive in detecting abnormalities in soft body tissues. CT scanners have the ability to provide images of internal organs, which x-ray machines cannot.

LIST—list in point form what you know or remember about x-rays and CT scans. If you remember a term but not the definition, make a note of that too.

INQUIRE—share your list with three of your classmates. Have them share their lists with you. Ask each other what connections between x-rays and CT scans were made in your notes and why.

NOTE—put away your lists and give yourself a brief quiz to see what you remember about your discussions and connections made.

KNOW—compare your quiz results to your notes. What do you still need to know or learn?

Computed Tomography (CT)

Computed Tomography (CT) uses x-radiation to create higher resolution images than a simple x-ray machine can produce alone.

Tomography is the process of obtaining a two-dimensional "slice" or cross section of a three-dimensional object, such as a patient undergoing imaging to detect an abnormality.

In CT scans, multiple tomographs, or cross sections (from the Greek words "tomos" meaning "section" and "graphos" meaning a "picture") of a patient can be produced and linked together by a computer to create a three-dimensional image of the area being studied, something not possible with simple x-ray machines. This type of technology is invaluable in determining the presence of cancer, as the images produce measurable pictures of tumour growths. They also clearly show soft tissues (and potential damage), as well as even the tiniest bones or fragments broken off due to injury. CT scans can be used to determine bone mineral density too.

Sometimes, patients are asked not to eat or drink anything for 12 hours before going for a CT scan. This is so that technicians can administer a contrast agent internally, allowing for better diagnosis of certain conditions or diseases. For instance, barium sulfate is sometimes used to make parts of the gastrointestinal tract opaque (dense to x-rays) during a CT scan.

Francine's Case Study Continued:

Francine's doctor ordered a CT scan to confirm the initial diagnosis of a broken neck. The x-ray obtained showed fractures in two vertebrae. The CT scan confirmed those fractures, but was also able to show if there were any bone fragments and where they were located. The doctor then determined if the fragments should be removed, or if they would be able to remain safely.

Cancer Connection

Do x-rays, CT and PET scans increase your risk of getting cancer?

Exposure to x-rays and gamma rays over time, even at low-dose levels, increases the risk of cancer. That is the conclusion of a comprehensive five-year study by a National Research Council (NRC) committee. Keep in mind that this is a statistical risk based on who gets cancer and who does not seem to.

"There appears to be no threshold below which exposure can be viewed as harmless," said Stanford University's Herbert L. Abrams, Professor Emeritus of radiology at both Stanford and Harvard Universities and a member in residence at the Centre for International Security and Cooperation (CISAC) in the Freeman Spogli Institute for International Studies.

However, if you were to ask Dr. David Boreham of McMaster University in Canada the same question, his experimental results suggest otherwise.

"There are lots of people out there making the argument that if you get a single CT scan a year over five years, your risk of getting cancer goes up four or five percent. This is all based on extrapolation from radiation exposure studies of WWII atomic bomb survivors, and that was one single, large dose." Based on his research that studies patients who have x-ray exposures and other diagnostic radiation procedures, Boreham believes that low dose radiation may not be cumulative in its effects at all. In fact, he believes that cells can even adapt to low levels of radiation exposure. This is an exciting scientific debate, and you are encouraged to explore it.

Sources: Stanford University. "Even Low Exposure To X-rays, Gamma Rays Increases Cancer Risk, Study Finds." ScienceDaily 27 October 2005. 29 July 2008 www.sciencedaily.com /releases/2005/10/051027090539.htm

McMaster University. "The Strange Arithmetic of Radiation." Ontario Innovation Trust n.d.. 29 July 2008 www.oit.on.ca/Pages/SStories41-60/StoryMcMasterRadiation.html

CASE STUDY CONTINUED: Francine's Next Steps

Francine now understood with greater clarity what the differences were between x-ray and CT scans. She knew that CT scans provided her doctor with more information than the x-ray had due to its greater resolution of soft tissues. She understood the importance of having more than one type of diagnostic procedure, because each technology could provide her doctor with different information.

Could her doctor obtain a diagnosis without resorting to technology that uses radiation? Not likely with this kind of injury that can have hidden difficulties. She was beginning to realize that radiation-based technology was sometimes the only choice available. As is always the case with radiation exposure, the benefits of undergoing the procedure are weighed against the known risk factors. In this case, Francine and her doctor looked at both the nature of her injury and the consequences of low-level exposure to ionizing radiation sources.

So now that they knew two vertebrae were damaged, what would be the next steps for Francine? Her doctor told her that at least one other diagnostic procedure needed to be performed in order to confirm whether any soft tissue damage had occurred around the spinal cord. But he had other news for her too….

Figure 1-19

Positron Emission Tomography (PET) Scanning

Positron Emission Tomography (PET) usually involves injected radioactive tracer material (radiotracers) to diagnose differences in biological activity in the body. Thus, the source of radiation is internal rather than external (as with x-ray and CAT scanners). The radiotracer collects in the area of body to be examined. The tracer continually radioactively decays, producing **gamma rays** that are detected by the PET scanner. A computer takes the detected ray data and converts it into pictures that show details of organs and tissues. These pictures do not produce clear images of organ and tissue structure (as CT scans would). Rather, the pictures show levels of biological activity in the body. Violet areas (areas of greater chemical activity) are called hot spots and indicate where large amounts of the radiotracer have accumulated. Lighter (blue) areas, or cold spots, show smaller concentrations of the radiotracer and therefore less chemical activity.

The most common radiopharmaceutical (or radiotracer) used in conjunction with PET scans is fluorine-18 (^{18}F). Other radiotracers used are oxygen-15 (^{15}O), nitrogen-13 (^{13}N), and carbon-11 (^{11}C), however these isotopes are typically confined to use in research activities. All of these isotopes emit positrons. A positron has the same mass as an electron, but has opposite charge.

PET scanners are commonly used to detect cancers. Images from PET scanners are created by having the device measure the varying amounts of radiotracer within the patient's body.

Figure 1-20 *PET scans measure body functions such as blood flow, oxygen use, and metabolic rates. This helps doctors evaluate how well organ and tissue systems are working. Oftentimes, medical technicians are able to superimpose CT scans with PET scans from the same diagnostic machine, which correlate information and images from more than one source and leads to greater accuracy in information obtained and diagnosis of conditions. Most modern PET scanners incorporate a CT scanner within them.*

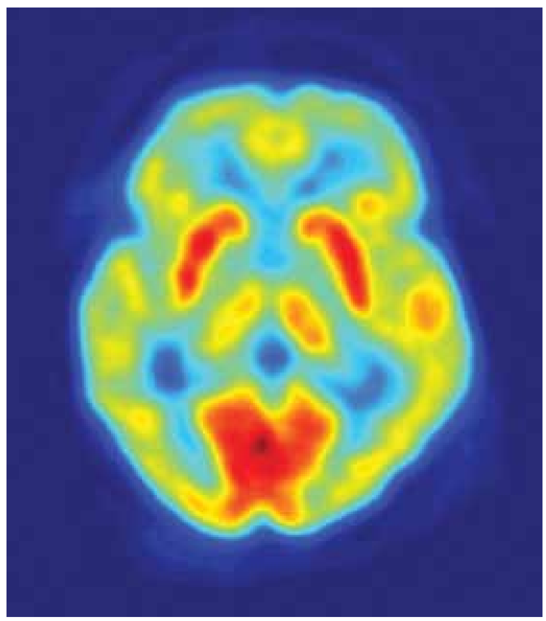


Figure 1-21 *PET scans can be in black and white or in colour. Darker images (on black and white scans) or "hot spots" (red and orange parts of colour scans) indicate the collection of more of the tracer given to the patient. Tracers tend to be added to something like sugar water that is injected, so the tissues and organs that use glucose for energy show radioactive decay. Cancerous tissue uses more glucose than normal tissue, thus the darker images or hot spots can be cause for analysis by the technician.*

Figure 1-22

Career Moves

Nuclear Medicine Technologist

All it takes is two years post-secondary to become a nuclear medicine technologist. In this growing career area, trained individuals use radiopharmaceuticals and specialized instruments to help with diagnosis and treatment of injuries and diseases. As of 2009, there are practicum programs located in Calgary, Edmonton, Red Deer, Regina, Saskatoon, and Winnipeg. After graduation, work can be found in a hospital, private laboratory, community clinic, and in research or teaching institutions.

Career Connection Website – Canadian Association of Medical Radiation Technologists: *www.camrt.ca/english/career/nmt.asp*

Chapter 1 Review: Concepts and Terms

Concepts: X-ray machines and CT (computed tomography) scanners both use radiation in order to create an image for diagnostic analysis. Contrast agents (which are not radioactive) can be used in concert with these procedures to develop greater contrast in the images for better analysis. Arthrography and mammography are specialized forms of x-ray diagnosis.

PET (positron emission tomography) scanners use radiopharmaceuticals (radioactive tracers) to create a tomographic image (cross-sections in the body) for diagnostic analysis. Modern PET scanners have CT technology built into them.

There are many forms of natural radiation – this chapter focused on alpha, beta, and gamma radiation.

Terms of Interest:	
alpha particle	health physics
arthrography	isotope
attenuation	mammography
beta particle	PET (Positron Emission Tomography)
CT (Computed Tomography)	positron
electromagnetic radiation	radiograph
electromagnetic spectrum	radiopharmaceutical
electromagnetic wave	tomography
electron-volt (eV)	x-ray
frequency	UV radiation
gamma ray	

chapter 2

Other Forms of Diagnostic Technology

CASE STUDY CONTINUED: Francine Has Questions About Radiation

Francine knew now that the doctor's initial request for an x-ray was to obtain a quick diagnosis. The doctor ordered the CT scan in order to locate the bone fragments from her injury that first turned up on the initial x-ray image. Next, a neurologist visited Francine and ordered an MRI scan. The results of this procedure confirmed that the second and third vertebrae had two small sections broken off and these sharp bone fragments were dangerously close to the spinal cord. Though she had not been sent for a PET scan or ultrasound, Francine could not help but wonder what the effects from this technology would be on her body in the longer term. Why did she need to get an MRI when she had already had an x-ray and a CT scan? Would she need a PET scan or ultrasound? Did MRI represent another instance of radiation exposure for Francine?

Figure 2-1

Magnetic Resonance Imaging (MRI)

Magnetic Resonance Imaging (MRI), often referred to as magnetic resonance (MR), does not depend on radiation to create images. Instead, MRI devices use powerful **magnetic fields** to align hydrogen atoms in the body. Radiofrequency coils produce high frequency magnetic fields that excite the protons in the nuclei of these atoms. The protons release this gained energy in detectable amounts by creating their own magnetic fields. A computer analyzes these magnetic field signals to produce detailed images of organs, other soft tissues, bone, and almost all other internal body structures with astounding resolution. This type of imaging produces even more contrast detail than that realized by CT scans. Like CT scans, multiple images can be produced and then linked together by a computer to create a three-dimensional image that can then be studied.

The typical contrast agent used in conjunction with an MRI is **gadolinium**. Gadolinium is a ferro-magnetic element, perfect for use in a diagnostic procedure dependent upon magnetic field interactions. Diagnosticians need to be diligent about removing metal objects from the general area where testing occurs, as the objects' magnetic fields could affect the image results.

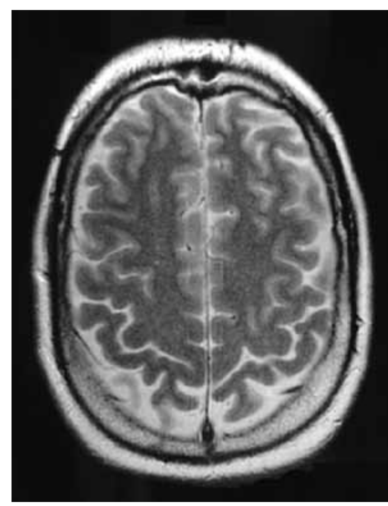


Figure 2-2

MRI scans can be used for both diagnosis and monitoring of conditions. Typically, the distinction between abnormal and normal tissues on an MRI is more easily detected than on a CT scan, x-ray, or even ultrasound. This does, however, depend strongly on the type of study done.

Figure 2-2 *This image of a cross-section of the human brain was produced using MRI . Whether using colour or black-and-white images, however, technicians will look for a contrast in colour or shading. What they look for depends strongly on the scan parameters and the sequence of scans. Technicians look for "hot spots" (or so-called "false colour" images, hot spots can sometimes be coded as being yellow) that may indicate tumour growth. Cold spots (sometimes shown by selecting cooler colours like shades of blue and violet) may indicate normal tissues and fluids.*

Figure 2-3 The MRI machine pictured at left looks similar to a CT scanner in that there is a ring around the patient and bed. In MRI, however, the only moving part is the patient table. Many cross sections or images are taken, and multiple images can be compiled to create a three-dimensional image.

Research & Extension Questions:

1. Why is gadolinium used as a contrast agent for MRI scans? Why wouldn't they use barium? Or cobalt?
2. Discuss with a classmate what the list of general characteristics may be that would qualify an isotope as a "good" choice for use in diagnosis.
3. Could gadolinium be used in PET scans? Why (not)?

Francine's Case Study Continued:

Francine found out that the MRI scan did not involve any exposure to radiation. Though her x-ray and CT scan involved radiation exposure, her doctor assured her that total exposure was so minor it would not affect her overall health. In fact, her total exposure was much less than that received by a business traveller who flies periodically at high altitudes in jet aircraft. Just to provide some background on this issue, according to the Health Physics Society we receive about 3,600 microsieverts of radiation exposure every year from the environment as background radiation. A chest x-ray provides about 170 microsieverts, and a dental x-ray about 7 microsieverts. If you were a very frequent air traveller (say, >120,000 kilometres per year), then you actually receive the recommended yearly dose of radiation just by doing that. For more answers, check out the FAQs at: http://hps.org/publicinformation/ate/faqs/

Figure 2-4

Reality Check

Question | Do Magnetic Fields Created By Power Lines Cause Cancer?

Origin: Various researchers have studied the relationship between the rates of certain types of childhood cancer and the proximity of the children to high-voltage power transmission lines. Over the years, various e-mails have circulated saying that there is a direct link between how close you live to power lines and your risk of getting cancer.

Reality Check: According to Health Canada, research has shown that electromagnetic fields (EMFs) from electrical devices and power lines are not associated with any known health risks.

Many studies have been done on the effects of exposure to EMFs at extremely low frequencies. Though some studies have suggested a possible link between exposure to electromagnetic fields and certain types of childhood cancer, scientists at Health Canada claim that the evidence appears to be very weak.

The International Agency for Research on Cancer has classified electromagnetic fields as "possibly carcinogenic" to humans based on studies of childhood cancer. According to Health Canada, however, the evidence is not strong enough to conclude that EMFs definitely cause cancer in children. They believe that more studies are needed to draw firm conclusions.

