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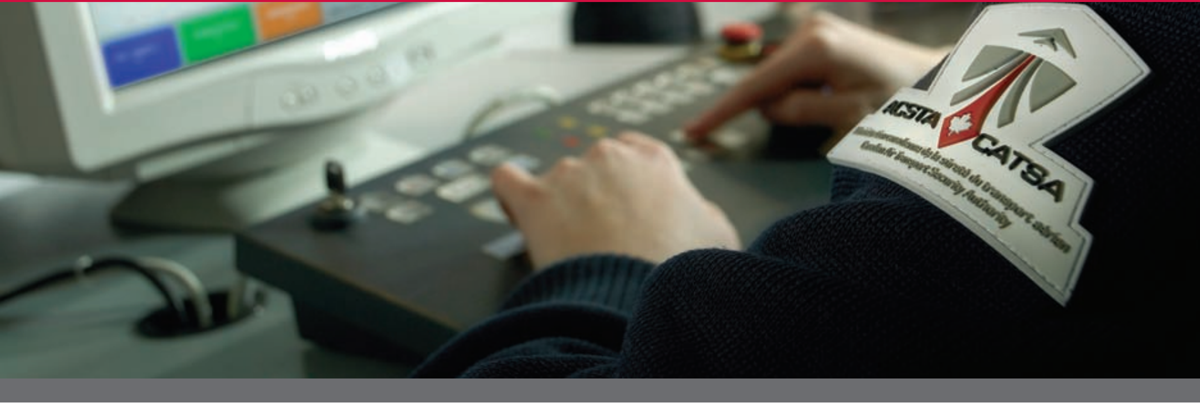
Radiation Safety Institute of Canada
Institut de radioprotection du Canada

X-Ray Safety Awareness Handbook



Canadian Air Transport Security Authority
Administration canadienne de la sûreté du transport aérien

Canada

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Canadian Air Transport Security Authority

X-Ray Safety Awareness Handbook

For Baggage X-Ray Machine Operators

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Acknowledgements

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Foreword

This informational handbook was created by the Radiation Safety Institute of Canada for the Canadian Air Transport Security Authority. It is designed to provide plain language answers to typical questions asked by airport personnel who work with, or near, baggage x-ray systems.

Some of the topics covered in this handbook are the basics of radiation, an explanation of x-rays, the specific risk posed by baggage x-ray systems, the principles of radiation safety, and some of the key points of *Health Canada Safety Code 29*, which addresses baggage x-ray machines and the screeners that work with and around these machines.

Although a handbook cannot provide all the answers, it is our hope that it will prove to be a valuable reference tool.

This handbook is not intended to outline specific CATSA policies, processes, or procedures. They can be found in CATSA's Standard Operational Procedures manual.

Equipment discussed in this handbook reflects those in use by CATSA at time of publication.

The Radiation Safety Institute of Canada, founded in 1980 is an independent, national organization dedicated to the promotion of radiation safety in the workplace, in the environment and in homes and schools.

Introduction to Radiation

What is radiation?

To understand radiation, it is important to know what atoms are. Atoms are the tiny particles that all matter is made of. They are the building blocks of our world. Atoms are made out of smaller particles called protons, neutrons, and electrons. Protons have a positive charge, while neutrons have no charge at all. Both protons and neutrons are found in the centre of the atom, much like our sun is found in the centre of our solar system. The centre of the atom is called the nucleus. Electrons are very tiny particles that have a negative charge. The negative charge on an electron is equal in strength, though opposite in charge, to the positive charge on the proton. Electrons can be thought of as orbiting the nucleus of an atom much like the planets orbit the sun in our solar system.

Figure 1 shows a representation of a helium atom. Helium has two protons and two neutrons in the nucleus and two electrons in orbit around the nucleus

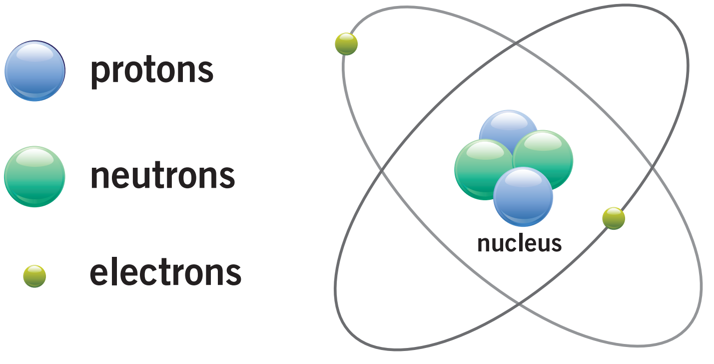

Figure 1: Diagram of an atom.

The term "radiation" refers to subatomic particles (particles that come from an atom, like protons, neutrons, and electrons) or electromagnetic waves (pure energy with no mass) which are emitted by an atom. Basically, radiation is "stuff" which flies out of an atom. When radiation is emitted by an atom, it is travelling at a very high speed. The radiation has a lot of energy because it is travelling so fast.

Since radiation is made up of particles which are smaller than atoms, or waves which have no mass, it is able to travel through objects that are solid to us. Different types of radiation have different abilities to penetrate through materials. The types of radiation and their penetrating abilities are discussed later in this handbook.

Note: The glossary at the end of this handbook contains definitions of terms important to understanding radiation.

What do "radioactive" and "radioactivity" mean?

"Radioactive" is how atoms which emit radiation are described. A radioactive atom is one that emits radiation. The radiation is emitted from the nucleus of a radioactive atom. Uranium is an example of a radioactive atom. It emits a type of radiation called an alpha particle from its nucleus. An atom is said to decay when it emits radiation.

"Radioactivity" refers to the "activity" of a radioactive material. The activity of a material, made up of many, many atoms, is the number of atoms in the material that will decay in a certain amount of time and emit radiation. Radioactivity is usually measured in number of decays per second. A material that has one decay occurring in one second is said to have an activity of one becquerel (Bq).

X-ray machines are not radioactive. X-ray machines are designed to produce radiation and the radiation is controlled by the operator of the machine. The radiation can be turned on and off by the press of a button. Electricity is used to supply energy to the machine so that the radiation, the x-rays, can be created. The x-rays do not come from the nuclei of the atoms within the machine. Without electricity, there would be no way for an x-ray machine to actually emit x-rays.

With a radioactive material, such as uranium, the emission of radiation cannot be stopped. Radioactivity is a property of the material that we cannot speed up, slow down, or stop. A material will only cease to be radioactive when it has decayed to a stable state.

What types of radiation exist?

The most common types of radiation are alpha, beta, gamma, and x-ray.

Alpha radiation is emitted by radioactive atoms that are very heavy. An alpha particle (*Figure 2*) is a heavy particle made up of two protons and two neutrons and is positively charged. Alpha radiation comes out of the nucleus of an atom. Alpha radiation loses its energy very quickly. It comes to a stop after travelling through a few centimetres of air. Alpha radiation is completely stopped by the dead layer of skin on the outside of our bodies.

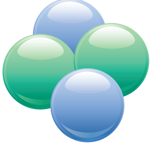

Figure 2: Diagram of an alpha particle.

