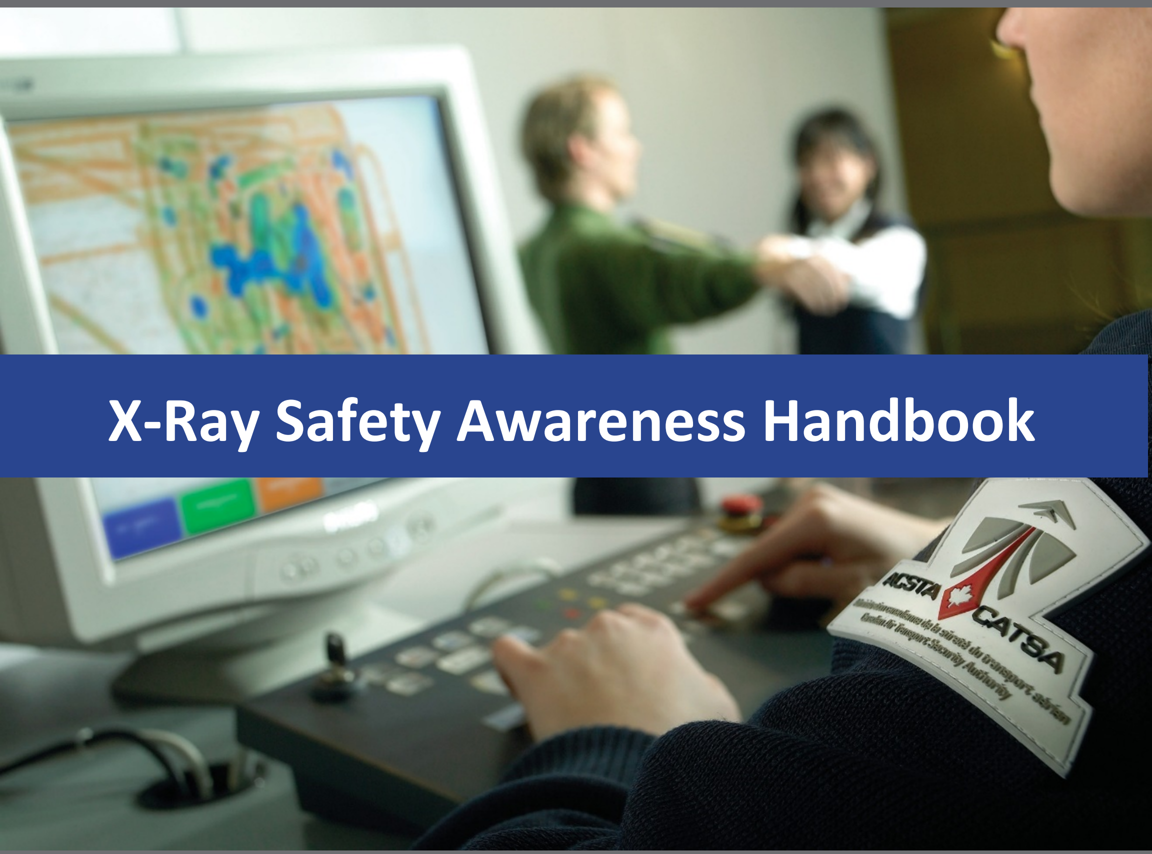
International Safety Research Inc.

X-Ray Safety Awareness Handbook



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Canadian Air Transport Security Authority

Administration Canadienne de la sûreté du transport aérien

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CATSA ACSTA

Canadian Air Transport Security Authority

X-Ray Safety Awareness Handbook

For Baggage X-Ray Machine Operators

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Foreword

The third edition of this informational handbook was created by International Safety Research, building on earlier editions created by the Radiation Safety Institute of Canada, for the Canadian Air Transport Security Authority (CATSA). 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.

Acknowledgements

The Canadian Air Transportation Security Authority wishes to express its appreciation to International Safety Research for compiling the third edition of this handbook.