Source: Minister of Health. "It's Your Health – Electric and Magnetic Fields at Extremely Low Frequencies." Health Canada April 2004. 29 July 2008
www.hc-sc.gc.ca/hl-vs/iyh-vsv/environ/magnet-eng.php

Figure 2-5 *Although ultrasound may be better known for its use in prenatal care, it is also an effective diagnostic tool for blood and fluid-related problems. In a very specialized technique using dedicated equipment, ultrasound may also be used to detect osteoporosis. Ultrasound does not have the potential harmful side effects of radiation exposure possible from x-ray, CT, and PET scanners.*

Figure 2-6 *An ultrasound image is best analyzed in real time as the image changes on the monitor. A technician uses the real time images to determine whether heartbeats are normal, to analyze the regularity of blood flow, and to determine whether fluids and tissues are abnormal. Still images from ultrasound, in certain particular instances, are studied to analyze abnormalities in bone density or fluid flow.*

Ultrasound

Ultrasound imaging uses ultrasonic sound waves to diagnose various conditions. A transducer converts an electrical pulse into a mechanical vibration – a high frequency sound wave. This sound wave bounces off various surfaces in the body. The transducer registers returning reflected sound waves, and converts them back into electrical pulses. A computer transforms these pulses into an image on a monitor.

Some kinds of tissue or fluid cannot be detected in x-ray images but are locatable with ultrasound technology. A large advantage of ultrasound technology is the ability to produce real-time images in motion format.

The **Doppler Effect** and ultrasound technology can be used to determine blood flow. The Doppler Effect registers the change in frequency with which a wave from a given source reaches an observer if the source is in motion relative to the observer. This ability to determine motion can help diagnose narrowing of blood vessels, clogged arteries, and fetal heartbeats. It is also useful in determining if a structure in the body is fluid-filled (like a cyst) or a more dense mass such as a tumour.

Figure 2-7

Cancer Connection

Sorenson's Tumour-Suppressing Gene

Tumour-suppressing genes are regular genes whose job it is to slow down cell division, repair mistakes in DNA, and tell cells when to die. If these genes do not do their jobs, cells can grow out of control. When cells grow out of control, cancer may form. Approximately 30 different genes like this have already been discovered.

Researchers at the University of British Columbia, headed by Dr. Poul Sorenson *(Figure 2-7)*, have discovered a new tumour-suppressing gene for the most common type of kidney tumour seen in childhood. Their studies have shown that lower levels of this gene, called HACE 1, may contribute to tumour development. As well, restoring levels of this gene within cancer patients has inhibited tumour formation.

This ongoing study will help scientists understand how loss of this gene leads to tumour formation in children, which may then lead to new preventive treatments for patients.

Source: University of British Columbia. "Award Recipients – Trainee Profiles – Fan Zhang." Michael Smith Foundation for Health Research June 14 2005. 29 July 2008
www.msfhr.org/sub-funding-recipients-profile.asp?award_recipient_id=549

Barium Enemas and Colonoscopy

The diagnosis of cancer and other diseases of the colon are usually aided by using an isotope of **barium**. A barium **enema** procedure involves injecting a barium sulphate fluid into the patient's lower digestive tract. While the patient clenches the anal muscles, the **colon** is slowly filled with this liquid. Once that is done, air is injected into the colon to inflate it. The procedure allows for a greater contrast in soft tissues around the gastrointestinal tract when an x-ray radiograph is taken. If a patient is required to undergo a barium enema, fasting and laxatives are prescribed up to two days in advance of the procedure to ensure that the colon is empty and the x-ray image is not blocked by partially digested food particles.

Another diagnostic procedure that can be used instead of barium enemas and x-rays is to obtain a colonoscopy. In this procedure, a small camera at the end of a long flexible tube, called an endoscope, is inserted into the patient's lower digestive tract (via the anus) and is slowly pushed further into the colon right up to the junction of the large and small intestines (at the caecum). Real-time imagery is observed on a television screen or monitor, allowing doctors to pause and examine questionable areas. The flexible tube contains fibre optic light and miniature diagnostic tools for obtaining tissue samples as well. As with the barium enema, patients who participate in this procedure undergo a fasting and laxative regimen two days in advance to ensure an empty colon for observation.

Check out the online colonoscopy activity at www.insidestory.iop.org/insidestory_flash1.html

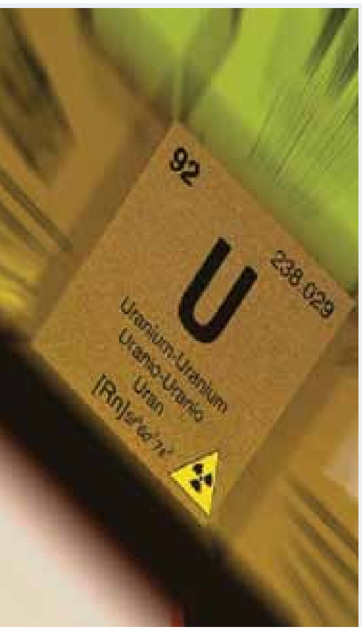


Figure 2-8

Did You Know

Canadian Isotope Production

Producing isotopes for use in medicine was a field pioneered in Canada. Two hospitals in Saskatchewan and Ontario became the first to apply radioactive cobalt to the treatment of cancer in the early 1950s, a technique now widely used around the world. Today the National Research Universal reactor (NRU) in Chalk River (Ontario) is the world's main source for both cobalt-60, a high-activity radioisotope used for cancer treatment, and technetium-99, used for diagnostic imaging, as well as many other isotopes.

The range of isotopes produced at NRU are distributed across Canada and internationally by MDS Nordion, the world's largest medical isotope supplier. Periodically, due to unplanned reactor shutdowns, the world supply of needed medical isotopes from the Chalk River facility has been strained or stopped altogether. On occasion, the very short half-life of certain radioactive isotopes (e.g. fluorine-18) raises particular problems, as these have only hours or days of effective use in such applications as PET scans. How might such a concentration of production constitute a risk to ongoing treatment programs for patients around the world? Might you be able to offer a solution to this dilemma?

internet activity

The Visible Human Project ®: www.nlm.nih.gov/research/visible/visible_human.html

Explore what's available at "A Guided Tour of the Visible Human" website. This is the effort of over a decade of cross-sectional CT and MRI scans of both male and female cadavers compiled for access online to both students and teachers. The Visible Human Project® is part of the U.S. National Library of Medicine's long-range plan to create "complete, anatomically detailed, three-dimensional representations of the normal male and female human bodies." Note that this website does not show abnormalities or diseases on the CT and MRI scans, but it does provide detailed 3D images of healthy humans.

www.dhpc.adelaide.edu.au/projects/vishuman2/VisibleHuman.html

(Java Applet—you decide what cross-section of the Visible Human you want to see!)

www.uchsc.edu/sm/chs/browse/browse_m.html (Male–clickable)

www.uchsc.edu/sm/chs/browse/browse_f.html (Female–clickable)

Medical Isotopes

An **isotope** of an atom is another atom with the same **atomic number** but a different **mass number**. In other words, the two different atoms have the same number of protons and electrons, but the number of neutrons in each nucleus varies. The differing number of neutrons in the nucleus can make the atom unstable, and then the isotope has the ability to release energy in the form of photons or particles. It is these unstable, particle-releasing isotopes that are useful in medical procedures.

We have seen in the previous chapter that contrast agents (which are not radioactive) can be used with some forms of diagnostic technologies. These contrast agents can improve scan results and show more details than without their use. CT scanners can be used in conjunction with a barium contrast agent. This chapter has described the use of the contrast agent gadolinium alongside MRI technology to produce better images.

Some forms of diagnostic technologies can be coupled with the use of a medical isotope, sometimes referred to as a **radiotracer** or **radiopharmaceutical**. Using radiotracers alongside technology can also improve scan results and allow the technician to focus on details of certain organs, tissues, or even bone structure. We have seen in Chapter 1 how there are four isotopes used in conjunction with PET scanners (oxygen-15, nitrogen-13, carbon-11 and fluorine-18).

Each radioactive isotope used in a medical procedure is chosen for its half-life, its ability to be injected or ingested, and its risk potential for side effects (having little to no side effects is the goal). The use of these isotopes can allow for detection of diseases or tumours weeks or months in advance of using the diagnostic technologies alone.

The following is a chart of the different types of radioisotopes used in diagnosis, or treatment, of illness.

Isotope	Half-life	Uses
Arsenic-74	17.9 days	Locate brain tumours
Barium-131	12.0 days	Detect bone tumours
Carbon-14	5730 days	Treat brain tumours
Chromium-51	27.8 days	Determine blood volume
Cobalt-60	5.26 years	Treat brain tumours
Fluorine-18	109 minutes	Ideal for PET scans
Gold-198	64.8 hours	Test kidney activity
Iodine-131	8.05 days	Treat thyroid problems; find blood clots
Iron-59	45.6 days	Test rate of blood cell production
Mercury-197	65.0 hours	Find brain tumours; test spleen function
Technetium-99	6.0 hours	Detect brain tumours; detect blood clots

Figure 2-10
Canadian researchers and the equipment needed to create quantities of the cobalt-60 isotope.

In The Media

Cobalt-60 and the Canadian Connection

Before 1947, radium was considered the best available option for treatment of cancerous tumours. Doctors and treatment specialists realized, though, that radium had limitations when it came to deep-seated tumours in the body. But it was because of an uniquely Canadian research group that cobalt-60 quickly became the isotope of choice for treating cancer patients. Radium was effective only when in direct contact with cancerous tissue—cobalt-60 allowed treatment specialists to create "cobalt bombs" which would attack cancerous growths almost anywhere in the body. By 1951, treatments were being tested in Saskatoon. Eldorado Mining and Refining, a Crown Corporation that owned and operated many of Canada's uranium mines then, quickly retooled MDS Nordion, its radium sales department, to handle the high demand for cobalt-60 worldwide, positioning Canada as a world leader in isotope production and delivery.

Comparing Diagnostic Technologies and Techniques

activity

Concept Map

Sometimes a picture that shows the connections amongst all the vocabulary works better than forming categories to sort the words. **Create a concept map for RADIATION** (like a spider-web that shows how the concepts are interconnected) to link the diagnostic technologies and techniques vocabulary together.

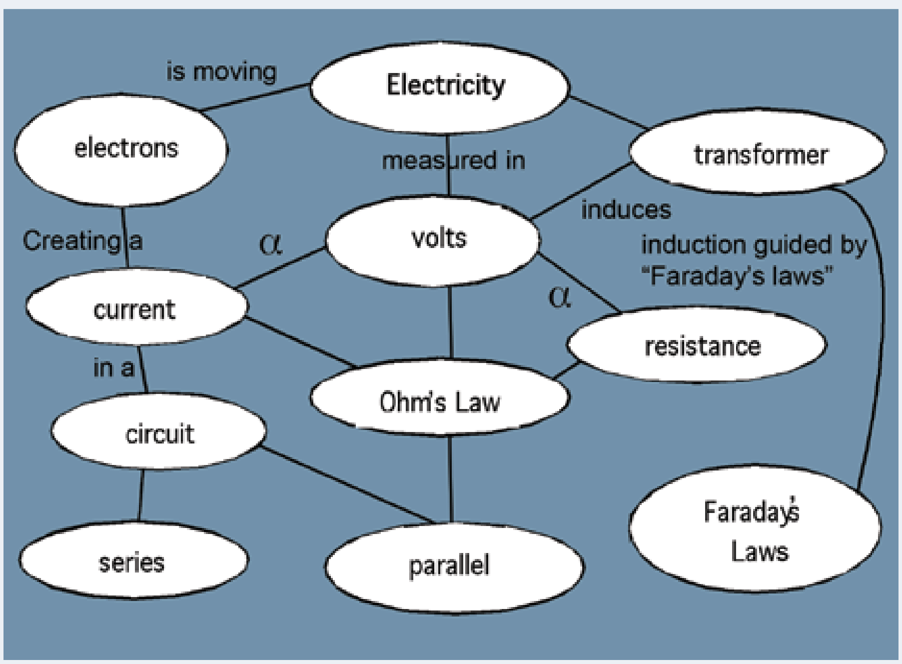


Figure 2-11

This simple example of a concept map shows how the individual thought of the words and concepts within the larger topic of Electricity. Inter-connections between concept "bubbles" are labeled with a word or a phrase to show how the two concepts are related.

CASE STUDY CONTINUED: Francine's Diagnosis

After the technician and the doctor discussed the results of the CT and MRI imaging, Francine's doctor shared the information with her. The MRI showed that the spinal cord had slight abrasions on it due to the bone fragments grinding against it. Thankfully, the spinal cord had not been severely damaged. The CT scan clearly showed where the bone fragments were, and the doctor was confident that with careful surgery, they could be removed.

The MRI showed one more unexpected result—a tumour on the thyroid gland at the base of Francine's neck. Francine was informed that there were various treatment options available to her, including surgical removal of the tumour. She would be provided with details on the various options, and her doctor assured her that with treatment, this isolated growth could be removed completely and most likely without recurrence.

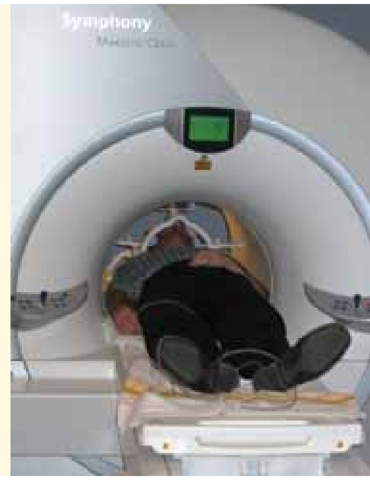


Figure 2-12

Career Moves

Health Physicist

As a health physicist, you participate in both protecting humans from the harmful effects of technologies using ionizing radiation while encouraging its beneficial uses. Career opportunities exist in any field or industry using such technology—nuclear reactor energy plants, research laboratories, hospitals, and defence plants. Typically, health physicists also perform work as environmental consultants for both government and industry when issues such as decontamination and decommissioning of reactors are required.

Career Connection Website – Manitoba Career Profiles:
mb.jobfutures.org/profiles/profile.cfm?noc=2111&lang=en&site=graphic

Figure 2-13

Chapter 2 Review: Concepts and Terms

Concepts: MRI (magnetic resonance imaging) uses high frequency magnetic fields to produce detailed images of organs, soft tissues, and bones—more detailed than x-ray or CT scans. This diagnostic technology is not dependent on radiation to create images.

Ultrasound imaging uses ultrasonic sound waves to diagnose various conditions involving biological functions. Sound waves converted into electrical pulses are transformed by a computer into an image on a monitor.

Two different diagnostic procedures used to analyze the colon were discussed in this chapter: barium enemas and colonoscopy. An enema involves injecting a barium sulphate contrast agent into a patient's anus to create a more detailed x-ray of the region. A colonoscopy involves inserting into the anus, and up into the colon, a long flexible tube with a small camera at the end of it.

An isotope of an atom is another atom with the same atomic number but a different mass number. Medical isotopes, sometimes called radiotracers or radiopharmaceuticals, can be used alongside technology to improve scan results and allow the technician to focus on details of certain organs, tissues, or even bone structure.