Beta radiation is emitted by radioactive atoms. A beta particle (*Figure 3*) is a very small, very light particle and can have either a negative or positive charge. If it is negatively charged, it is exactly like an electron. If it is positively charged, it is called a positron. A positron has the same size and mass of an electron, but an opposite charge. Both types of beta radiation come from the nucleus of an atom. Beta radiation can travel farther than alpha radiation. In air, beta radiation can travel a couple of metres. Beta radiation can penetrate through the dead layer of skin on our bodies and reach the live skin underneath. A sheet of plastic can completely stop beta radiation.

Figure 3: Diagram of a beta particle

Gamma radiation is made up of very high energy electromagnetic waves (see *Figure 4* - visible light is made up of electromagnetic waves of lower energy). Gamma radiation has no mass and no charge. Gamma rays come out of the nucleus of a radioactive atom. Gamma radiation is very penetrating. It can travel right through our bodies. In fact, gamma radiation can never be stopped completely. A small number of gamma rays will even be able to pass through a very thick layer of lead.

Figure 4: Diagram of an electromagnetic wave. The arrow indicates the direction in which the wave is travelling.

X-rays are produced by special machines. They are made up of high energy electromagnetic waves but do not come from the nucleus of the atom. They are produced through specific interactions between electrons and atoms. Like gamma rays, x-rays are very penetrating. We can never completely stop them, but we can use materials, like lead, to reduce the number of x-rays that will reach our bodies. This is discussed in more detail later in the handout.

The following chart, called the electromagnetic spectrum (*Figure 5*), shows some of the most familiar forms of electromagnetic radiation. The energy of the radiation decreases from left to right, with gamma rays being the highest energy electromagnetic radiation.

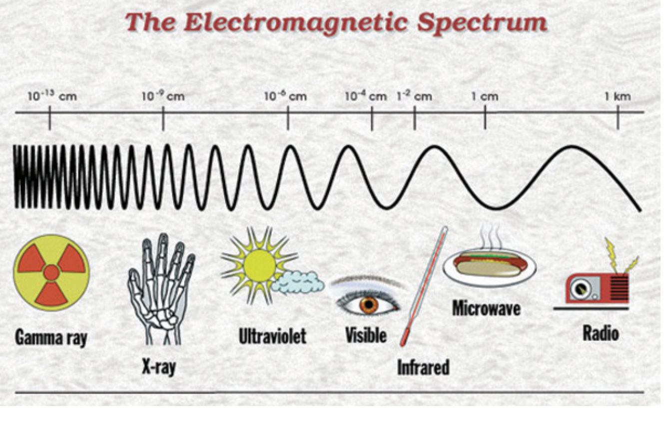

Figure 5: The electromagnetic spectrum. Courtesy NASA/JPL-Caltech.

The main types of ionising radiation, along with common sources and uses, are listed in *Table 1* below.

Type of radiation	Examples of radiation sources	
	Source	Use
Alpha particle	Uranium atoms	Fuel for nuclear power plants
Beta particle	Carbon -14	Archaeological carbon dating
Gamma ray	Caesium-137	Treatment of cancer
X-ray	Electronic machine	Non-invasive imaging

Table 1: Examples of radiation types, sources, and uses.

What are internal and external radiation exposures?

Internal and external radiation exposures refer to the location of the source of the radiation.

With an external radiation exposure, the source of the radiation is outside of the body (*see Figure 6*). Exposure to x-rays is an example of an external radiation exposure. The source of the radiation, the x-ray machine, is located outside of the body.

Figure 6: External radiation exposure. A baggage x-ray machine is a source of external radiation exposure.

With an internal radiation exposure, the source of the radiation is inside the body (*see Figure 7*). Potassium-40, a radioactive form of potassium naturally found in bananas, and elsewhere, is a common example of a source of internal radiation exposure. When a person eats a banana, the small amount of radioactive potassium that is contained in the banana is taken into the body. That potassium then emits radiation while it is inside the person's body.

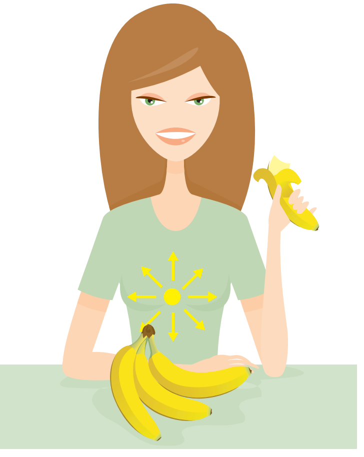

Figure 7: Internal radiation exposure. We are all exposed to radiation internally from the foods we eat. When we eat food, we take small amounts of naturally occurring radioactive atoms into our bodies.

How much radiation am I naturally exposed to?

Radiation is something that cannot be avoided in our world; the foods that we eat, the air we breathe, the ground beneath us, and the stars above us, all expose us to radiation. These sources of radiation are referred to as "naturally occurring radiation" or "background radiation." We receive a dose of approximately 2 to 3 milli-sieverts (mSv)[1] of radiation every year from background radiation.

Let's explore some of the major sources of naturally occurring radiation:

Cosmic radiation

Outer space is a sea of radiation. Stars, including our sun, emit many forms of radiation, including gamma radiation. Much of the gamma radiation is unable to get through our atmosphere, but some of it does reach the surface of the Earth and our bodies.

Terrestrial radiation

The Earth contains all sorts of radioactive materials. Soil all over the Earth is made up of small amounts of uranium and other radioactive atoms. We are exposed to the radiation emitted by these atoms. Also, when the uranium decays, along the way to becoming stable, it turns into radon which is a gas. This gas rises up from the soil and mixes into the air. When we breathe, we take in radon gas which then becomes an internal source of radiation exposure.

Food

The food we eat is grown on the Earth and gathers nutrients and minerals from the soil. Some of these nutrients and minerals will contain radioactive atoms which are incorporated into the food. When we eat the food, we consume the radioactive atoms which become an internal source of radiation. Potassium-40, which is contained in bananas, and carbon-14, which is contained in all plant and animal matter, are two examples of radioactive atoms found in foods.

[1] *Note: Sievert is the unit of radiation dose. 1 mSv is one thousandth of a sievert. Please refer to the glossary for a summary of common units used in radiation measurements.*

Will this "background" radiation hurt me?

All radiation has the potential to be harmful and background radiation is no different. For example, radon gas, found naturally in the air, has the potential to cause lung cancer. We can take steps to minimise this risk but it is impossible to eliminate it, just like it is impossible to eliminate our exposure to other background sources of radiation. Generally, the amount of radiation exposure we receive from background sources of radiation is so low that we need not be concerned about it. In fact, Health Canada states that "There is no evidence of increased cancer risk at natural background levels" in *Safety Code 29* (which we will discuss later in this handbook).

▶ What are ionising radiation and non-ionising radiation?

Ionising radiation is radiation that has enough energy to knock electrons from orbit of the atoms that it hits. This is the category of radiation that alpha particles, beta particles, gamma rays, and x-rays belong to.

Figure 8 shows an atom being ionised by an electromagnetic wave.