Terms of Interest:	
atomic number	gadolinium
barium	HACE 1 gene
cobalt-60	isotope
colon	MRI (Magnetic Resonance Imaging)
colonoscopy	magnetic field
Doppler Effect	mass number
electromagnetic field (EMF)	radiofrequency coil
endoscope	radium
enema	transducer
fibre optic light	ultrasound

chapter 3

Effects of Radiation on Humans

CASE STUDY CONTINUED: Francine Has More Questions

Francine had gone through various diagnostic procedures, confirming not only a neck injury involving two fractured vertebrae, but a thyroid tumour as well. Francine asked her doctor whether her neck injury had caused the tumour to grow. The doctor said that was not the case. The MRI merely picked up something that was already there before the injury occurred. Francine was lucky to have had the MRI when she did, because the tumour otherwise may not have been discovered in time to prevent metastasis (spreading to other regions of the body). The doctor told Francine that once treatment was complete, regular thyroid checkups using ultrasound (shown in *Figure 3-1*) would be necessary. Though Francine knew she would have many questions about the types of treatment available and the technology used for ongoing checkups, she first wanted more details on what effects the CT and x-ray scans would have on her for the long term. The MRI did not involve radiation, but the other two diagnostic procedures did. "What exactly was this ionizing radiation all about?" she inquired within herself.

Figure 3-1

Non-Ionizing Radiation

Any type of electromagnetic radiation that does not carry enough energy to ionize an atom is called **non-ionizing radiation**. An atom becomes ionized when it loses or gains an electron. Ionizing radiation causes a chemical change and thus causes more damage than non-ionizing radiation. Still, observable effects can be tracked from non-ionizing radiation.

Visible light, infrared light, microwaves, and radio waves are some examples of non-ionizing radiation. The light from the sun that reaches Earth is largely non-ionizing radiation, yet some ultraviolet rays (which have the ability to ionize) do reach the surface of Earth as well.

Infrared or laser light can cause burns to skin and damage to eyes, depending on the levels of energy they carry. Laser light energy levels can also be controlled to avoid skin and eye damage. Typical household laser pointers are designed to do no damage to skin. **Microwaves** carry enough energy to heat surfaces, which is why they are used in microwave ovens. Some sources say that the energy levels found near low-frequency electrical fields by power lines can cause nerves and muscles to respond erratically.

Figure 3-2

Did You Know

Many people have concerns concerns about the safety and use of commercially-available laser products. These include DVD players, smoke detectors, being near laser light shows, and laser pointers. A common fallacy is that laser light is in fact amplified sound waves, and constitutes a form of ionizing radiation that can do harm even at the cellular level of tissues. This false reasoning can result in an unwarranted fear of lasers. The better choice is to use laser light under safe, controlled conditions and that means finding out more about the physics behind laser phenomena as a good first step.

Figure 3-3

activity

SunSense

Check out the information you can get from **SunSense** provided online by the **Canadian Cancer Society**. This resource includes helpful information about "sun exposure myths". To obtain a free package for yourself (or for your whole class), go to *www.cancer.ca* and click on the tab that says "Publications." Scroll down in the list to find the SunSense link.

Cancer Connection

Ultraviolet Radiation

In Canada, sunlight is strong enough to cause premature aging of the skin and skin cancer. As the ozone layer becomes thinner due to increasing levels of pollution and chemicals, it protects us less from harmful UV rays and we are exposed to more of them. Thankfully, the production of ozone-thinning chlorofluorocarbons was banned in 1996, helping to protect the ozone layer.

There are three types of UV rays:

- Ultraviolet A rays (UVA) form most of the sun's natural light. They can penetrate deep into the skin and cause wrinkles and aging.
- Ultraviolet B rays (UVB) cause the most damage to our skin. They are the main cause of sunburns as they are nearly 1000 times stronger than UVA rays.
- Ultraviolet C rays (UVC or short-wave radiation) never reach the earth's surface: the atmosphere filters them out.

UV rays cannot be stopped by haze, fog or clouds. Water, sand, concrete and especially snow can reflect, and sometimes increase, the effect of the sun's burning rays. The head, face, neck, hands and arms are areas that are typically left uncovered. It is in these uncovered areas where most skin cancers start. Your risk of getting skin cancer increases if you have had several blistering sunburns as a child; if you regularly work, play, or exercise in the sun for extended periods of time; if you have light-coloured skin, eyes and hair; or if you take medication that makes you more sensitive to UV light (such as birth control pills).

Ionizing Radiation

The nucleus of an atom can decay or transform releasing energy in the form of either particles or waves. **Alpha decay** occurs when the nucleus of a radioactive element, such as uranium, uses the strong nuclear force to release an alpha particle. **Alpha particles** occur naturally, yet have enough energy to participate in nuclear reactions. Alpha particles are exactly the same as helium nuclei, containing two protons and two neutrons each.

When an unstable atom spontaneously decays or transforms, its nucleus releases a **beta particle** and a **neutrino**. The beta particle can be either a positively charged particle (**positron**) or a negatively charged beta particle similar to an **electron**. The neutrino released is electrically neutral. This process of beta decay occurs when the nucleus of an atom has either too many protons or too many neutrons. The weak nuclear force then causes a neutron to be converted into a proton (or vice versa) in order to become stable. In general, beta particles are a form of ionizing radiation. There are some low-energy beta particles that do not cause ionization, however.

Gamma radiation is a form of ionizing radiation, and thus produces a chemical change in the substance through which it passes. Elements with high atomic numbers such as lead have the density to be able to absorb gamma rays and prevent them from penetrating. Note, however, that attenuation coefficients can vary with atomic number. Researchers need to take into account more than just atomic number to determine whether an element will block gamma rays.

All forms of ionizing radiation can destroy or cause damage to **DNA** in cells. Large doses of ionizing radiation have been shown to cause mutations in radiation victims' descendants. Dr. David Boreham, of McMaster University, believes that low levels of ionizing radiation may help protect cells against DNA damage from other causes and help decrease cancer risk. His ideas are controversial and are based on studies done on laboratory mice. Most radiation researchers do statistical analysis of cancer victims from such catastrophic events as the Hiroshima and Nagasaki atomic bombs, the Three Mile Island disaster, and the Chernobyl

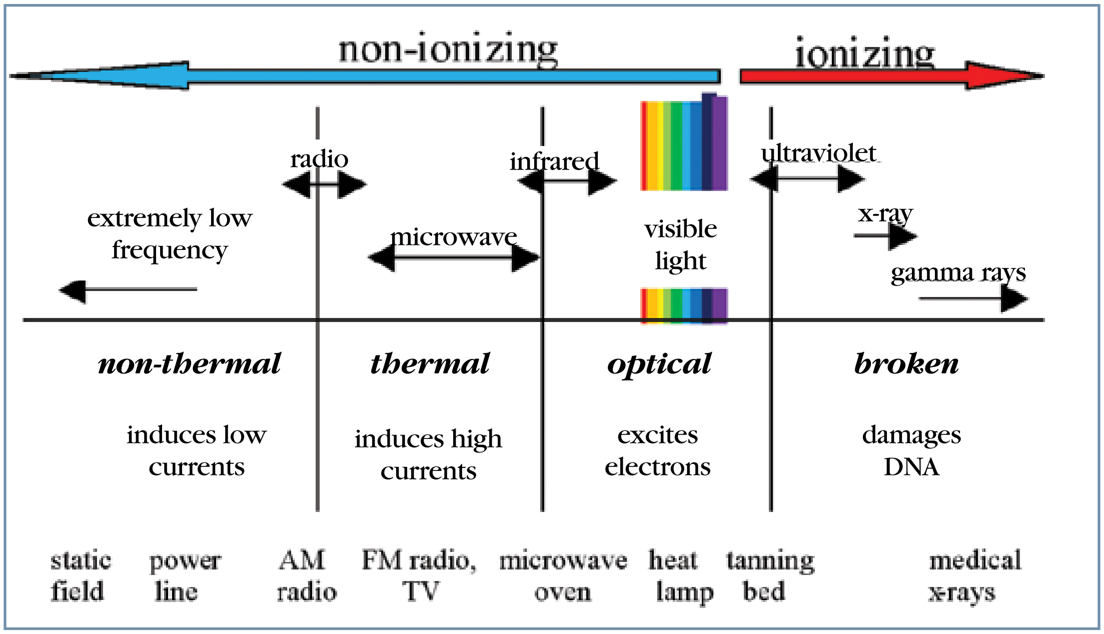


Figure 3-4
The relationship between types of radiation and the electromagnetic spectrum is shown on the chart above.

disaster. Boreham wishes to challenge the notion that sweeping conclusions can be made solely on large-scale radiation dosage statistics.

There is a way to mathematically determine the amount of **gamma radiation** a substance will absorb: the probability of absorption is proportional to the thickness of the substance. This relationship can be expressed as a formula:

Gamma Radiation Absorption Equation: $I(d) = I_0 e^{-\mu d}$

In this equation, I_0 represents the original number of gamma rays (or incident intensity), I(d) represents the number of gamma rays which do pass through a substance of thickness d (measured in cm), e is the mathematical constant 2.71828183 and μ is the linear absorption coefficient. The linear absorption coefficient is a measure of how effectively gamma radiation passes through a material, and will be a function of the kind of material used to block gamma rays. In particular, it strongly depends on the material's density. That is why lead has such a high value when compared to aluminium, and so is a good protective layer for the body in blocking the penetration and transmission of ionizing radiation.

Source: The American Physical Society. "Gamma Ray Absorption Coefficients at 6.13 MeV." Physical Review Online Archive 7 September 1954. 29 July 2008 www.prola.aps.org/abstract/PR/v96/i6/p1563_1

Substance	μ	Substance	μ
Carbon	0.0244	Cadmium	0.035
Aluminium	0.0264	Uranium	0.0459
Water	0.0284	Lead	0.436
Sodium Iodide	0.0350		

Sample Calculation:

A worker has just been irradiated with gamma rays. HazMat teams are on hand to determine whether the levels of radiation were high enough to cause long-term damage. They base their calculations on the assumption that the gamma rays carried 100 keV of energy. At this energy level, μ=0.1692. If the arm muscle of the potentially injured worker is 4 cm thick, compare how much gamma radiation passes through this muscle to a situation where the worker was exposed to x-rays whose energy levels were 30 keV and thus μ=0.3651.

Solution:

First scenario: $I(d) = I_0 e^{-\mu d}$
$I(d) = I_0 e^{(-0.1692x4)} = I_0 (0.5082)$

Second scenario: $I(d) = I_0 e^{-\mu d}$
$I(d) = I_0 e^{(-0.3651x4)} = I_0 (0.2321)$

0.5082/0.2321 = more than twice as much gamma radiation passes through the worker in first scenario compared to the x-radiation in second scenario.

Figure 3-5

Reality Check

Question | Does radiation have a green glow?

Origin: Comic book "logic" encourages us to believe that if you are exposed to radiation, you have a green glow and you become radioactive. Perhaps this stems from the early part of the 20th century, when green glow-in-the-dark watches contained paint that was radium-based. Factory workers who spent many months on the job licking their paintbrushes to form a tip sharp enough to paint the tiny numbers on watch faces eventually suffered from radiation-related illnesses.

Reality: The radium-based paint used for those early 20th century watches contained a phosphor (a transition metal element with glow-in-the-dark properties) that caused the green glow. Radium is both phosphorescent and radioactive, but phosphorescence is what causes the glow. Humans can only register a small portion of the electromagnetic spectrum through sight—the visible light spectrum. Radiation, in all its forms, falls nowhere near that section of the spectrum (with either wavelength or frequency). So, unless the human eye is genetically manipulated to be able to register wave interference from alpha, beta, gamma or x-rays, we will never be able to see a "radioactive glow"…green or otherwise!

Practice Questions:

1. Compare the number of non-absorbed gamma rays for a substance with a thickness of 30 cm, and absorption coefficients of 0.000025 for an energy level of 1000 keV and 0.00027 for an energy level of 120 keV.
2. If a substance that is 10 cm thick has 35 times as much gamma radiation passing through it when the rays carry 90 keV compared to 30 keV, determine the absorption coefficient for the higher energy gamma ray scenario. Assume μ = 0.018 for 30 keV.

Somatic Effects

Radiation damage to living organisms is divided into two categories: somatic and genetic. **Somatic damage** by radiation is damage to any part of the body except the reproductive organs. Somatic damage directly affects the individual exposed to the radiation, and does not deal with after-effects in future generations. Skin that is damaged by excessive radiation radiation exposure may develop cancer later on. Irradiated bone marrow can cause anaemia (low red blood cell count) and therefore fatigue and muscle weakness. Poor digestion and absorption of nutrients can stem from an irradiated gastrointestinal tract. Large doses of radiation cause hair loss and dryness of skin. Over time, large doses of radiation can cause cancer and the formation of cataracts on the lenses of the eyes. The risk of developing these types of somatic damage is usually consistent with the level of exposure to radiation beyond a certain threshold amount.

Did You Know

Hiroshima and Nagasaki, Japan and WWII

On August 6, 1945, the first atomic bomb was dropped on Hiroshima, Japan by the United States. Three days later, another atomic bomb was dropped on Nagasaki. The devastation that was caused by the bombs was far-reaching. Both cities were reduced to ashes and rubble. Thousands of people were killed instantly by the blasts. Doctors who survived the blast and attempted to treat surviving victims were overwhelmed by the magnitude of the injuries. A PBS documentary titled *"The Day After Trinity"* includes interviews with the scientists who participated in the construction of the atomic weapons, and explains the nature of the widespread radiation sickness caused by these explosions.

One day after the Nagasaki bombing, photographer Yosuke Yamahata began to record the devastation in photographs. A painter and a writer traveled with him on this odyssey, recording their reactions. Fifty years after the journey began, these memories in pictures and print are displayed on the Internet for all to see and remember. It is worth your while to ponder this event in world history, and discuss it with friends.

NAGASAKI JOURNEY can be found at www.exploratorium.edu/nagasaki/index.html

Figure 3-6
Nagasaki, August 1945

Genetic Effects

Radiation that causes **genetic damage** directly damages the reproductive organs, and therefore affects any offspring that individual may have after the damage has occurred. Radiation damage is done to genes and chromosomes, which can be passed on to future generations. Studies of survivors of the Hiroshima and Nagasaki bombings and of the Chernobyl survivors in Ukraine have shown that there are increased rates of stillbirths, miscarriages, and infant deaths. If the children survive past the first few years of life, they tend to develop leukemia or microcephaly (slower cranial development), have birth defects (limbs missing, large growths), or mental impairments.

If exposure to radiation was not acute, then genetic effects may be minor or may not appear at all. However, Health Canada acknowledges that exposure to even minute doses of radiation from medical procedures such as x-rays or CT scans can have repercussions on the unborn fetus and therefore it is recommended that no procedures involving ionizing radiation be performed during pregnancy.

Cancer Warrior

www.pbs.org/wgbh/nova/cancer/program.html

Originally broadcast in February 2001, the one-hour NOVA documentary entitled "Cancer Warrior" can be viewed entirely online. The program follows **Dr. Judah Folkman** of the Children's Hospital in Boston, who spent more than 30 years researching ways to curb cancer by cutting off the blood supply to tumours. Follow the growth of a **malignant tumour** from its origin as a single cell until it becomes grape-sized. Learn about the **ground-breaking discoveries** Folkman and his research team made over the years. Though Folkman died in January of 2008, his research forms the basis for many new projects on the cutting edge of cancer research.

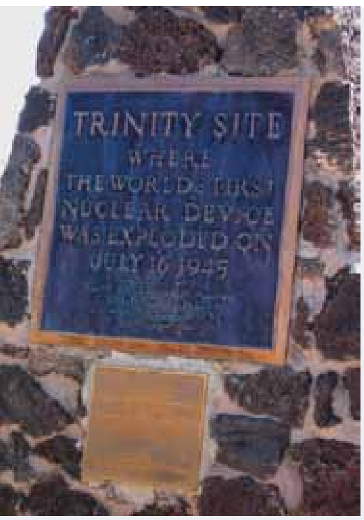


Figure 3-7
Plaque at the original atomic bomb test site in New Mexico

In The Media

"Fat Man and Little Boy" – the Winnipeg Connection

In 1989, Paramount Pictures released the movie Fat Man and Little Boy, which re-enacts the Manhattan Project. The Manhattan Project was a secret wartime initiative that the U.S. government set up (primarily at Los Alamos in New Mexico) with the purpose of creating the world's first atomic bomb. More than 6000 scientists and engineers were involved in the effort in laboratories across the United States.

One of the lead characters in the drama, Michael Merriman, is played by John Cusack. Though the movie makes no mention of it, this character is based on an actual, real-life scientist from Winnipeg. Louis Slotin, a Manitoban and one of a few Canadians participating in the Manhattan Project, was born in 1910. He obtained science degrees at the University of Manitoba, winning gold medals for both physics and chemistry.

One of his duties as part of the Los Alamos research team was to perform experiments with uranium and plutonium cores, determining their critical masses. While performing one of these experiments on May 21, 1946 (almost a full year after the bombings of Hiroshima and Nagasaki), Slotin was involved in a serious accident that occurred in his laboratory that released massive quantities of radiation into the surroundings. Others of the research team were nearby. Nine days after the accident, Slotin died of his injuries derived from a massive radiation dose. Posthumously, he was praised for his own, selfless actions that prevented the death of his colleagues. His family has set up a monetary award for researchers that use safe laboratory procedures.

The Story of Manitoba's Radiation Physicist - Louis Slotin

The Canadian Nuclear Society has an archive publication available that provides a very readable and understandable account of the scientific life and contributions of Winnipegger Dr. Louis Slotin. Thankfully, a reviewer of this site has taken the time to clear up a few errors that have surrounded the criticality incident that claimed Slotin's life.

Check it out at: www.cns-snc.ca/history/pioneers/slotin/slotin.html

Questions:

1. How accurately does the movie portray the criticality incident?
2. How accurately does the movie portray Louis Slotin?

Francine's Case Study Continued

After doing some research, Francine was reassured that though her x-ray and CT scan involved radiation exposure, there would be no long-term somatic or genetic effects. Had she been pregnant, the unborn foetus may have been affected – but her doctor would not have performed the diagnostic procedures in that case. Her next step was to obtain a biopsy of the tumour to determine whether or not it was cancerous. A surgeon would remove a small piece of it for laboratory analysis.

See Chapter 5 page 41 *for a chart of examples for both natural and synthetic (human produced) radiation.*

EXTENSION: Units of Measurement - A Historical Approach

Because ionizing radiation can cause biological damage to both the person exposed to it and to the offspring of that individual, scientists have devised ways to quantify radiation. There are three main measurement methods used: exposure, absorbed dose, and biologically equivalent dose.

Exposure measures the amount of ions produced by x-rays or gamma rays in air. It was the first radiation method to be defined, with the unit of measurement named after one of the scientists studying radiation effects. Though the roentgen (R) is still used today, the Systeme Internationale (SI) unit of measurement for exposure is defined as coulombs per kilogram (C/kg). This unit stems from the method of measurement, whereby a beam of x-rays or gamma rays is sent through a given mass (kg) of dry air at standard temperature and pressure. This beam produces positive ions with a total measurable charge (C). To convert from roentgens to coulombs per kilogram:

Exposure (in roentgens) = $2.58\text{x}10^{-4}$m

In other words, 1 R = $2.58\text{x}10^{-4}$ C/kg

The units of measurement for exposure do not connect radiation effects to living tissue, however. For living tissue, absorbed dose is the energy absorbed from radiation per unit of mass of absorbing material (or living tissue):

$$\text{Absorbed dose} = \frac{\text{Energy absorbed}}{\text{Mass of absorbing material}}$$

The SI unit for absorbed dose is the **gray** (**Gy**), which is equivalent to **joules per kilogram** (J/kg). Another unit, not part of the Systeme Internationale, is the **rad** (**rd**). The word "rad" stands for radiation absorbed dose. To convert from rads to grays, 1 rad = 0.01 gray

Questions:

1. What is standard temperature and pressure? How might the amount of ionization in air due to radiation change as temperature increases? How might the amount of ionization in air due to radiation change as pressure increases?
2. In human tissue, one Roentgen of gamma radiation exposure results in about one rad of absorbed dose. Why is this number (1 rad) an approximation?

The absorbed dose unit was an improvement on the exposure units developed earlier, however researchers soon realized that the amount of damage to living tissue by ionizing radiation varied with differing forms of radiation. The absorbed dose units gave no indication of those differences. To compare damage caused by different types of radiation, the relative biological effectiveness (RBE) or quality factor (QF) is used.

The relative biological effectiveness of a specific form of radiation compares the dose of 200 keV x-rays needed to produce a certain amount of damage to the dose of the specific form of radiation needed to produce the same amount of damage:

$$\text{Relative biological effectiveness (RBE)} = \frac{\text{The dose of 200 keV x-rays that produces a certain biological effect}}{\text{The dose of radiation that produces the same iological effect}}$$

The RBE depends on the type of ionizing radiation and its energy, as well as the type of tissue being irradiated. The RBE for gamma rays and negative beta particles (electrons) is 1, whereas the RBE for protons is 10. The larger RBE value for protons indicates that more tissue damage is done than by gamma rays or beta particles. Alpha particles, protons, and neutrons all have larger RBE values than gamma rays and beta particles.

Sometimes, the RBE and the absorbed dose in rads are combined to form what is called the **biologically equivalent dose**:

$$\text{Biologically equivalent dose} = \begin{matrix}\text{Absorbed dose}\\\text{(in rads)}\end{matrix} \quad \text{x} \quad \text{RBE}$$

The unit of measurement for the biologically equivalent dose is the **rem**, "short for roentgen equivalent, man". Occupational radiation exposure is measured in rems. Typically, there are no observable biological effects if an individual is exposed to up to 25 rems of radiation. (Note that there are government-imposed limits on the amount of radiation workers are exposed to in the workplace – no more than 5 rem is allowable.) To gain some perspective on the rem and the millirem (1/1000th of a rem), here are some statistics: you can increase your total amount of exposure to radiation by one millirem by watching an average amount of television for one year. That is the same amount of radiation you would receive by going on a coast-to-coast flight.

The SI unit for biologically equivalent dose is the **Sievert (Sv)**. One Sievert equals 100 rem.

If exposure to radiation occurs over a period of time, then this exposure is expressed as a **dose rate**, measured in millirems per hour (mrem/hr).

Research Questions:

1. Fiestaware was a popular style of dishes in the 1960s. However, we now know that Fiestaware releases low levels of radiation. Research why, and how much radiation (in rems) is released.
2. How many rems of radiation was Switzerland exposed to when the toxic cloud of radiation blew over their country from the Chernobyl event in Ukraine?

Calculation Questions:

1. An individual is exposed to the following forms of radiation: 20 mrad of gamma rays, 35 mrad of electrons, 10 mrad of protons, and 5 mrad of slow neutrons (RBE = 2). Rank the types of radiation from highest to lowest, according to their biologically equivalent dose.
2. If an individual is exposed to two different types of radiation where the absorbed doses are the same but RBEs are different, which type of radiation—the one with the larger RBE or the smaller RBE—will cause the greater damage?
3. The typical biologically equivalent dose for a chest x-ray is 2.5×10^{-2} rem. If the mass of exposed tissue is 19 kg and the energy absorbed is 5.9×10^{-3} J, what is the RBE for this type of radiation on chest tissue? How does this compare to the RBE for gamma rays?
4. If you stand in an area where the dose rate for an unknown source of radiation is 40 mrem/hr for half an hour, what would your total dose of radiation be? If this radiation was aimed at your chest (as in question #3), with the same mass of exposed tissue and the same amount of energy absorbed, what is the RBE for this unknown source of radiation?

Units of Measurement... another approach

Imagine you are standing outside in the rain. If we were to use SI units for radiation and radioactivity and connect them to something about the rain:

- the number of dust particles that become raindrops would be comparable to exposure, measured in **coulombs per kg**
- the amount of rain hitting you would be like the a**bsorbed dose**, measured in **grays**
- how wet you get would be like the **biologically equivalent dose**, measured in **Sieverts**

CASE STUDY CONTINUED: Francine's Surgical Procedures

The surgery to remove the two bone fragments was a success. Though Francine was quite tired from the whole ordeal, she knew she was one step closer to being completely healed. The biopsy of the tumour was done while she was in surgery for the bone fragments, and she soon found out from her doctor that the results were indeed malignant (cancerous). Now she needed to discuss treatment options and potential side effects with her doctor.

Figure 3-8

Career Moves

Environmental Consultant

Career opportunities exist in any field or industry using radiation technologies—nuclear reactor energy plants, research laboratories, hospitals, and defence plants. Environmental consultants perform work for both government and industry to ensure that standards are maintained that will protect both the environment and the population. When issues like decontamination and decommissioning of reactors are required, environmental consultants are there to ensure that adequate procedures are followed with both cleanup and storage of waste materials.

Career Connection Website – Eco Canada: *www.eco.ca*

Figure 3-9

Chapter 3 Review: Concepts and Terms

Concepts: Electromagnetic radiation that does not carry enough energy to ionize an atom is called non-ionizing radiation. Examples of this are visible light, infrared light, microwaves, and radio waves.

When the nucleus of an atom decays, energy is released in the form of either particles or waves. Both alpha decay and beta decay release particles (alpha particles, and either positrons or beta particles, respectively). Both methods release ionizing radiation. Gamma radiation is a form of ionizing radiation that produces a chemical change in the substance through which it passes.

This chapter included mathematical extensions into how to calculate the amount of gamma radiation a substance will absorb, as well as a foray into the historical progression of units of measurement and their relationships. Somatic damage is any damage caused by radiation to the human body other than to the reproductive organs. Genetic damage is radiation damage caused to the reproductive organs.

Terms of Interest:	
absorbed dose	microcephaly
absorption coefficient (μ)	neutrino
biologically equivalent dose	non-ionizing radiation
dose rate	quality factor (QF)
gamma radiation	radiation absorbed dose (rad)
genetic damage	relative biological effectiveness (RBE)
gray (Gy)	roentgen (R)
incident intensity (I0)	roentgen equivalent, man (rem)
metastasis	sievert (Sv)
somatic damage	

chapter 4
Radiation and Treatment

CASE STUDY CONTINUED: Francine's Treatment

The doctor explained to Francine that she would have to participate in regular checkups after the surgery to track the healing process and to make sure that the cancer did not return. She had been reassured that there would be no genetic effects (future children she may have would not be affected by the radiation treatments), unless she was currently pregnant. The total amount of radiation she had already been exposed to from her x-rays and CT scan were also considered as minimal in comparison to the treatment options. Francine asked questions and listened carefully to the answers given on the two treatment options the doctor had described: radiation, or surgery along with radiation.

Figure 4-1

History of Radiation Treatment

The discovery of x-rays in 1896 eventually led to their use for cancer treatment by 1899. In that year, the literature reported that skin cancer had been cured on an individual with the use of x-ray treatments.

In the early days of using radiation as treatment, **radium** was the source of choice. Dosage calculations were impossible because there was not enough known about radium and the amount of radiation it emitted. Only superficial cancers could be treated with this limited knowledge and "rough-edged" technology. During this time, there were many reported incidences of tissue damage, recurrence of cancers, and death resulting from radiation treatment. Perhaps much of the fear surrounding radiation treatment today stems from these early days of misunderstood and uncontrolled methods.

By the late 1920s, a unit of measurement for dosage had been established. Physicians changed their techniques, from delivering one massive dose of radiation to delivering daily smaller quantities of radiation to the site that needed treatment. Though treatment did extend patients' lives somewhat, there was still not significant enough a rate of survival to warrant confidence in techniques or technologies. Further research into methods and equipment was needed, with technologies that could deliver higher energy levels of radiation.

Soon after World War II had ended, radioactive **cobalt**-60 (synthetically produced from the stable isotope, cobalt-59) replaced radium as the radioactive substance of choice for treatment. Canada played a lead role in this new era of nuclear medicine. Technologies were developed to create mega-voltage outputs of energy and to deliver treatments. With higher energy levels came the ability to target cancers below the skin's surface, decreasing the severe skin reactions of the past. With the advent of the computer age, dosages could be calculated with speed and accuracy, and radiation energy could be delivered to targeted areas with limited to no damage of healthy cells. Physicians and medical physicists soon began clinical trials, to create a database of information to allow for more informed opinions of treatment method choices.

Today, radiation treatments realistically give patients the ability to control and/or cure their cancer.

The Canadian Nuclear Association maintains a large number of online modules for student use that connect you to the world of the nuclear industry. If you have an interest in exploring more of the Canadian history in the field of nuclear medicine, check out:

cna.ca/curriculum and look for the links to "Nuclear Technology at Work" activity

A Personal Cancer Connection

Have you, or has anyone in your family or circle of friends, been diagnosed with cancer?

What kinds of treatment did that individual go through?

What kinds of side effects did they have?

Did it affect their daily life?

How has their struggle with cancer inspired you?

Did You Know

Chlorinated Drinking Water and Cancer Risk

Figure 4-2

Question: *Is your water source chlorinated?*

For the past few decades, researchers have been studying the link between chlorinated water and cancer. Most studies show that long-term usage of chlorinated water leads to a slightly increased risk of cancer, particularly bladder cancer. Currently, it is believed that the benefits of chlorination outweigh the slight increase in the risk of developing cancer.

Humans have been chlorinating water to make it safer to drink for over 100 years. Using chlorine to disinfect water and kill microbes has prevented many illnesses. In 2000, the improper care and treatment of well water in Walkerton, Ontario resulted in more than 2300 illnesses and 7 deaths. Chlorine not only kills microbes at the treatment station, but its effects last as the water travels from the station to your tap, ensuring the safety of the water you drink.

Problems arise when chlorine reacts with plant matter that has not been properly removed from the water to be treated. Better filtration methods and more accurate determination of the amount of chlorine needed decrease risks associated with chlorination.