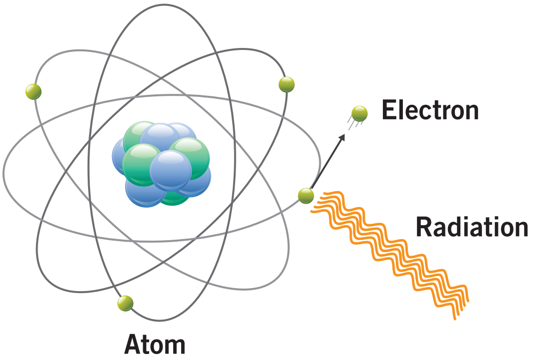

Figure 8: Ionisation.

Non-ionising radiation is radiation that does not have enough energy to knock electrons from orbit of the atoms that it hits. This is the category of radiation that radio waves, microwaves, infrared (e.g., the heat from a fire), and visible light belong to.

▶ How can ionising radiation affect my body?

Ionising radiation has the potential to damage the DNA within your body's cells. DNA is the "blueprint" of your body, containing all your genetic information. More importantly, it dictates how a cell is to behave, including when and how often to reproduce. If the DNA molecule is damaged, the effect could be that the cell reproduces often and before it reaches a mature state. The new cells will also have the same defect and behave in the same way. The result is a growth of cells with no beneficial function in the body. This is a tumour. If the tumour invades other tissues in the body, it is called cancer.

Cancer is the main health effect we are concerned about in regards to low levels of radiation exposure over long periods of time.

Exposure to a high amount of radiation in a short period of time could lead to more immediate health effects. These effects include things like lethargy, nausea, vomiting, diarrhoea, and, in very severe cases, death. A person would have to have an acute x-ray dose about 250 mSv or above for any of these effects to even start to show up. Death only becomes a possibility at acute x-ray doses around 2,000 mSv. The maximum radiation dose a baggage x-ray machine operator could receive in a year, which is too long a time frame for the dose to be considered acute, is approximately1.4 mSv. This dose will be discussed fully in a later question, but it's easy to see that even at this overestimated dose there would be no way to reach 250 mSv even in a lifetime of working as a baggage x-ray machine operator.

What kind of radiation are x-rays?

X-rays are a type of ionising radiation. Like gamma rays, x-rays are high energy electromagnetic radiation. However, gamma rays come from the nucleus of a radioactive atom (*Figure 9*) whereas x-rays are produced by interactions between electrons and atoms and are generally created in special machines. X-rays are just like visible light; the difference is that x-rays have much more energy. In fact, x-rays have so much energy that we cannot detect them with any of our senses.

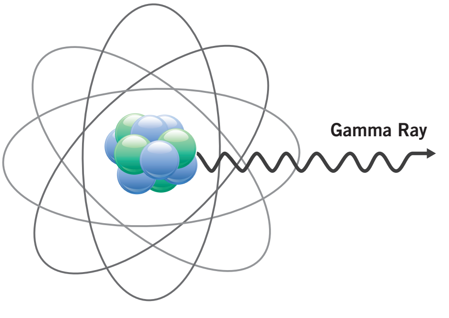

Figure 9: Diagram of the emission of a gamma ray. Gamma rays are emitted from the nuclei of radioactive atoms.

X-rays are most often made by machines, a man-made source of radiation (see *Figure 10*). When these machines are turned on that doesn't mean they are definitely producing x-rays. The operator of the machine has to give the machine a specific command (push a button, flick a switch) in order to cause it to create x-rays.

▶ How are x-rays different from nuclear radiation?

As the name indicates, nuclear radiation (such as alpha, beta, and gamma radiation) is radiation that is emitted from the nucleus of a radioactive atom. We have no control over nuclear radiation, we can't control its energy, when it's emitted, or how often it is emitted.

X-rays are created in machines by firing electrons at a target material. When these electrons interact with the atoms in the target material, they slow down, which means they lose energy. This "lost" energy creates an x-ray. Through the design of the machine, we are able to control the energy of the x-rays, how many are produced, and most importantly, when the x-rays are produced. We have the ability to start and stop the x-ray production.

Figure 10 shows how x-rays are produced by an electrically operated machine.

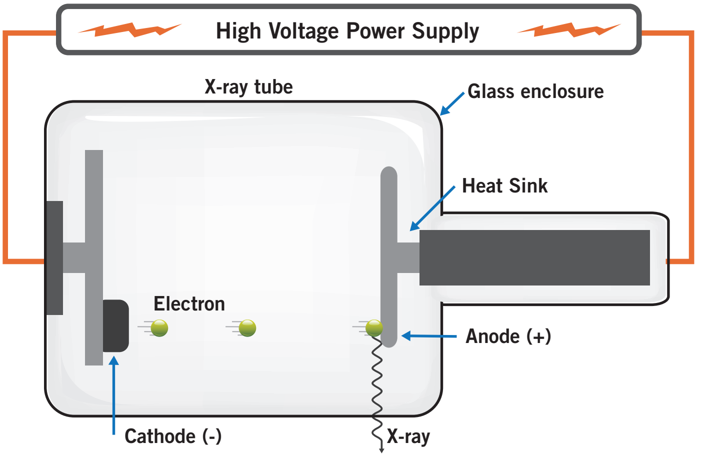

Figure 10: Diagram of x-ray generation. X-rays are created by special machines that use x-ray tubes similar to the one pictured above. Electricity is required for the generation of x-rays by these machines.

How does an x-ray move from one place to another?

Like visible light, x-rays travel in straight lines. When x-rays hit an object, they can travel straight through the object, but sometimes they will bounce off the object and can end up travelling in any direction – this is called "scatter" *(Figure 11)*. Still other x-rays will lose their energy as they travel through an object and since an x-ray is just energy, when the energy is gone so is the x-ray! This is called "attenuation" (*Figure 12*).

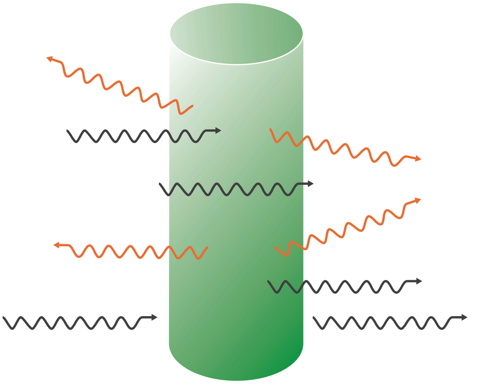

Figure 11: X-ray scatter. When x-rays encounter an object, some will interact and be scattered in different directions while others will travel through the object unimpeded. In this diagram, the scattered x-rays are shown in red.

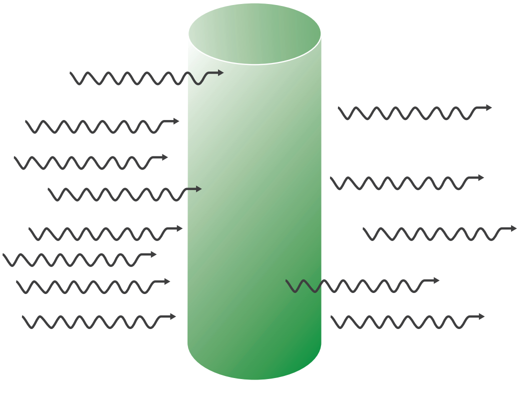

Figure 12: X-ray attenuation. When an x-ray beam encounters an object, some of the x-rays will interact with the atoms in the object and lose all of their energy. As a result, fewer x-rays will make it out the other side of the object. This lowers the number of x-rays in the beam and is called attenuation.