Ultraviolet (UV) light treatment is currently being used in Winnipeg, Manitoba in parts of its water treatment system. This type of treatment is effective against most microbes, but is less effective when the water is murky. The effects of UV light treatment do not last from the station to your tap, so this type of treatment is still used in combination with chlorination for better results.

Source: Author Unknown. "Chlorinated Water." Canadian Cancer Society 15 May 2008. 29 July 2008 www.cancer.ca/ccs/internet/standard/0,3182,3172_372124__langId-en,00.html

Radioisotope Therapy

Figure 4-3

Radioisotope therapy works by using an isotope as a source of radiation. The radiation source is combined with technology that sends photons, electrons, neutrons, protons, or ion beams to damage the DNA of cells at the atomic level. Cancer cells generally reproduce more and faster than normal healthy cells. Cancer cells also have a lesser ability to repair cellular damage than do normal healthy cells. Thus, when DNA damage occurs through irradiation, this damage is inherited in the next generation of cells. Cancer cells either slow in reproduction or die altogether.

There are three main types of radiotherapy: brachytherapy, systemic radiation, and teletherapy. Each of these types of therapy has advantages and disadvantages, and is more suited for treating particular types of cancer.

Figure 4-3 *A "seed" used in brachytherapy is smaller than a grain of wheat (pictured here) and thinner than pencil lead. Palladium-103, iodine-125, and cesium-131 are typical isotopes used in seed implants. These isotopes all emit a very low energy radiation. Nevertheless, patients are cautioned during treatment not to come into contact with pregnant women or children for the first few days, to ensure they are not exposed to radioactive decay.*

Internal Methods of Treatment: Brachytherapy

Brachytherapy is sometimes referred to as sealed internal radiation therapy, or implant therapy. Tiny radioactive pellets or seeds are implanted in a patient's body, surrounding the cancerous growth. Brachytherapy is designed to deliver a concentrated dose on or near the tumour in a short amount of time. Anywhere from 40 to 60 implants or seeds may remain in the patient's body or be removed after temporary treatment has occurred. Removal depends upon the type of cancer being treated. Temporary implants remain in the patient's body from several hours to several days. During this time, the patient is isolated in a hospital room.

Typically, anaesthesia is required to perform implantation. Most patients tend to feel little to no discomfort with brachytherapy. When implants are held in place with applicators there is some discomfort, but patients are able to return to their normal routines within a few days of treatment.

Figure 4-4
Above is actual radiograph showing the arrangement of radioactive pellets around a prostate cancer tumour.

Cancer Connection

Photodynamic Therapy

Within the past 8 years, a relatively new treatment for cancer has been developed—photodynamic therapy. This process involves injecting the patient with a light-sensitive chemical. The chemical travels to the faster-growing cells within the body (cancerous cells). A laser is used to activate the chemical once it is residing in the cancerous growth (*Figure 4-4*), and the chemical then literally destroys cancerous cells.

This technology is far less invasive or damaging than other techniques, is simple to use, but is still quite expensive. Photodynamic therapy works best with cancers of the skin, lungs, esophagus, brain, and bladder.

Figure 4-5

Question:

Would there be complications if this technology were used to treat children?

Internal Methods of Treatment: Systemic Radiation

Systemic radiation therapy is also called unsealed internal radiation therapy. In systemic radiation therapy, the patient is given a radioactive drink, pill, or injection. The radioactive source travels throughout the body and collects at the spots where faster cell growth is occurring (cancerous cells). As time progresses, the radioactive source releases energy and decays, killing cancerous cells and leaving the body. This type of therapy is not painful. Radiation therapists discuss precautions the patient may need to take as the radiation leaves his/her body over the course of a few days. Until the high levels of radiation leave the patient's body, (s)he may need to remain isolated in a hospital room.

Figure 4-6

Figure 4-6 *Radioactive iodine capsules are sometimes given to patients to treat thyroid cancer. An increased incidence of thyroid cancers in Ukraine and the surrounding countries of Belarus and the Russian Federation has been linked by some researchers to the Chernobyl nuclear disaster of 1986. The population most affected by this increase were children at the time of the reactor explosion and fire and were living in close proximity to the Reactor #4 complex. Many scientists accept the position that if a potassium iodide pill had been given to people immediately after exposure to the radioactive fallout, the number of cases of thyroid cancer would have been dramatically reduced. Iodine concentrates itself in the human thyroid gland, and at a more rapid rate among growing children than adults.*

Figure 4-7 *A gymnasium near Chernobyl.*

Figure 4-8 *A chemistry classroom in the "no go zone" near the Chernobyl site.*

In The Media

The Chernobyl Incident… Two Decades Later

In 1986, the world's worst nuclear disaster of a civilian nature occurred in Chernobyl, Ukraine. On April 25, workers were preparing to shut down Reactor #4 for regular maintenance. They decided to perform a safety test of the electrical grid to determine if enough energy was there to keep the reactor core's cooling system running. They turned off the emergency cooling system, and what occurred after that was a series of operational errors and results of design flaws that led to a power surge, a hydrogen and steam explosion, and the world's largest nuclear disaster.

Over the next few days, fallout dropped on Belarus, Ukraine, The Russian Federation, Poland, and Sweden. Sweden's scientists were the first to alert the world of the disaster, as the Soviet Union at the time was remaining officially silent.

Two people died in the explosion and twenty-nine firemen died in the following week. The deaths of the firemen could have been prevented, as they were sent to the site without proper radiation protection.

Today, long-term effects of the radioactive isotope release are still being studied. Children, both those who were near the site when the explosion took place and the following generation of children, have had a statistically significant increase in thyroid cancers. Nearly two thousand cases have been reported thus far. The ongoing list of diseases occurring among the more than 200,000 individuals sent to clean up the site is staggering—more than 4,000 have died from radiation exposure, and more than 170,000 suffer from various chronic illnesses. These recovery operation workers received doses between 0.01 and 0.5 Gy (grays). This cohort is at potential risk of late consequences such as cancer and other diseases and their health will likely be followed closely for decades to come.

The last working nuclear reactor at Chernobyl was shut down in 2000. Though the damaged reactor and the ensuing rubble were quickly enclosed in a concrete and steel tomb, that structure is now crumbling. Ukraine hoped to complete the re-sealing of this tomb by the end of 2008.

Note: The photographs are by David McMillan of Manitoba, who first visited the Chernobyl Exclusion Zone in 1994, eight years after the accident.

Source: Mulvey, Stephen. "The Chernobyl Nightmare Revisited." BBC News 18 Apr. 2006. 29 June 2008
news.bbc.co.uk/1/hi/world/europe/4918742.stm



Photographing in the Chernobyl Exclusion Zone

David McMillan

In 1986, because of poor design and human error, one of four reactors near the Ukrainian city of Chernobyl* exploded. The radioactive contamination was widespread, but it was considered so severe in an area extending 30 kilometres around the damaged reactor that 135,000 people had to be evacuated. I became interested in visiting what became known as the Chernobyl Exclusion Zone after reading a 1994 magazine article about the area's post-accident condition. After many telephone calls and faxes, I was able to gain entry and was allowed to photograph freely. I soon recognized that the subject was diverse and complex, offering the opportunity of making photographs that couldn't be made anywhere else. I never expected to return more than once or twice, but after each subsequent visit, I discovered new possibilities which encouraged me to return. Within the millions of acres of the exclusion zone, there are fields left to lie fallow and cities and villages where the vestiges of the defunct Soviet Empire and the everyday remnants of the lives of the former citizenry remain. Superimposed on this is the proliferation of nature and the deterioration of the built environment – all blanketed with unseen radiation. Every time I've returned to photograph I've realized the subject is larger than my original conception. Within this area, virtually untouched by civilization since the 1986 accident, there was a kind of change that was the result of the passage of time and the inexorability of nature. For the past several years, I've photographed almost exclusively in the city of Pripyat. Once home to 45,000 people, it was the largest population centre within the exclusion zone. It was built to house the workers from the nearby nuclear power plant, and several apartments were still under construction at the time of the accident. Pripyat has many schools, kindergartens, playgrounds, hospitals, and cultural facilities. The city was considered one of the finest places to live in the former Soviet Union, but it will never be lived in again. Although the geographical location for my work has become circumscribed, the photographic possibilities still seem rich and varied.

David McMillan is a photographer who teaches at the University of Manitoba's School of Art. As of 2008, he has photographed in the Exclusion Zone 14 times.

* The English translation of the Russian word is "Chernobyl." Since Ukraine established its independence from the Soviet Union in 1991, the Ukrainian spelling is translated as "Chornobyl."

activity

Flashlight "Beamlets"

Choose two classmates to help you. Each person should have a flashlight of differing dimensions and power, and should stand in different spots around the classroom. Attempt to illuminate Figure 4-7 on page 34 and nothing else.

What problems occur?

What variables do you need to control or change to obtain a better result?

How do these results help in understanding IMRT?

Figure 4-9 *An image of the Clinac Linear Accelerator Treatment Machine. Note how the source of high energy beams rotates around the patient.*

External Methods of Treatment: Teletherapy

Teletherapy, also known as external beam radiation therapy, uses a machine outside of the body to direct radiation at the cancer and surrounding tissue. This type of therapy is widely used to treat most types of cancer. A linear accelerator, or "linac," produces a beam of high energy x-rays or electrons. A technician, in conjunction with an oncologist and a medical physicist, plans the size and shape of the beam as well as the amount of time the patient is exposed to the beam.

Because this form of treatment uses an external source of radiation, surgery is not necessary. However, teletherapy may be combined with other forms of treatment such as brachytherapy (depending on the type of cancer).

Proton beam therapy is a similar treatment method, using protons instead of x-rays or electrons. The advantage of proton beam therapy is that it is easier to control the size and shape of the beam, reducing damage to normal healthy tissue surrounding the cancerous tissue. Not all hospitals have access to the equipment needed for this type of treatment, as it is more expensive than the classic teletherapy procedure.

Intensity Modulated Radiation Therapy (IMRT) is a particular kind of external beam therapy, which allows radiation to be shaped specifically to a tumour's size and shape. Instead of one intense beam, the beam is broken up into smaller "beamlets," with each smaller beam's intensity individually adjustable. This increases the chance for a cure while decreasing damage to healthy tissues.

Francine's Case Study Continued:

Francine and her doctor decided that it was impossible to perform surgery to remove the tumour. The tumour was not uniform, and chances were good that surgery would be unsuccessful to remove the tumour in its entirety. But what was the best option? Systemic radiation? Teletherapy? Some combination of both? Francine needed more information to make a more informed decision.

Reality Check

Question | Is a barium enema dangerous?

Origin: A high level of discomfort is associated with a barium enema procedure. Placing radioactive liquid into an orifice in your body has led people to believe that this is dangerous to your health.

Reality: Barium is not radioactive. According to Health Canada, a barium enema, though uncomfortable, does not pose any significant health danger to the patient unless there is a small tear in the gastrointestinal tract. On rare occasions, the act of blowing air into the gastrointestinal tract during the barium procedure may cause a tear in the lining. If there is a tear in the lining, there is a chance of the barium sulphate liquid leaking into the intestinal area. If this occurs, surgery must be performed and antibiotics given to prevent infection.

Rarely, a patient may experience constipation as a side effect after the procedure. Drinking lots of water will eventually take care of this problem. After having a barium enema, most patients will have light-coloured stool for two to three days afterward, and will feel fatigued. Drinking water to expunge the last remaining amounts of barium sulphate from the gastrointestinal tract is recommended. Fatigue is dealt with by obtaining more rest.

An alternative to the barium enema is to have a colonoscopy, though currently more details are seen through the barium enema contrast radiographs than through colonoscopy procedures. This may change as technology and training improve.

Source: MediResource Clinical Team. "Barium Enema: Lower GI (gastrointestinal) Series - Lower GI Exam." MyFox Dallas n.d.. 29 July 2008
health.myfoxdfw.com/TestFactsheet.aspx?id=10&pg=1#S4

Figure 4-10
X-ray of a colon with a barium contrast agent injected

The Gamma Knife

Neurosurgeons, radiation oncologists, and medical physicists team up to carry out a procedure known as gamma knife surgery (GKS). In this procedure, a patient is fitted with an almost helmet-like contraption called a collimator. The collimator helps guide the technology to pinpoint a brain tumour's location. Up to 201 different sources of the cobalt-60 isotope are used to irradiate the tumour, inundating it with a single high dose of ionizing radiation in a small amount of time. Typically, patients remain in the hospital for a day if complications do not arise. They resume their normal activities within a couple of days of having the procedure. No actual knife is used during the procedure.

The individual beams entering each hole do not have enough energy to damage the normal tissue. When these beams meet at a focal point (the tumour), they have a combined effect powerful enough to deliver a deadly dose of radiation to the cancerous cells.

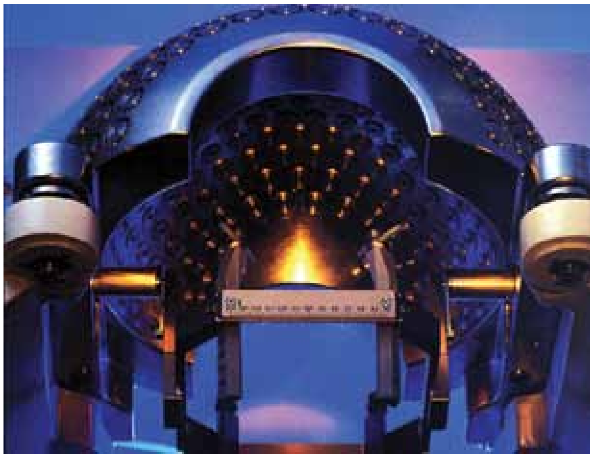


Figure 4-11
The picture above is of a collimator. The collimator serves two purposes: it holds the patient's head still, and it guides the gamma rays through small openings found throughout the surface of the half-sphere.

Gamma knife surgery has benefits over the use of linear accelerators (linacs) to deliver radiation treatment. Rather than having multiple visits with lower doses of radiation delivered in fractions (fractionated treatment), GKS delivers one dose in one visit with outpatient processing happening within 24 to 48 hours.

The first gamma knife, invented in Sweden, was installed in a private hospital in Stockholm in 1968. The United States installed its first gamma knife in Pittsburgh in 1987. Winnipeg became home to Canada's first gamma knife equipment and GKS program in 2003, with Quebec City obtaining one in 2004 and Toronto in 2005. This technology is used only for intracranial conditions.

Questions For Further Research:

1. Which type of radiation therapy discussed in this chapter is the least invasive? Which one has the least impact on quality of life immediately after treatment?
2. Why do you think it took more than 30 years to obtain gamma knife technology in Canada from the time of its invention? Justify your answer.
3. What types of treatment is your water plant using to make sure drinking water is safe? How have methods changed with time? Acknowledge your sources of information.
4. Research the Three Mile Island disaster that took place in Pennsylvania in 1979. Discuss the similarities and differences between this disaster and the Chernobyl disaster, both in terms of damage to the environment and in how the government handled the public health after that. Acknowledge your sources of information.

Figure 4-12

Career Moves

Radiation Oncologist

A radiation oncologist works together with physicists and technicians to develop a radiation treatment plan for cancer patients. In consultation with the patient, decisions are made as to whether and which type of radiation treatment is needed, which particular part of the body will be irradiated, and how long treatment will last. The oncologist has expertise in cancer management, and is with the patient throughout the treatment process and afterwards, assessing treatment success and side effects.

Career Connection Website – Canadian Association of Radiation Oncologists
www.caro-acro.ca/site3.aspx

Figure 4-13

CASE STUDY CONTINUED: The Final Decision

The treatment plan that Francine and her doctor agreed upon to eradicate the thyroid tumour was a combination of systemic radiation and teletherapy. Francine's systemic radiation therapy was the ingestion of radioactive iodine capsules, the same effective treatment given to many people who suffered from the Chernobyl disaster in the Ukraine in 1986. The iodine capsules were added to her treatment plan to ensure that any cancerous cells left behind by teletherapy treatments would be obliterated. Her hospital stay was brief—only two weeks—and her side effects were manageable. She felt nauseous and weak after each of her two teletherapy treatments. The iodine pills left her with a strange taste in her mouth and no appetite for food. When she did eat, she occasionally had difficulty keeping the food down. She noticed, too, that she tired more easily. Her doctor had alerted her to all of these side effects before her treatments, so she was fully prepared for them. She also knew that with time they would reduce and disappear—in about a month.

Chapter 4 Review: Concepts and Terms

Concepts: A summary of the history of radiation treatment from the early 1900s began this chapter. Radioisotope therapy was then described as an external treatment method using an isotope as a source of radiation for treatment of cancer cells. Cancer cells either slow in reproduction or die altogether with this treatment.

Brachytheraphy is an internal treatment method, which is designed to deliver a concentrated dose of radiation on or near a tumour in a short amount of time. Typically, anaesthesia is needed to perform the implantation of a brachytherapy seed.

Systemic radiation therapy involves the patient ingesting a source of radiation that collects at cancer cells, killing them. Until the high levels of radiation leave the patient's body, the individual may need to remain in a hospital room.

Teletherapy uses a machine outside of the body to direct radiation at cancer and surrounding tissue. Though surgery is not necessary, teletherapy may be combined with other forms of treatment such as brachytherapy.

Gamma knife surgery uses extremely precisely aimed ionizing radiation, usually from cobalt-60, to inundate a tumour with a single high dose of radiation in a small amount of time. This type of treatment delivers one dose in one visit, whereas teletherapy may involve multiple visits and doses.

Terms of Interest:	
anaesthesia	intensity modulated radiation therapy (IMRT)
barium enema	intracranial
biopsy	linear accelerator (linac)
brachytherapy	neurosurgeon
cobalt	photodynamic therapy
collimator	radiation oncologist
colonoscopy	radioisotope
esophagus	radium
fractionated treatment	systemic radiation
gamma knife	teletherapy

The image here is of a “creation mural” inside one of the schools in Pripyat, Ukraine. The photograph was taken in 2003 by Winnipeg arts professor Dr. David McMillan, who has an interest in documenting the “return to nature” of the human-constructed world in and around the Chernobyl nuclear power facility. The so-called 30-kilometere Exclusion Zone surrounding the science city of Pripyat is still so radioactive, humans cannot live there for the foreseeable future. This is a good opportunity to assess the benefits and risks of operating a nuclear facility without the necessary safeguards against the release of radioactive isotopes. Many more images and commentary can be found online at:
http://home.cc.umanitoba.ca/~dmcmill/index.html

chapter 5
Radioactivity

CASE STUDY CONTINUED: Life After Cancer

Six months after Francine's treatment plan was completed, she returned to her doctor for another MRI. The scan showed that the tumour was completely eliminated. Her doctor informed her that she should come in after a year had passed to ensure the tumour would not reappear in that time. Her thyroid would continue to be monitored by regular ultrasound appointments over the next five years, along with her annual physical checkup. Because the cancer had not metastasized, Francine had an excellent chance of staying cancer-free.

Figure 5-1

A History of Radioactivity

While Roentgen was busy announcing his discovery of x-rays, French scientist Henri Becquerel was studying substances for the property of fluorescence in 1896. Fluorescence is a physical property of a substance that causes it to glow brightly when exposed to light. Becquerel studied the levels of fluorescence by placing the substances on photographic plates and recording the phenomenon. On a particularly cloudy day, Becquerel wrapped the photographic plates carefully and placed it in a drawer along with the substance he was studying – a compound containing **uranium** oxide.

Later, Becquerel wanted to use the plates for further fluorescence investigations. He discovered, though, that the plates that were in the drawer with the uranium compound were fogged – as if they had been exposed to sunlight. Since that had been impossible – he had wrapped them too carefully for that to occur – he concluded that the uranium compound was emitting some kind of invisible ray. This was the first recorded discovery of natural radiation. It would be two years after his discovery that Marie and Pierre Curie would report similar findings with the element **radium**. By then, the worldwide scientific community became interested in the phenomena associated with radioactivity.

The Curies, who were Polish scientists, were studying the natural radiation emitted by uranium compounds. They believed that there were other elements that were radioactive. It was through their experiments that both radium and polonium were discovered. Both of these elements are more radioactive than uranium.

Radium became a natural source for gamma rays and was used well into the 1950s. In the mid 1940s, synthetically produced sources for gamma rays started to replace the use of radium. These synthetically produced substances – cobalt and iridium – were cheaper to process.

The early studies of radioactivity led to many laboratory-related diseases, including loss of limbs and loss of life. Researchers diligently recorded the effects of radiation on living tissue at their own personal expense. It is through these forays into radioactivity and radiation that the area of health physics began to emerge – to promote the study of radiation, radioactivity and its effects, and to promote safe procedures in the handling, storage and experimentation with these substances.

Figure 5-2

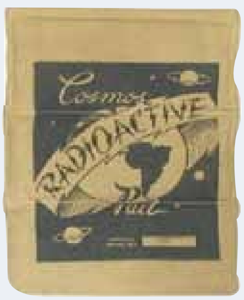


Figure 5-3

Cancer Connection

Radium Cures Everything!… Or Does It?

Once radium was discovered, it began to be studied in detail in the early 1900s. Many scientists believed that the radioactive property of radium could help cure many ailments—toothaches, arthritis, PMS, stomach disorders, high blood pressure, goitre, cancer…you name it, and radium could cure it. Soon, medical doctors in hospitals were ordering patients to drink radium-laced water. Other patients were prescribed radium rub therapy, where radium ore was literally rubbed on a wound or sore area of the body. Dr. John Harvey Kellogg, founder of the Kellogg cereal company, set up a radium spa where patients could come for a day of radium treatments that included radium ore mud baths, breathing in radioactive steam, and finishing off with a refreshing radioactive glass of water.

Companies wanting to cash in on the cure-all craze began selling products such as **Radithor**, "Certified Radioactive Water" that was marketed as a cure-all as good as a radium spa treatment – but it was less expensive. Henry Cosmos invented the **Cosmos Bag**, a cloth bag filled with radium ore powder. Householders could wrap this bag around their arm, leg, or neck to ease pain and rid themselves of arthritis.

See other examples of radium-based "cures" at www.orau.org/ptp/collection/quackcures/quackcures.htm

Nuclear Model of the Atom

All substances are composed of **atoms**, the basic unit in particle theory. According to the nuclear model, an atom consists of a nucleus surrounded by electrons. The nucleus contains subatomic particles called **nucleons**. Both protons and neutrons are considered nucleons as they are located in the nucleus. **Electrons** have a negative charge; **protons** have a positive charge; **neutrons** are neutral and carry no charge.

The **strong nuclear force**, one of the four fundamental forces of physics, holds the nucleus together—it would have to be strong to force protons and neutrons to stay together in an incredibly tiny space. It is the **electromagnetic force**, another of the four fundamental forces, which holds atoms together and keeps electrons surrounding the nucleus. The electromagnetic force manifests itself through forces between charges (such as those between protons and electrons). This force is what determines atomic and molecular structure—the other three fundamental forces are negligible influences on structure.

Atoms are electrically neutral, containing the same number of protons and electrons. If an atom gains or loses electrons, and thus becomes negatively or positively charged, it is no longer an atom but an **ion**.

Atoms of the same element have the same number of protons and electrons, but can have differing numbers of neutrons in the nucleus. Variations of atoms of an element based on neutron-count are called **isotopes**. Isotopes of an element have the same **atomic number** as the element. The atomic number of an element represents the number of protons an atom of the element has. For instance, carbon has an atomic number of six. Isotopes of an element have differing **mass numbers**. The mass number of an element represents the total number of nucleons in an atom of the element.

Typically, one isotope of an element is more stable than other isotopes for the same element. If an isotope is unstable, it can radioactively decay and release an alpha particle or a beta particle (see Chapter 1) to become more stable. An isotope can also become more stable by releasing energy in the form of gamma rays.

Carbon has three naturally occurring isotopes: carbon-12, carbon-13, and carbon-14. Both ^{12}C and ^{13}C are stable. ^{14}C is the isotope of carbon that is used for radioactive carbon dating.

Uranium exists in nature in three forms: uranium-238 (almost 99% of all uranium), uranium-235 (almost 1% of all uranium), and uranium-234.

Cobalt exists naturally as cobalt-59 as we mentioned in an earlier chapter. However, with more than 22 radioactive isotopes of cobalt from which to choose from, there is one that became widely used in radiation therapy: cobalt-60. This isotope of cobalt is synthetically produced in Canada in reactors under licence from Atomic Energy of Canada.

Molybdenum has seven naturally occurring isotopes with mass numbers 92, 94, 95, 96, 97, 98, and 100. The isotope molybdenum-99 (^{99}Mo) is synthetically produced and is a vital part in the process of manufacturing radioactive isotopes for medical purposes.

Reality Check

Question | Does Food Become Radioactive When Irradiated? When Heated in a Microwave?

Origin: The most likely cause for these concerns stem from misuse of the microwave oven. The first microwave oven was put on the market in 1947 by the Raytheon Company of the United States. The oven stood 5½ feet tall, weighed over 750 pounds, and sold for approximately $5000 each. With the advent of computer technology, microwave oven design has improved greatly and most households have at least one microwave oven. There is also some confusion over the difference between microwaving food and irradiating food in order to sterilize it.

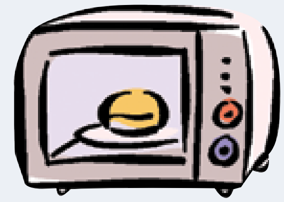


Figure 5-4

Reality Check: Microwaves do not use ionizing radiation to heat food. However, ionizing radiation is being used to irradiate food—this to kill unwanted pests and prevent spoilage from the growth of bacteria and microscopic flora. According to Health Canada, food does NOT become radioactive when irradiated and there is no scientific evidence that suggests harmful chemical changes are produced during the process of irradiation. Though most people may think of the microwave oven when asked about food irradiation, in fact some foods on the market today go through a process of being irradiated before hitting store shelves in order to kill off bacteria that can cause illness or death.

Research Question:

Research the June 2008 YouTube phenomenon of videos on "microwaves, cell phones, and popcorn" attempting to show how cell phones can take raw kernels of corn and convert them into popcorn.

1. What is the hoax behind the videos? (How did they **really** pop the corn?)
2. Was there any motive for promoting these videos on YouTube?

Figure 5-5

Radioactive Decay

Radioactive decay occurs naturally. There are three common types of radioactive decay that an isotope will use to spontaneously decay: alpha decay, beta decay, and spontaneous fission. In these processes, there are four options for the types of radioactive rays that are released: alpha rays, beta rays, gamma rays, and neutron rays.

If radioactive decay occurs through **spontaneous fission**, then the original atom splits to form two or more smaller atoms or **daughter nuclei**. The process involves release of extra neutrons or neutron rays. Fermium-256 typically undergoes spontaneous fission, and can form two daughter nuclei. We can show this process in the form of a chemical equation:

$$^{256}Fm \longrightarrow {}^{140}Xe + {}^{112}Pd + 4\ n^{0}$$

Xenon, palladium, and four extra neutrons are the products of this fission. Sometimes gamma rays are also emitted in the process, in order to make the two daughter nuclei more energy-stable.

When **alpha decay** is the process by which an atom radioactively decays, there is a chemical change that takes place: a daughter nucleus is formed and an **alpha ray** (alpha particle or helium atom) is released. Uranium-238 undergoes this process:

$$^{238}U \longrightarrow {}^{234}Th + {}^{4}He$$

There are **three types of beta decay**: a beta-minus particle can be released, a beta-plus particle can be released, or an inner-orbiting electron can be absorbed by an unstable nucleus and changed into a neutron.

In our first form of beta decay, sometimes unstable atoms that have an excess of neutrons may attempt to stabilize by converting a neutron into a proton. This process emits an electron, or a beta-minus particle (beta ray). It would make sense that if this process occurs inside the nucleus, the electron created in the process could not exist inside the nucleus and therefore must be ejected. Iodine-131 undergoes this type of beta decay:

$^{131}I \longrightarrow {}^{131}Xe + e^{-1}$

Note that with this type of beta-decay, the mass number remains the same. The atomic number, however, increases by one.

A second form of beta decay occurs when unstable atoms have an excess of protons for the size of the nucleus. To attempt to gain stability, the nucleus may convert a proton into a neutron and in the process a positron or beta-plus particle (beta ray) is emitted. Recall that a positron is like an electron, except that it has a positive charge. An example of this type of radioactive decay occurs in sodium-22:

$^{22}Na \longrightarrow {}^{22}Ne + e^{+1}$

For this type of beta decay, the mass number remains the same but the atomic number decreases by one.

The **third form** of beta decay occurs when unstable atoms attempt to gain stability by attracting an inner electron into the nucleus, where it combines with a proton to form a neutron. (See the "In the Media" section for this chapter to explore how this may be possible.) Iron-55 decays in this way:

$^{55}Fe + e^{-1} \longrightarrow {}^{55}Mn$

Once again, the mass number remains unchanged but the atomic number decreases by one.

Questions:

1. If ^{14}C were to release an alpha particle, what would the daughter nucleus be? Write the chemical equation.
2. If ^{14}Cwere to release a positron, what would be the chemical equation for this process?
3. If ^{14}C were to release a beta-minus particle, what would be the chemical equation for this process? Why might ^{14}C release a beta particle instead of alpha or gamma rays?

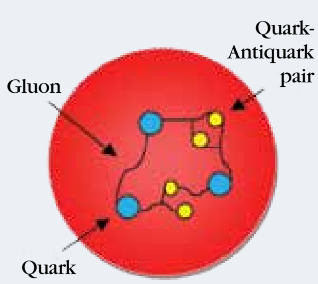


Figure 5-6

In The Media

Quarks and Radioactive Decay

Quarks are a relatively recent discovery and addition to the nuclear model of the atom. Though many of our experimental results can be explained by using the three basic subatomic particles (protons, neutrons, and electrons), beta decay cannot be explained without discussing quarks.