How risky is working with x-rays compared to other activities?

Every human activity has a risk associated with it. Baggage x-ray machine operators generally receive much less than 1 mSv of radiation dose per year (a CATSA operator actually receives an average of about 0.02 mSv per year, as will be explained later). Working with this amount of radiation is less risky than working in manufacturing, transportation, and construction. There is more of a chance of dying in an accident on the road or at home than from receiving a 1 mSv radiation dose in a year (*Table 2*).

Hazard	Risk of death per year
1 mSv of radiation dose	1 in 20 000
Accident at home	1 in 11 000
Working in manufacturing	1 in 11 000
Accident on the road	1 in 5 000
Working in transportation	1 in 4 000
Working in construction	1 in 3 000

*Values taken from “Canada: Living with Radiation” by the Atomic Energy Control Board, 1995.

Table 2: Risk of death per year from various hazards.

Protection from Radiation

What is the ICRP?

ICRP stands for "International Commission on Radiological Protection." The ICRP is the foremost international authority on the health effects and safe use of ionising radiation. It is an independent group of experts in fields related to radiation protection. They review existing scientific information on the health effects of radiation exposure and based on the data, make recommendations for dose limits. Most countries adopt the recommendations of the ICRP, including Canada.

What is the ALARA principle?

ALARA stands for "As Low As Reasonably Achievable." The ALARA principle refers to the idea that remaining just below a legal dose limit is not good enough. ALARA requires employers to take measures to ensure that the radiation doses to employees are kept as low as reasonably achievable. The ALARA principle is a reminder that the dose limits are not a goal. The goal is instead to keep doses as far below the limit as is reasonable for the workplace.

What are the best ways to protect myself from radiation?

In keeping with the ALARA principle, where you are always trying to reduce the amount of potential radiation exposure to "As Low As Reasonably Achievable", the best ways to protect yourself from radiation are by applying the following three principles of radiation protection: time, distance, and shielding.

Time
Even though the level of radiation exposure may be very low, applying the ALARA principle means limiting the amount of time you spend around sources of radiation. The logic is simple: the less time you are next to something emitting x-rays, the less chance you have of being exposed to radiation. So really, if someone doesn't have a reason to be around an x-ray machine – no matter how low the level of radiation – they should practice the ALARA principle and not hang around.

The time principle is also one of the reasons that baggage x-ray machines are designed so that they only emit x-rays when they are scanning a bag. Aside from saving electricity, this helps to ensure that operators are exposed to x-ray radiation for as little time as possible. Of course, that's just extra security in addition to the other key principles: distance and shielding.

Distance

This principle is just as simple: the further you are from a radiation source, the less radiation you can be exposed to. While the baggage x-ray machines are well shielded, no amount of shielding can prevent 100% of the x-rays from escaping: theoretically, an x-ray can still travel through material and not be either attenuated or scattered, regardless of the thickness of the material. The chance of this happening may be very low, to the point of being negligible, – say fractions of a percent – but it is possible.

That said, increasing your distance doesn't mean moving metres away from the machine; even increasing your distance by centimetres can have a significant effect – which is certainly the case with baggage x-ray machines.

For example, if you stood at 5 cm from the curtains of a Heimann x-ray machine 40 hours a week for 50 straight weeks, you would be exposed to approximately 1.4 mSv of x-ray radiation. But if you moved back to 50 cm (which is the normal CATSA operator position), you would only be exposed to approximately 0.014 mSv – a hundred times less than the amount at 5 cm.

The entrance and exit to the machine are shielded by curtains which can move around. As a result, these areas will likely have the highest radiation levels found around the machine. The distance principle of radiation protection can be put into action by avoiding close contact with these areas as much as possible and never reaching past these curtains into the machine while x-rays are being produced. This is one of the reasons CATSA machines are equipped with plastic or metal barriers at the entrance and exit. These barriers make it more difficult for someone to put a body part close to the curtains, or even inside the machine.

Shielding

Putting materials between you and the radiation source will reduce the amount of radiation that can reach you as some of it will be attenuated by this shielding material. The type of material used to make the shielding will affect how good the shielding is at attenuating the radiation. The heavier and thicker the material is, the better it is at attenuating x-rays. The machines are designed so that the built-in shielding is sufficient to reduce the number of x-rays escaping from the machine to a negligible level.

In order for the curtains to shield against as much radiation as possible, they should be hanging straight down, with no bends or twists in them, while the x-rays are being produced. If the machine is producing x-rays while bags are entering or exiting the machine (which can happen with Heimann X-rays machines at PBS) the curtains will be displaced at those times, allowing more radiation to escape from the machine.

This is where both the time and distance principles come into play to compensate for the shielding being moved. The Heimann machine only produces X-rays when it is scanning a bag (an application of the time principle), and the shrouds at the entrance and exit of the machine prevent both the public and screening officers from getting too close to the moving curtains (an application of the distance principle).

How does time impact radiation exposure?

The longer a person is exposed to radiation, the more energy the body will absorb from the radiation. This is not to be mistaken that with the idea that the radiation will somehow stay in the body and possibly make it radioactive. An x-ray transferring its energy to the body is similar to a person getting hit by a baseball. When the baseball hits the person's body it transfers its energy to the body. The ball loses its energy and stops moving. The body absorbs this energy which can cause blood vessels to break which shows up as a bruise. When the body absorbs the energy of the baseball, it does not actually absorb the baseball and the absorbed energy is not somehow "stored" in the body. Upon being transferred, the energy is immediately used to cause blood vessels to break. In the same way, if energy from radiation is absorbed by the body, it is not stored in the body. The energy will immediately affect the body by breaking bonds in molecules or affecting the cells in the body.

It is the absorption of energy that may lead to health effects. Every time radiation interacts with the body, it has the potential to damage the cells in the body, possibly leading to health effects. As more and more energy is transferred to the body by the radiation, the chances of causing a health effect increases. Limiting the amount of time a person is exposed to radiation, for example, limits the amount of energy that is transferred to the body by the radiation which in turn limits the chances of causing a negative health effect.

▶ How does distance impact radiation exposure?

X-rays are concentrated in a small area right around the source but spread out over a larger area as they move further and further away from the source. The closer you stand to the source, the more x-rays will contact your body. Because the same number of x-rays takes up a larger amount of space further away from the source, if you stand further away then fewer x-rays will actually come in contact with your body. So moving further away from the source of x-rays will reduce the amount of radiation you are exposed to.

In *Figure 13* below, the circle on the left represents an x-ray source and the arrows represent x-rays. When standing closer to the x-ray source, the person's body is contacted by more x-rays than when she stands further away from the x-ray source.