While researchers were studying beta decay, the **weak nuclear force** was discovered. This force, one of the four fundamental forces, changes one flavour (or type) of quark into another. Protons and neutrons are each made up of three quarks. Another subatomic particle—the gluon—holds these quarks together. During beta decay, the weak interactive force breaks up the gluons and causes one quark inside a proton to change so that the proton becomes a neutron, or vice versa. Researchers continue to hone the nuclear model of the atom to include increasingly more subatomic particles – over two hundred, in fact!

Half-Life

It is difficult to predict at what moment a radioactive atom will decay. It is possible, however, to discuss the length of time it takes one-half of the total number of atoms in a sample of a radioactive isotope to decay. This length of time is defined as the **half-life** or $T^{1/2}$ of the isotope. The half-life of carbon-14 is approximately 5730 days; the half-life of uranium-238 is about 4.47×10^9 years. Radium-226 has a half-life of 1600 years.

The **activity** of a radioactive sample is the number of disintegrations (decays) per second. If the sample starts out with a given number $\boldsymbol{N}$ of radioactive atoms, then over time the number of radioactive atoms decreases. To calculate the activity, we must take the change in the number of radioactive atoms, ΔN, and divide it by the time it took that change to occur, Δt. The number of disintegrations per second that occurs in any given sample is proportional to the original number of radioactive nuclei present, thus we can state that

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

where λ is a proportionality constant called the **decay constant**.

Because the amount of radioactive atoms present at any given time decreases exponentially, we can also write an equation to represent the number of radioactive nuclei, N, present at any given time t, assuming we know the original number of radioactive nuclei, N_o:

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

Alternatively, we can relate the half-life $T^{1/2}$ to the decay constant λ (with some substitution of one equation into another and natural logarithms coming into play) by the following formula:

$$T^{1/2} = \frac{0.693}{\lambda}$$

activity—the half-life of pennies

Obtain about 200 (or more) pennies and distribute them among your classmates. Initially, each penny represents an unstable nucleus. Each person should shake their pennies in a cup and then invert the cup so that each penny lies flat. A penny that comes up heads represents a nucleus that has decayed (and is assumed to now be stable), and a penny that comes up tails represents a nucleus that has not yet decayed—it is still unstable. Obtain the total number of pennies that come up tails—this is the number of unstable nuclei—and place them back inside the cups. Place a piece of masking tape over each of the pennies that have come up heads. They have decayed, but they are still part of the total mass and should be placed back in the cup. Repeat this several times until the number of pennies that remain in the game is less than 20.

Figure 5-7

Graph the number of unstable nuclei versus the toss number. Theoretically, we expect that approximately half of the coins should decay with each toss. The half-life for the pennies is the amount of time it takes to go through the above process.

Write up a laboratory report. Include in your report what type of safety considerations would need to be considered if the pennies were in fact truly radioactive.

Source: Don Metz, PhD. Senior 4 Physics (40S): A Foundation For Implementation. Manitoba Education, Citizenship and Youth, 2005.

Figure 5-8

Did You Know

Geiger Counters and Detecting Decay

Geiger counters are named after Hans Geiger, who developed a similar device in 1908 together with Ernest Rutherford. Geiger counters are devices used to detect alpha, beta and gamma radiation. They are rarely used to detect neutrons. Detection of alpha particles usually requires a specialized Geiger tube.

The device has a sensor in the shape of a tube. The tube is filled with an inert gas, such as helium or neon, which has the ability to conduct electricity briefly when a charged particle (which could be alpha, beta, or gamma) temporarily makes the inert gas conductive. This conductivity is amplified as a pulse of current, displayed on a gauge with a needle for measurement purposes and audible clicks. More clicks, and faster clicking, indicates more radiation present in the item being tested.

Approximately 20 years after developing the device with Rutherford, Geiger teamed up with a Ph.D. student of his (Walther Muller) to improve it. This is why the device is sometimes referred to as a Geiger-Muller counter.

Calculation Questions:

1. In 16 days the number of radioactive nuclei decreases to one-eighth the number present initially. What is the half-life (in days) of the mystery substance?
2. Francine's thyroid disorder was treated with an isotope of iodine, ^{131}I. If this isotope has a half-life of 8.05 days, what percentage of the radioactive material in the pill remains after one month (30 days)?
3. To make the dials of 1950s watches glow in the dark, radium-226 is painted on. Assuming that the mass of paint ending up on one watch is one-billionth of a kilogram, how much radium, in kilograms, disappears while the watch is in use for 50 years? (Assume the half-life of radium is 1600 years.)
4. Two radioactive substances Q and X are being observed by researchers, with equal amounts at the start of the experiment. Three days later, there are three times as many Q atoms as there are X atoms. If the half-life of the Q atoms is 2.0 days, find the half-life of the X atoms.
5. The number of radioactive atoms present at the beginning of an experiment is $5.0x10^{12.}$ The number of radioactive atoms present thirty days later is $8.2x10^{11}$. What is the half-life (in days) of this substance?

Units of Measurement

Just as there are units of measurement for radiation exposure, absorbed doses, and relative biological equivalents, measurement units have been developed for radioactivity. The SI unit for activity is named in honour of one individual who studied it—Henry Becquerel. The unit of measurement is Becquerels (Bq). One Becquerel is equal to one radioactive decay per second. (Note that a Geiger counter records "counts per minute," however this only indicates what is reaching the detector and does not tell us what the radioactive substance is actually doing.)

While Becquerel was studying radioactivity, so were the Curies. Thus, a second unit of measurement (not within the SI accepted units of measurement) was the Curie (Ci). One Curie was equal to the number of particles per second decaying from one gram of radium. When conversion was needed from Curies to Becquerels, the following factor was used:

1 Curie = 37 000 000 000 Becquerels

or 1 Ci = 3.7×10^{10} Bq

Review of SI Units of Measurement for Radiation and Radioactivity - What were they again?

Radiation Exposure (ions created in air): measured in *coulombs per kg (C/kg)*

Radiation Absorbed Dose: measured in *grays (Gy)*

Radiation Biologically Equivalent Dose (takes into account different absorption capabilities of different tissues and organs): measured in *Sieverts (Sv)*

Radioactivity (number of decays per second): measured in *Becquerels (Bq)*

Units of Measurement… another approach

(Remember what we began in Chapter 3?)

Imagine you are standing outside in the rain. If we were to use SI units for radiation and radioactivity and connect them to something about the rain:

- the *number of dust particles that become raindrops* would be comparable to **exposure**, measured in **coulombs per kg**
- the *amount of rain falling* would be like **radioactivity**. Measured in **Becquerels**
- the *amount of rain hitting you* would be like the **absorbed dose**, measured in **grays**
- *how wet you get* would be like the **biologically equivalent** dose, measured in **Sieverts**

activity—radioactivity of household object

For this activity, you will need to have your teacher access a Geiger counter and as many of the following household items that you can find: a watch made in the 1950s, a piece of Fiestaware® pottery, a smoke detector, a piece of paper, a piece of plastic, a piece of lead, potassium chloride salt (KCl)—sold as "No Salt" in stores, and aluminium foil. You may need earphones or a speaker to be able to hear the clicks from the Geiger counter for some of these objects—in particular the potassium chloride salt.

Procedure:

1. Determine which items are radioactive at a distance of 5 cm from the Geiger counter—record the radioactivity readings from the Geiger counter.
2. Determine which items—paper, plastic, or lead—block radiation when placed between the Geiger counter and the radioactive substance, and by how much. What does this tell you about the kind of radiation being released—alpha, beta, or gamma?
3. Choose one radioactive object, and use the Geiger counter to measure radiation levels at 2 cm, 4 cm, 6 cm, 8 cm, and 10 cm from the object. How does distance affect radiation?
4. This last step will allow you to measure the attenuation of beta radiation from the potassium-40 isotope found in KCl (0.7% is K-40, the rest is K-39). Place one layer of aluminium foil over a pile of KCl. Use the Geiger counter at close range to measure beta decay. Place a second Al layer on top of the first layer, and measure beta particles again. What thickness of Al will reduce beta particales to half the original amount? What thickness will stop all beta decay particles from reaching the detector?

ESTIMATES OF RADIATION LEVELS: Natural and Synthetic

Level (mSv)	Duration	Description
0.001-0.01	Hourly	Cosmic ray dose on high-altitude flight, depends on position and solar sunspot phase.
0.219	Annual	Natural background radiation, including radon, in Winnipeg, Manitoba
0.46	Acute	Estimated largest off-site dose possible from March 28, 1979 Three Mile Island accident
1.4	Annual	Natural background radiation, including radon, in Nunavut
2	Annual	USA average medical and natural background
2.2	Acute	Average dose from upper gastrointestinal diagnostic X-ray series
6.4	Annual	High Background Radiation Area (HBRA) of Yangjiang, China
7.6	Annual	Fountainhead Rock Place, Santa Fe, NM natural
175	Annual	Guarapari, Brazil natural radiation sources
500-1000	Acute	Low-level radiation sickness due to short-term exposure
500-1000	Detonation	World War II nuclear bomb victims

Career Moves

Medical Physicist

Anita Berndt and Daniel Rickey are medical physicists working at CancerCare Manitoba. They are health care professionals with graduate training (Ph.D.) in the medical applications of physics and both have certification by the Canadian College of Physicists in Medicine (CCPM). Their work involves the use of radioisotopes, x-rays, ultrasound, magnetic and electric fields in diagnosis and therapy. Anita works in radiation therapy, which uses high-energy radiation in the treatment of cancer. Her role in radiation therapy includes treatment planning and radiotherapy machine testing, calibration, and troubleshooting. Daniel specialises in diagnostic imaging which uses x-ray, ultrasound, magnetic resonance, and nuclear medicine for imaging patients. His role in diagnostic imaging includes machine purchasing and installation, testing, quality control, and operation. Anita and Daniel have academic appointments with the University of Manitoba and so are also involved in research and teaching.

Career Connection Website – International Organization for Medical Physics: *www.iomp.org*

Figure 5-9
Manitoba medical physicists Daniel Rickey and Anita Berndt with the gamma knife located at the Health Sciences Centre in Winnipeg.

Chapter 5 Review: Concepts and Terms

Content: In the late 1800s to early 1900s, Henri Becquerel was the first to record natural radiation from an uranium source. The Curies reported similar findings with radium and polonium. In the mid-1940s, cobalt and iridium were easily and cheaply produced synthetically and became prime sources for gamma rays.

The nuclear model of the atom consists of a nucleus, containing subatomic particles called nucleons, surrounded by electrons. The strong nuclear force holds the nucleus together. The electromagnetic force keeps the electrons near the nucleus. Variations of atoms of an element based on neutron-count are called isotopes, which have the same atomic number but differing mass numbers. An unstable isotope can become more stable by releasing energy in the form of gamma rays.

Radioactive decay occurs naturally through release of alpha particles, beta particles, gamma rays, or neutron rays. If radioactive decay occurs through spontaneous fission, then the original atom splits to form two or more daughter nuclei (smaller atoms). When alpha decay occurs, a chemical change takes place and a daughter nucleus is formed from the original atom.

There are three types of beta decay. In the first form of beta decay, unstable atoms which have an excess of neutrons may attempt to stabilize by converting a neutron into a proton and emit an electron in the process. In the second form of beta decay, unstable atoms with an excess of protons in the nucleus may convert a proton into a neutron and emit a positron in the process. I n the third form of beta decay, unstable atoms may attempt to stabilize by attracting an electron into the nucleus to combine with a proton and form a neutron.

The half-life of an isotope is the time it takes one-half of the total number of atoms in a sample of a radioactive isotope to decay. The activity of a radioactive sample is the number of disintegrations (decays) per second.

Terms of Interest:	
activity	Geiger-Muller counter
Becquerel (Bq)	gluon
beta-minus particle	half-life
beta-plus particle	Henri Becquerel
Curie (Ci)	mass number
daughter nucleus	neutron
decay constant	neutron ray
electromagnetic force	nucleon
fission	quark
fluorescence	spontaneous fission
fundamental force	strong nuclear force
Geiger counter	weak nuclear force

chapter 6

Further Applications of Radiation

CASE STUDY CONTINUED: The Final Verdict for Francine

Francine kept going back to her doctor for physical examinations every year. Five years after her radiotherapy, the cancer had still not returned. The doctor congratulated her and told her she could look forward to a long and fulfilling life. Throughout the process of treatment, her doctor had encouraged her to continue practicing the healing ceremonies of her aboriginal cultural heritage. That encouragement, plus the support of her family and community members, helped her through the up-and-down emotions she had throughout the process of diagnosis, treatment and recovery. She could now say with some degree of confidence that she was "cancer-free."

Figure 6-1

Figure 6-2

Ionizing Radiation Applications: Sterilization

Gamma rays are commonly used to sterilize disposable medical equipment such as needles, IV sets, and syringes. Typically, cobalt-60 is the radioisotope of choice as it continuously emits gamma rays. Storage of this in a medical facility needs to take into account the hazards of gamma radiation on humans, as the gamma rays produced by this isotope are extremely high in energy.

Electron beams can also be used for medical equipment sterilization. The advantage of using electron beams rather than gamma radiation is that gamma rays continuously emit radiation, but electron beam processing can be turned on and off. As well, higher doses can be administered through electron beams so less exposure time is required to sterilize the equipment. This can prevent the degradation of plastics that may be sterilized (the longer plastic is subjected to radiation, the greater the risk of the polymers breaking down). One negative property of electron beam technology is that it does not penetrate as deeply as gamma rays.

Though it is not ionizing radiation, ultraviolet light has limited use for sterilization purposes, but is still popular in the form of **germicidal lamps**. Surfaces and some transparent objects can be sterilized in this way, including the interiors of biological safety cabinets. However, if the surfaces are dirty the UV radiation will not sterilize the surface underneath it. UV light can also damage many plastic surfaces, including polystyrene foam (used in home insulation).

Irradiation is used by the United States Postal Service to sterilize mail destined for the Washington, D.C. area. Food irradiation for some spices and ground meats is now widely used to prevent illness.

Did You Know

Litvinenko, Thallium, and Russian Radiation Intrigue

In November of 2006, the public's interest in espionage was piqued as The Russian Federation was thrust into the international spotlight with former KGB agent Alexander Litvinenko allegedly having been poisoned by another former KGB agent. The KGB was the "spy agency" of the former Soviet Union.

Litvinenko, a published author who had frequently spoken out against then Russian president Vladimir Putin, had a brief meeting with Andrei Lugovoy in a central London restaurant before meeting an Italian man for lunch. The following day, Litvinenko became violently ill and was taken to hospital by his wife. It would take more than two weeks for the effects of the poison – hair loss, shut-down of internal organs, breathing difficulty – to become clear. Toxicology tests finally confirmed that thallium was present in Litvinenko's bloodstream.

Scotland Yard detectives investigated both of the men with whom Litvinenko met previous to his illness for possible connections to the poisoning. They have not ruled out the possibility of the use of a "poison pen" that could have been used to inject the man with thallium unnoticed. This would be consistent with a previous assassination in London of Georgi Markov, a Bulgarian dissident stabbed with a poison-tipped umbrella in 1978.

Research Question:

What are the effects of thallium poisoning on the human body?
In what everyday products can thallium be found?

Ionizing Radiation Applications: Tracer Methods in Nuclear Medicine (Gamma Scans)

Figure 6-3
A bone scan done with a tracer of radioactive strontium. In this image, bones can clearly be seen along with tendons.

We have already discussed how radiotracers are used in the various types of diagnostic technologies to enhance the results of the scan and indicate areas of interest or "hot spots." In nuclear medicine, gamma scans are done on bones to determine bone growth patterns, potential for arthritis, or identify cancerous areas. Almost all nuclear medicine studies are performed using an isotope of technetium – ^{99}Tc.

Gamma scans are done by a camera that picks up gamma rays emitted by a radiotracer. These gamma rays are converted into images that contain light and dark spots. Dark spots or "hot spots" do not necessarily indicate areas of cancer. Hot spots show where the radiotracer has collected. Since the radiotracer is typically attached to a substance that will gravitate towards areas of the body where cells are growing at faster or abnormal rates, the hot spots can either indicate cancer or arthritis or some other type of bone disease. Use of gamma cameras is much more common than PET scans.

Questions:

1. Can you identify what might be potential areas of concern in this bone scan?
2. Research what type of radiotracer might be used to enable doctors to see tendons on a scan.

In The Media

The Canadian Medical Isotope Controversy

Earlier, in Chapter 2, we were introduced to the importance Canada has in the production and distribution of what are called medical isotopes. In recent years, Canada has an interesting story to tell about how critical we are to the world supply of certain isotopes used in medical treatments - particularly cancer treatments. In November of 2007, the Canadian Nuclear Safety Commission (CNRC) and Atomic Energy of Canada Limited (AECL) brought Canada's role in providing much of the world's supply of medical isotopes to the forefront. In a controversial move, the CNRC shut down the nuclear reactor (run by AECL) at Chalk River, Ontario for twenty-seven days. It was a shutdown related to a safety concern on the part of the CNRC.

At that time, much of the world supply of certain medical isotopes produced by Canadian reactors became an urgent situation to address. On December 16, 2007 the Canadian government passed emergency legislation allowing the Chalk River reactors to reopen and to continue to provide medical isotopes to their clients around the world. This is an important example of how science connects to the well-being of people, and the reliance we have on technology to serve our health care needs. It also highlights the Canadian nuclear industry and our need to understand it better.

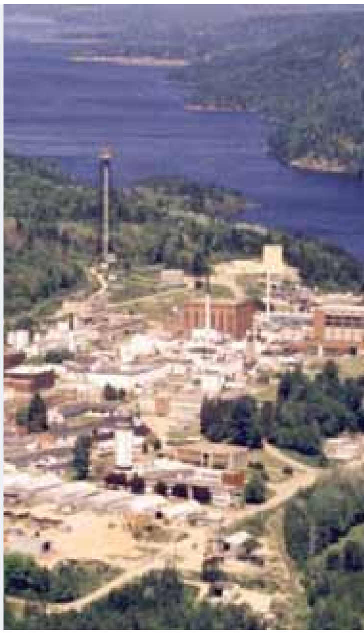


Figure 6-4

Research Question:

1. Check into this fascinating story, and explore in a balanced way the positions of the CNRC, the Canadian government, and the AECL (a good place to start is online at: http://www.cbc.ca/technology/ and use the search bar with the keywords "medical isotopes"). If you were the Natural Resources Minister for the federal government and you had to make the decision whether or not to shut down a Canadian reactor that produces one-third of the world supply of medical isotopes — even temporarily — what would you decide to do? You might want to have teams of students take positions on this controversy and debate the issue in class.
2. Read the public written and verbal statements made by both the CNRC and the AECL (which can be found online). If you were the Health Minister for the federal government and you had to make the decision whether or not to shut down the reactor—albeit temporarily—what would you decide? Justify your decision.

Non-Ionizing Radiation Applications: Tanning Beds

Non-ionizing radiation is electromagnetic radiation without enough energy to cause ionization. It does have enough energy to give to particles, with the end result usually being heating. Non-ionizing radiation includes frequencies from one hertz (1 Hz) up to 300 GHz (gigahertz), and wavelengths from 10^{-7}m to 10^{9} m. As wave frequency decreases and wavelength increases, the energy level decreases. Types of non-ionizing radiation include UV light, visible light, infrared light, microwaves, and radio waves.

Figure 6-5

Ultraviolet (UV) light is naturally obtained from sunlight. Artificial sources include germicidal lamps, mercury vapour lamps, halogen lights, fluorescent and incandescent lights, and tanning booths. Germicidal lamps are designed to emit UVC radiation to kill bacteria and sterilize surfaces. Humans can obtain severe sunburn to the face, sometimes called snow blindness, with overexposure to UVC light. Though very painful, it does clear up in a few days.

A component of sunlight is UVB light, and is the most destructive form of UV radiation. It has enough energy to cause damage at the cellular level (DNA is affected). Some tanning beds operate using UVB light. Effects of UVB on humans include erythema (sunburn), cataracts, and skin cancer.

Cancer Connection

Non-Ionizing Radiation Applications: Tanning Beds

Non-ionizing radiation is electromagnetic radiation without enough energy to cause ionization. It does have enough energy to have an effect on particles, with the end result usually being heating. Non-ionizing radiation includes frequencies from one hertz (1 Hz) up to 300 GHz (gigahertz), and wavelengths from 10-7m to 109 m. As wave frequency decreases and wavelength increases, the energy level decreases. Types of non-ionizing radiation include UV light, visible light, infrared light, microwaves, and radio waves.

Ultraviolet (UV) light is naturally obtained from sunlight, and is probably the most familiar form of non-ionizing radiation for most people. Artificial sources include germicidal lamps, mercury vapour lamps, halogen lights, fluorescent and incandescent lights, and indoor tanning facilities. Germicidal lamps are designed to emit UVC radiation to kill bacteria and sterilize surfaces. Humans can obtain severe sunburn to the face, sometimes associated with “snow blindness,” with overexposure to UVC light. Though very painful, it does clear up in a few days. A component of the spectrum of sunlight is UVB light, and this is the most destructive form of UV radiation where exposed skin is a concern. It has enough energy to cause damage at the cellular level (so DNA is affected). Some indoor tanning beds operate using some component of UVB light (less than 10% of the total exposure), with the remainder as UVA. Known effects of UVB on humans include erythema (sunburn), eye cataracts, and skin cancer. Most tanning beds are a concentrated source of UVA, and sometimes UVB, light and so these should be used with real caution. It is recommended these days that young people under the age of 18 not make use of indoor tanning at all, and those who are aged 35 or less face a dramatically increased risk of developing a form of skin cancer – called cutaneous malignant melanoma – later in life if they have significant exposure to UVA from tanning bed use.

Figure 6-6

Non-Ionizing Radiation Applications: Communications

Cell phones, AM and FM radio, microwave towers all radiate electromagnetic energy. These microwaves and radiofrequency waves surround humans daily.

Radiowaves are constantly being emitted by radio station towers. If you listen to a radio station labelled 99.9, that number indicates its frequency: it is operating at 99.9 megahertz. The wavelength of this station can be determined by taking the speed of light and dividing it by the frequency. (Recall: $v=\lambda f$). A station operating at 99.9 MHz would therefore have a wavelength of approximately 3.03 metres.

AM, FM, and cellular signals travel in a straight line, unimpeded through the earth’s atmosphere. Since the earth’s surface is curved, at some point these signals will be lost – unless they are reflected back to the earth’s surface by the ionosphere or a transmission tower. The ionosphere (an atmospheric layer where sunlight ionizes atoms) reflects radiowaves with less than 30 MHz in frequency. Typically, FM signals carry higher frequencies and thus are not reflected by the ionosphere. AM radiowaves use shorter frequencies than cellular and FM waves, and so are typically reflected back to the earth’s surface from the ionosphere.

Health Canada has a safety code which restricts exposure to the general public to no higher than 1/50th of the levels where harmful biological effects have been observed. The Safety Code restricts both the absorption rates and the corresponding exposure levels for these types of electromagnetic waves.

According to Health Canada, it is possible to exceed the maximum allowable exposure limit if an individual stands less than three metres away from a transmitting cellular antenna. However, there are safety fences around these sites and normally the general public does not have access. Workers in the vicinity of towers such as these can be exposed to no more than 1/10th the levels where harmful biological effects have been observed (according to Health Canada’s regulations).

Research Questions:

1. Which new frequencies did the Canadian government recently open up to allow for more competition amongst cellular service providers? How does a cellular service provider or radio station obtain an operating frequency?
2. Why are radio station signals sometimes more clear at night than during the day?

Reality Check

Question | Can Cell Phones Cause Cancer?

Origin: A few individuals attempted to take cell phone companies to court in the early 1980s, claiming brain tumours were caused by their cell phones. Online communities continue to perpetuate this and similar ideas, claiming that the electromagnetic energy radiating from cell phones is powerful enough to pop popping corn and to do damage to brain tissue.

Reality Check: The website *Discovery Health* states that the US Food and Drug Administration's Centre for Devices and Radiological Health believes that there is no consistent association between cell phone use and cancer. Rather, the Centre states that studies have shown that there is an identifiable link between cell phone usage and increased risk of having a car accident.

Source: Gansler, Dr. Ted. "Discovery Health:: Top 10 Cancer Myths: Myth 8." Discovery Health n.d.. 29 July 2008 health.discovery.com/centers/cancer/top10myths/myth8.html

Figure 6-7

Non-Ionizing Radiation Applications: Microwave Ovens

Microwave ovens for consumer use typically operate at 500 to 1000 watts at a frequency of approximately 2450 megahertz (MHz). The energy from these microwaves is used to boil water or cook food that is placed inside the oven.

Microwave ovens cook food by irradiating them with high-frequency, very low wavelength waves. Wavelengths typically are around 10-12 cm inside a microwave. Since most food has a high water content, and since water is a polar molecule, the energy carried by the electromagnetic waves inside the oven is imparted to the water molecules. This extra energy is converted into heat, which eventually cooks the food. Leave the food in long enough, and water will begin to evaporate, drying out the food.

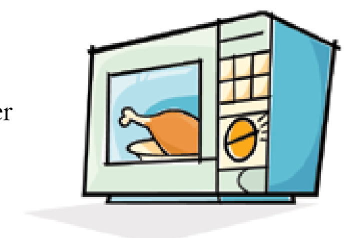


Figure 6-8

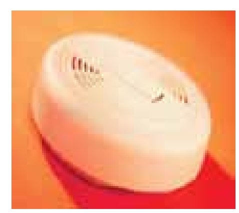
Regulations require that microwave ovens be constructed so that radiation leakage to the outside of the oven is minimal – approximately 1000 times less than what is present inside the oven. Contrary to some emails and online bloggers, the radiation that does leak from your microwave is not harmful. Microwaves cannot penetrate metal, which is why the oven is constructed of metal (sometimes coated in plastic). Even the viewing window has a mesh made of metal on it. Unless your microwave is damaged or altered it will not leak sufficient amounts of microwave energy to cause damage.

activity—marshmallows, microwaves, and mathematics

Microwaves without turntables cook unevenly, due to wave patterns. We can use that principle to confirm that the electromagnetic radiation inside a microwave oven does, in fact, travel at the speed of light.

1. Remove the turntable from the microwave—if it has one. Place a flat piece of cardboard over the bottom of the microwave.
2. Line the entire bottom of the microwave with mini marshmallows.

   Set the microwave on high power and cook the marshmallows until you start to see a pattern of melting/toasting and uncooked marshmallows. At this point, carefully remove the cardboard and marshmallows.
3. Take a ruler and measure the distance between two consecutive melted spots. This will be equal to the wavelength of the electromagnetic waves. (Are the melted spots nodes or antinodes?)
4. Check on the back of the microwave for a sticker which will tell you the operating frequency of the microwave (typically 2450 MHz). Use this value and your wavelength converted into metres to calculate the speed at which the electromagnetic waves are traveling in your oven. Is it $3x10^8$ m/s?



For Further Research:

How do smoke detectors use alpha-particle emitters?

Is it ionizing or non-ionizing radiation that is used?

Create a presentation of your results.

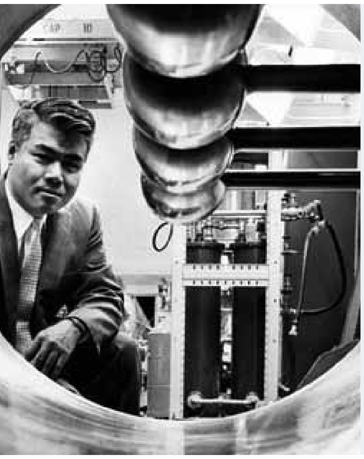


Figure 6-10

Career Moves

Accelerator Physicist

As an accelerator physicist, your job duties would include the operation of an accelerator complex: synchrotron, linear accelerator, and all the computer technology connected to those devices. Beam studies and high-level accelerator calculations aimed at understanding the performance of the accelerator and research into areas of personal interest are typically encouraged by employers. At this level of your career, you will have already completed doctorate-level studies, have several years of experience in theoretical and practical physics, and have developed the leadership skills to organize a team of researchers to meet specific goals. This is pure physics at an elite level!

Career Connection Website – Canadian Association of Physicists: www.cap.ca

Chapter 6 Review: Concepts and Terms

Concepts: Gamma rays can be used to sterilize disposable medical equipment. Typically, cobalt-60 is the radioisotope of choice for this, however electron beams can also be used for the same purpose. The advantage of using electron beams is that less exposure time is required to sterilize equipment, and electron beam processing can be turned on and off. Ultraviolet light has limited sterilization purposes in the form of germicidal lamps for surfaces and some transparent objects.

Gamma scans are done by a camera that converts gamma rays into images. Use of gamma cameras is much more common than PET scans.

Types of non-ionizing radiation include UV light, visible light, infrared light, microwaves and radiowaves. UV light is made up of UVA, UVB, and UVC light. UVC light can cause severe burns to human skin, which can clear up in a few days. UVB light can cause erythema (sunburn), cataracts, and skin cancer. Most tanning beds operate by using UVA and UVB light.

Applications of non-ionizing radiation include cell phones, AM and FM radio, and microwaves. Health Canada has a safety code which restricts exposure to the general public to no higher than 1/50 of levels where harmful biological effects have been observed. Contrary to some emails and online bloggers, the radiation that may leak from your microwave is not harmful.

Terms of Interest:	
accelerator physicist	gigahertz
Atomic Energy of Canada Limited (AECL)	ionization
blogger	radiofrequency
Canadian Nuclear Safety Commission (CNRC)	radiowave
Chalk River Laboratories	smoke detector
electron beam	sterilization
erythema	sterilization
gamma ray	synchrotron
gamma scan	World Health Organization (WHO)
germicidal lamp	