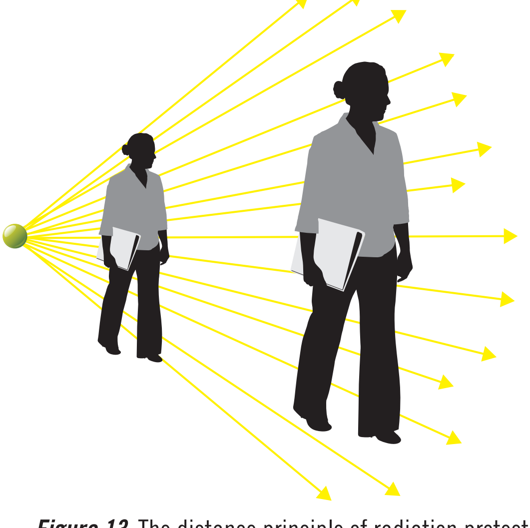

Figure 13: The distance principle of radiation protection.

▶ What is meant by the "Inverse Square Law" of distance for x-rays?

The inverse square law describes how quickly the radiation exposure level decreases as you move away from the source of the radiation. It states that as you move away from an x-ray source, the exposure decreases by a factor which is the inverse of the square of the distance. This means that if you double your distance from the source, your exposure falls to 1/4 of what it was where you were originally standing. If you triple your distance from the source, your exposure falls to 1/9 of what it was where you were originally standing. See *Table 3* for some one example of how the inverse square law affects the radiation exposure rate at various distances.

Distance from x-ray source	Amount of radiation exposure
5 cm	0.5 mR/h
10 cm (2 times 5 cm)	0.125 mR/h (1/4 of 0.5 mR/h)
15 cm (3 times 5 cm)	0.056 mR/h (1/9 of 0.5 mR/h)
20 cm (4 times 5 cm)	0.031 mR/h (1/16 of 0.5 mR/h)
25 cm (5 times 5 cm)	0.02 mR/h (1/25 of 0.5 mR/h)
50 cm (10 times 5 cm)	0.005 mR/h (1/100 of 0.5 mR/h)
100 cm (20 times 5 cm)	0.00125 mR/h (1/400 of 0.5 mR/h)

Table 3: Example of the inverse square law.

▶ How does shielding impact radiation exposure?

As radiation travels through shielding, interactions take place which can reduce the energy and intensity of the radiation. For example, when an x-ray encounters a shielding material, it can interact with the atoms of that material. The interactions cause the x-ray to lose energy (attenuation). It is possible for the x-ray to lose all its energy in this way, which would mean that as the x-ray travels through the shielding, it could disappear. It is also possible for an x-ray to travel through the shielding material and not interact with any of the atoms of that material. Because of this possibility, no amount of shielding can be said to completely stop all x-rays. However, shielding is usually designed to reduce the amount of radiation that is ends up passing through it to a level so low it is indistinguishable from the level of background radiation.

What kinds of shielding are best used against radiation?

No one kind of shielding is perfect for all types of radiation in all situations. We found out earlier that the dead layer of skin on our bodies can be used to stop alpha radiation and plastic is excellent for stopping beta radiation. These materials would not work well at all for stopping x-rays since x-rays are far too energetic and could easily travel through those materials. The best materials for shielding against x-rays are ones that are very heavy. The heavier the material is, the more chances that the x-rays will interact with the atoms of the material. The most common material used for shielding against x-rays is lead.

Baggage X-Ray Machines

▶ What is a baggage x-ray machine?

The *Health Canada Safety Code 29* definition of a baggage x-ray inspection system is "a machine that is specifically designed to generate x-rays in the low-to-medium keV energy region for use in security screening operations" that is designed for "the examination of carry-on baggage, personal items, sealed mail, etc." This definition includes the Hi-Scan systems used for inspection of carry-on baggage (*Figure 14*) as well as the VIS/VDS (*Figure 15*), and CT scan (*Figure 16*) x-ray systems used at the airports.

Figure 14: Hi-Scan x-ray machine used at pre-board screening.

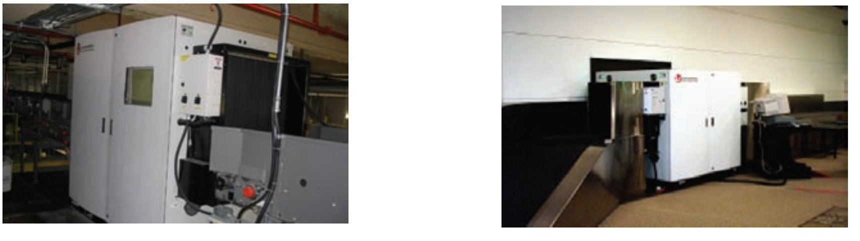

Figure 15: VIS and VDS x-ray machines. The in-line VIS108 machine is shown on the left and the stand alone VDS108 machine used for check-in of oversized baggage is shown on the right.

Figure 16: The CTX 2500 x-ray machine.

What does "low-to-medium keV energy" mean?

The energy of radiation is measured using the unit electron volt (eV). An electron volt is a measurement of energy similar to a calorie or joule, only it is much smaller than these units and it is used to measure how much energy radiation has. More commonly, radiation will have energy in the range of kilo-electron volts (keV) or mega-electron volts (MeV). 1 keV equals 1 000 eV and 1 MeV equals 1 000 000 eV.

"Low-to-medium keV energy" as stated in *Health Canada Safety Code 29* refers to machines that emit x-rays with energies of 350 keV or less. Baggage x-ray machines, as well as radiation therapy devices for superficial x-rays, dental x-ray machines, and many industrial x-ray machines, fall into this category. Some cargo x-ray scanners use x-rays that can have energies in the MeV range. These cargo scanners are very high energy x-ray machines and would be subject to more stringent regulations.

It should be pointed out that the energy of the x-rays is not the only factor in the dose that will be delivered by the x-ray machine. The intensity of the x-ray beam (the number of x-rays that are produced) and the length of exposure to the x-rays are also major factors in the amount of radiation dose delivered by the machine. Dental x-ray machines often use x-rays with energies around 70 keV. However, a dental x-ray exam can lead to a dose about ten times higher than the dose delivered to an object inside a baggage x-ray machine after one scan.

How does a baggage x-ray machine work?

A baggage x-ray machine looks like a large cabinet with an entrance and exit located on opposite sides of the machine. A conveyor belt runs from outside of the entrance, through the machine, to outside of the exit. Baggage is placed on the conveyor belt which transports it inside the machine where it is x-rayed. When the x-ray is complete, the baggage is taken along the conveyor belt through the exit and outside of the machine.

The x-rays are produced by something called an x-ray generator, which is located within the cabinet of the machine.

When a bag is being inspected, an x-ray beam is directed at the bag. The x-ray beam is attenuated by the bag as well as the objects within the bag. This means more x-rays will enter the bag and the objects within than will pass through and come out of the other side of the bag. Thicker and heavier materials within the bag will result in a higher attenuation of the x-ray beam, while lighter and thinner materials will result in less attenuation of the beam. On the side of the cabinet opposite the beam are sensors that detect the x-rays which pass through the bag. Based on the number of x-rays that passed through the bag and their energies, the sensors, which are similar to the sensors in a digital camera, will represent the x-ray detections as light and dark spots, giving an image of the objects within the bag. In the image on the screen, items that cause greater attenuation of the x-ray beam (allow fewer x-rays to pass through) appear darker than items that cause very little attenuation of the beam (allow more x-rays to pass through). The image may also be adjusted so that different densities show up as different colours (blue and orange, for example) to assist the operator to quickly identify items of concern.

What are the differences between baggage x-ray machines and other types of x-ray machines? (e.g., medical, dental, cargo, etc.)

Many x-ray machines operate on the same principle, though they are used for different purposes. Medical, dental, cargo, and many industrial x-ray machines are used to look inside objects, just like baggage x-ray machines. The differences are in the designs.

Medical and dental x-ray machines are used to look inside our bodies. The x-rays in these cases are not contained in any cabinet. This is considered an “open beam,” since the x-ray beam is open to the room and not completely surrounded by shielding.

Cargo x-ray machines serve a similar purpose to baggage x-ray machines. However, since the objects they are x-raying are so large, the x-ray beam is far more energetic and therefore more of a hazard. These x-ray machines come in both cabinet and “open beam” systems.

Industrial x-ray machines are much like cabinets with doors on them. The object is placed inside the machine and the door must be properly closed in order for the machine to produce the x-ray beam.

Regardless of the type of machine a worker uses, radiation doses must be kept to a minimum. *Table 4* below shows the average annual dose received by various types of workers.

Occupation	Average annual radiation dose for 2004 (mSv)
Aircrew	0.46
Dentist	0.02
Medical radiation technologist	0.10
Radiologist (diagnostic)	0.19
Radiologist (therapeutic)	0.10
Baggage x-ray machine operator	Estimated to be less than 0.014 mSv

Table 4: Annual radiation doses for various occupations (values obtained from Health Canada).

What kinds of baggage x-ray machines are used by CATSA?

Hi-Scan x-ray machines are used primarily for pre-board screening of carry-on baggage.

VIS and VDS units are used to examine oversized and checked baggage. The difference between them is that the VIS machines are located within the baggage sorting system whereas the VDS units are usually stand-alone and used for oversized baggage.

GE/InVision CT scan x-ray machines are also used for checked baggage. The two models used are the CTX 2500 and the CTX 9000. These machines are computed tomography x-ray machines, similar to those used in health care (except those used in health care do not have curtains at the entrance for additional shielding). Unlike the other units, the x-ray tube moves around the baggage and it takes many x-rays from different angles in order to get a three dimensional image of the object and make object identification easier.

All the x-ray machines used by CATSA are cabinet x-ray machines.

Are the x-rays always on when operating a baggage x-ray machine?

No. The x-ray machine can have the power turned on but that does not mean that x-rays are being produced. When the power to the machine is turned on, the machine is warmed up and ready to produce x-rays. The machine then has to be activated, through the push of a button or flick of a switch, to cause it to produce x-rays. There are red lights located at the entrances and exits of the machines. When those are lit, they indicate that x-rays are being produced. When those lights are off, no x-rays are being produced.

CATSA's baggage x-rays machines are also designed with special failsafes that do not allow x-rays to be generated under certain conditions, especially those that are operated manually by a screening officer. These failsafes include:

Footmats
If an operator is not standing on the footmat, x-rays cannot be produced. They are there to ensure that the x-ray machine can only produce x-rays when an operator is there controlling it.

Interlocks
Interlocks are used so that if the panels are opened, x-rays cannot be generated. This does not include the displacement of the curtains at the entrance and exit to the machine.

E-Stops
If an e-stop (which stands for "emergency stop") is pressed, x-rays cannot be generated until the e-stop is reset.

Key switches
If the key is not in the keyhole, or if the switch is turned to the OFF position, x-rays cannot be generated.

With some of the machines (all those in PBS, and the CTX 2500s in HBS), the operator stands next to the x-ray machine and controls when x-rays are produced. Other machines (all others in HBS) are typically operated remotely.

▶ How much radiation do the CATSA x-ray machines produce each time they scan a bag?

In a typical scan, a bag will receive a radiation dose of approximately 2 µSv (micro-sievert) from the Heimann x-ray units. This is about ten times less than the radiation dose from an average dental x-ray examination.

Note: A micro-sievert is one millionth of a sievert.

▶ How much shielding do CATSA baggage x-ray machines have? Is it enough to protect me from radiation at all times?

According to *Health Canada Safety Code 29*, in order to comply with regulations, at 5 cm away from any external surface of the x-ray unit, the dose rate can be no greater than 5 µSv/h (micro-sievert per hour). This is considered a negligible level of radiation. When the x-ray machines are manufactured, they are made with enough shielding to ensure that the dose rate at 5 cm from any surface of the machine is less than the 5 µSv/h limit.

Also, as noted in *Safety Code 29*, x-ray machines must be tested regularly by trained maintenance personnel to ensure that the dose rate at 5 cm from any surface of the machine is still within the 5 µSv/h limit.

The machines used by CATSA are made with the following shielding materials:

- **Hi-Scan:** 4.5mm lead
- **VIS/VDS:** 1.524mm lead and 1.524mm steel

▶ How do curtains stop or reduce radiation?

As with all shielding, the curtains at the entrance and exit to the x-ray machine cannot stop all the radiation from escaping the machine, but they do reduce the amount of radiation that gets out. They do this in the same way as the rest of the shielding around the unit. The curtains are made of a specific material and thickness in order to shield against the x-rays produced by the machine. There are two layers of curtains which help to minimise any gaps that might occur between sections of the curtains.

To be most effective, the curtains should not be displaced while x-rays are being produced by the machine. During x-ray production, the curtains should hang straight down.

▶ How does the location where I sit/stand affect my radiation exposure?

Where you sit or stand while you are around the x-ray machine follows the distance principle of radiation protection. The further away from the machine you are, the less radiation you will be exposed to.

You should also be aware of the entrance and exit to the machine. Because the curtains are able to move, these areas are the most vulnerable to leakage radiation. This is one of the main reasons why the plastic and metal barriers (we call them "shrouds") are in place – to prevent persons from getting too close to these openings.

▶ Can something going through a baggage x-ray machine (e.g., food, clothes, metal, etc.) become radioactive?

The answer to this question is absolutely not. There is no way for anything going through the x-ray machine to become radioactive. Anything that has gone through the x-ray machine is perfectly safe to handle and food is safe to consume.

The x-ray machine also will not affect any medications that are put through it. The energies are far too low to have any affect on the medication.

The energy of the radiation from CATSA's x-ray machines is too low to cause noticeable effects on unprocessed camera film up to at least 800 ASA. However, multiple scans of unprocessed camera film could start to cause noticeable damage to the film.

How much radiation do I receive if I work 40 hours a week next to a baggage x-ray machine?

Based on measurements taken over the last three years by the maintenance service provider for the x-ray machines and ones taken by the CATSA testing analysts, the approximate dose rates at 5 cm from the curtains of the machines (where the dose rate is the highest) are as follows:

- 0.4 µSv/h for the Heimann Hi-Scan
- 0.5 µSv/h for the VIS/VDS
- 0.7 µSv/h for the CTX 2500

Using the highest dose rate of 0.7 µSv/h from the CTX 2500, if you worked for 40 hours a week while standing within 5 cm of the curtains, with it constantly producing x-rays, you would receive a weekly dose of 28 µSv or 0.028 mSv. If you worked for 50 weeks in the year, your annual x-ray dose would be 1.4 mSv.

In reality, the doses calculated above are an overestimation. Generally you will not spend your entire shift working within 5 cm of the curtains – especially since CATSA recommends that you stand at least 50 cm from the curtains at all times. Furthermore, the machine certainly will not be generating x-rays constantly while you are working since each bag is only exposed to x-rays for a few seconds while being scanned. Therefore, in reality, your annual x-ray radiation dose should be less than 1.4 mSv – standing at 50 cm for the same amount of time, your annual x-ray radiation dose would be closer to 0.014 mSv!

Baggage X-Ray Regulations in Canada

▶ What does the government do to protect me from excess radiation?

Before the x-ray system even reaches the workplace, the government requires that it comply with the *Radiation Emitting Devices (RED) Act*. The *RED Act* and associated regulations detail the safety devices that must be in place on the machine and outline the standards the machine must meet in order to ensure safe operation. A machine cannot legally be operated in Canada unless it meets *RED Act* standards. The *RED Act* can be found on the internet at http://lois.justice.gc.ca/en/R-1/.

Once the baggage x-ray system has passed the requirements of the *RED Act* and is installed in a workplace, *Health Canada Safety Code 29* comes into effect. This safety code details the responsibilities of the owner, user, and maintenance personnel and outlines the safety standards that must be adhered to in regards to the safe operation and maintenance of the machine.

Health Canada conducts periodic inspections of the x-ray systems at federal workplaces to ensure that *Safety Code 29* is being complied with. These inspections include taking radiation surveys of the equipment to ensure it still meets *RED Act* standards, auditing the maintenance provider to ensure that they are maintaining the machines regularly and properly, and interviewing operators to ensure that they are knowledgeable of *Safety Code 29*'s requirements.

▶ What is *Safety Code 29*?

It is a document issued by Health Canada that outlines the federal regulations, policies, and procedures governing the safe use of baggage x-ray inspection systems. In regards to the baggage x-ray system, *Safety Code 29* states the responsibilities of the system owner, system operators, and maintenance personnel. This safety code also details the regulatory standards, installation requirements, maintenance responsibilities, and radiation protection survey requirements as they apply to baggage x-ray systems.

In addition, *Safety Code 29* deals with issues in regards to the health and safety of the general public as well as the operators of the x-ray machines. It presents procedures that must be followed in order to minimise the x-ray dose to anyone who is in the vicinity of the machine. The use of dosimeters and annual radiation dose limits are also discussed in *Safety Code 29*.

What about the other safety codes that talk about x-rays? Do they apply to my workplace?

Health Canada has many safety codes concerning x-ray machines in various environments. They are specific to the type of x-ray machine and the purpose for which it is used. *Safety Code 29* is the only one that applies to baggage x-ray machines, and thus, to screening officers.

Table 5 lists some of the safety codes for x-ray systems and the types of machines to which they apply.

Health Canada Safety Code	Area of application
20A	Medical diagnosis x-ray equipment
28	Veterinary x-ray equipment
29	Baggage inspection x-ray equipment
30	Dental x-ray equipment
31	Computed Tomography Installations (specifically for medical uses)
32	Analytical x-ray equipment (for microscopic examination or atomic analysis of materials)
33	X-ray machines used for mammography
34	Industrial x-ray equipment (includes x-ray systems used to check the integrity and structure of components or machines used for electron beam welding)

Table 5: Health Canada Safety Codes.

What is the maximum amount of radiation that Health Canada says people should be limited to?

Health Canada follows the international guideline set by the ICRP that states radiation workers should be limited to a maximum radiation dose of 20 mSv per year. This international guideline is followed by many countries around the world. In reality, the goal is to keep radiation doses much lower than this limit, as per the ALARA principle. For members of the public, including workers who are not designated as radiation workers, yearly radiation dose limit is 1 mSv. For the purposes of dose limits, baggage x-ray machine operators fall into the category of members of the public.

Table 6 was taken from ICRP Publication 60, 1990. In Canada, occupational limits are applied only to those designated as "radiation workers."

Application	Dose Limit	
	Occupational	Public
Effective dose	20 mSv per year averaged over defined periods of 5 years	1 mSv per year
Annual equivalent dose in:		
Lens of the eye	150 mSv	15 mSv
Skin	500 mSv	50 mSv
Hands and feet	500 mSv	-

Table 6: ICRP recommended dose limits.

Why aren't screening officers considered radiation workers?

For regulatory purposes, employees are generally not designated as "radiation workers" unless there is a probability of them receiving an annual radiation dose greater than 1 mSv (the public dose limit). Studies have shown that baggage x-ray machine operators receive well below 1 mSv of radiation dose per year from workplace activities and so they are not designated as radiation workers.

Why are radiation workers allowed to be exposed to 20 times more radiation than members of the public, including screening officers?

When setting recommended dose limits, the ICRP considers what most people would view as an acceptable health risk. They recognise that all occupations carry some amount of risk to the health of employees and in setting dose limits, the aim is to limit the risk to radiation workers to a level comparable to workers in other occupations.

Designating workers as “radiation workers” is for regulatory purposes. This designation requires employers to outline the risks of working with radiation to the workers and requires the workers to acknowledge and accept that risk. Because these workers are likely to be exposed to higher levels of radiation than those in the “public” designation, the controls over work practices and safety procedures for radiation workers are stricter to ensure that the radiation dose these workers receive is kept below the regulated limits.

What happens if I reach the 1 mSv annual limit?

In the highly unlikely case that you were to reach that limit, your employer would be required to ensure that you do not work in any areas that would further add to your radiation dose. An investigation would also have to be conducted to determine what led to you receiving a dose above the set dose limit and corrective action would be taken to try and ensure that such a thing does not happen again in the future.

How can I measure how much radiation I’ve been exposed to?

There are a couple of ways the amount of radiation to which a person has been exposed can be measured. An estimate of dose can be made with the help of a radiation survey meter. The specific dose a person has been exposed to can be measured through the use of a personal dosimeter.

What is a radiation survey meter?

A radiation survey meter is an instrument that is capable of detecting ionising radiation, such as x-rays. The meter itself will either be equipped with a "window" which allows radiation to enter the detector or a probe will be attached to the meter. The probe will have a "window" to allow the radiation to penetrate into the probe where it will be detected and the level of radiation will be registered by the meter. Probes come in different shapes and sizes. The selection of a probe depends on the type of radiation to be measured, the level of the radiation exposure, among other considerations.

A radiation survey meter (*Figure 17*) will generally measure the radiation exposure rate in mR/h or it will give an indication of the radiation dose rate in mSv/h. Remember that 1 mR/h is approximately equivalent to 0.01 mSv/h.

Figure 17: Example of a typical radiation survey meter.

What is a dosimeter?

A dosimeter is a special badge that is clipped on your clothing while you work to measure your radiation dose. It contains a special material that reacts when radiation strikes it. In order to determine your dose, the dosimeter is sent back to a licensed laboratory that uses specially designed machines to "read" the dosimeter.

A typical dosimeter can be appropriately filtered in order to differentiate between types of radiation, such as beta and x-rays. It cannot differentiate between the dose caused by different sources of radiation, such as the dose from natural background radiation and the dose caused by an x-ray machine. However, when using dosimetry, a control dosimeter is kept away from the occupational source of radiation of concern (in this case the baggage x-ray scanners) in order to get a measure of the background radiation. Knowing the level of the background radiation makes it possible to calculate the dose from the occupational radiation source.

A dosimeter cannot tell a person if they were exposed to more radiation one day and less the next. It simply records the total accumulated dose over the period for which it is worn and that result is obtained when it is “read” by a licensed laboratory.

Should I wear a personal dosimeter?

According to *Health Canada Safety Code 29*, studies have shown that the amount of radiation received by baggage x-ray machine operators is negligible. As a result, it has been determined that the use of dosimeters is, as Health Canada puts it, “neither required nor recommended.”

What are my responsibilities as a baggage x-ray machine operator to ensure safety for myself and others?

As an operator, you must do the following:

- Receive training on the proper operation of the x-ray system.
- Demonstrate that you are competent to operate the system.
- Read and understand the radiation safety guidelines, proper operating procedures, and sections 3.2 and 4.2 of *Safety Code 29*.
- Stop operating the equipment in the event of an unsafe situation or radiation accident and immediately notify the appropriate authority.
- Be responsible for carrying out the work in a safe manner.

The above list is not detailed or exhaustive. Please refer to *Safety Code 29*, section 3.2 for more information.

What are CATSA's responsibilities as an owner of an x-ray machine to ensure safety for the screening officers?

As the x-ray machine owner, CATSA holds the ultimate responsibility for the safe operation of the machine. Some of the responsibilities of the owner are as follows:

- Ensure that prior to using the x-ray inspection system operators and maintenance personnel receive training on the proper operation of the x-ray machine as well as on the hazards associated with it.
- Institute radiation safety guidelines and safe operating and emergency procedures in the workplace.
- Make *Health Canada Safety Code 29* available to operators and maintenance personnel for reference.
- Ensure that all operators and maintenance personnel have read and understood the radiation safety guidelines, proper operating procedures, and relevant parts of *Safety Code 29*, prior to using the x-ray system.
- Establish a maintenance program for the equipment.
- Respond appropriately in the event of a radiation accident or unsafe situation.

The above list is not detailed or exhaustive. Please refer to *Safety Code 29*, section 3.1 for more information.

What is Health Canada's role to ensure safety for myself and others?

The primary functions of the regulatory authority (Health Canada) are: to develop standards and provide guidance; to verify, ensure and enforce compliance with the standards and safety requirements; and to conduct evaluations of industrial x-ray equipment and of organizations carrying out radiography.

If Health Canada determines that either the machines or the operating practices are unsafe, they have the authority to immediately order the shutdown of the unsafe machines until they and/or the operating procedures are guaranteed to meet the safety requirements again.

Glossary of Terms

Note: For illustration of terms see *Figure 18* at end of glossary.

Acute radiation exposure Radiation exposure of a significant level, generally caused by some sort of accident or unusual event, that occurs over a short period of time.

Alpha particle A particle made up of two protons and two neutrons. It has an atomic mass number of four and is a type of radiation generally emitted from heavy atoms (atoms with an atomic number greater than 82).

Atom The basic building block of all matter. Atoms make up all physical things in our world. Tables, chairs, soil, paper, our bodies, are all made up of atoms. Even the air around us is made up of atoms. Atoms resemble our solar system; they have a very heavy centre (nucleus) with much smaller particles (electrons) orbiting around the centre. Atoms are very tiny. It takes millions of atoms to make up the thickness of one strand of hair.

Beta particle A particle with properties similar to an electron. It is a type of radiation emitted from the nucleus of a radioactive atom. It has very little mass and can have a positive or negative charge.

Electromagnetic wave This is what visible light is made up of. Visible light is made of the same “stuff” that makes up radio waves, micro waves, gamma radiation, and x-rays, the only difference between all these things is the amount of energy each has.

Electron A tiny negatively charged particle with a very small mass. In an atom, it is found orbiting around the nucleus, much like the planets orbit around the sun in our solar system.

Gamma radiation A high energy electromagnetic wave emitted from the nucleus of a radioactive atom. A gamma ray has no mass and no charge. It is pure energy.

Neutron An electrically neutral particle found in the nucleus of an atom. It has approximately the same mass as the proton.

Nucleus The massive centre of an atom. It is made up of smaller particles called protons and neutrons.

Proton A positively charged particle found in the nucleus of an atom.

Radiation units In order to have a better understanding of the physical and health effects of radiation, various quantities are used. These quantities all have associated units. The table below summarises the quantities and units.

Radiation Quantity	Associated Unit	Abbreviation
Absorbed dose	milli-gray	mGy
Equivalent dose	milli-sievert	mSv
Effective dose	milli-sievert	mSv
Exposure	milli-Roentgen	mR
Exposure rate	milli-Roentgen per hour	mR/h

Table 7: Summary of radiation quantities and units.

When referring to radiation doses caused by x-rays, mGy and mSv are equivalent units.

The units you will most likely encounter are mSv and mR. mSv is used to measure the radiation dose received by a person. It is found in the regulations when referring to the radiation dose limit. mR is used when measuring the amount of radiation coming from the x-ray machine. 1 mR is equivalent to a radiation dose of 0.01 mSv. It is most likely the exposure rate will be measured and will be given in mR/h, indicating the amount of radiation coming out of the machine every hour. 1 mR/h is equivalent to 0.01 mSv/h.

Subatomic particle A particle that is contained within an atom.

X-ray High energy electromagnetic radiation similar to a gamma ray. Unlike gamma rays, x-rays are not emitted from the nucleus of a radioactive atom. X-rays are created when high energy electrons slam into a target and lose much of their energy. Most often, x-rays are created by special machines.

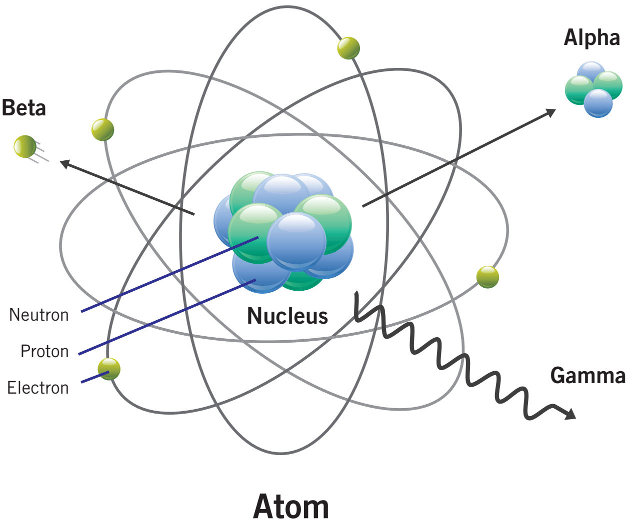

Figure 18: Atomic diagram for illustration of glossary terms.

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