CATSA further recognizes the contributions of Ms. Tara Hargeaves and Dr. Reza Moridi for compiling the original version of this handbook.

Introduction to Radiation

What is radiation?

Radiation is simply energy emitted in the form of particles or waves. You cannot detect it with your usual senses: you cannot see it, smell it, or feel it. Radiation can be emitted from many sources, including food, the sun, and rocks. Even you are naturally radioactive! Objects that emit radiation are called radiation *sources*.

Radiation sources are substances such as solids, dusts, gases, vapours, or, in the case of baggage x-ray machines, an x-ray generator. Usually, you can see or touch a radiation source. Radiation can occur from natural sources (e.g., background radiation) or from man-made sources (e.g., x-ray machines).

When radiation penetrates an object or a living organism in its path, such as a person, some of the energy of the radiation may be absorbed. This absorbed energy is called radiation *dose*. Dose is the physical effect, or consequence, of the radiation.

A good way to understand *radiation exposure* is to connect the three concepts just described - *source*, *radiation*, and *dose* – using the “Tree, Apple and Hit on the head” analogy. In this analogy, the source is the tree (what generates the radiation), the apple is the radiation that travels from the tree to the human body and the dose is the hit on the head which represents the physical health effect resulting from the apple (radiation).

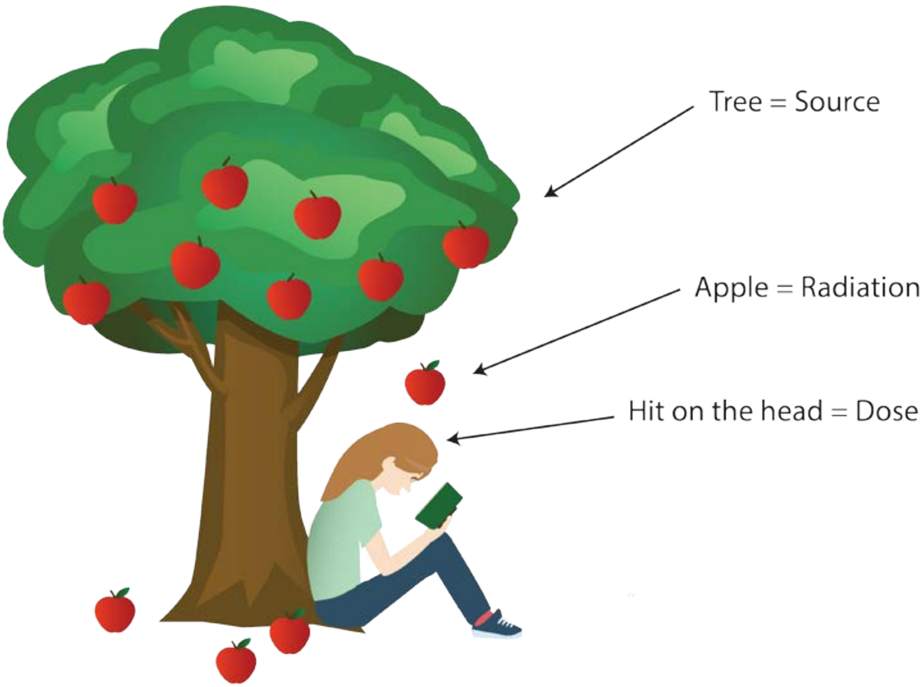

Figure 1: Tree, Apple and Hit on the head Analogy

Radiation dose is represented in units of Sieverts (Sv). One (1) Sievert is considered a very large dose. Therefore, when discussing doses received by people, we normally express the doses in terms of milli-Sieverts (mSv). One (1) mSv is one thousandth (1/1000) of a Sv (i.e., 1 Sv = 1000 mSv).

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

What are X-rays?

X-rays are electromagnetic waves, similar to radio waves and light, but at a higher transmission frequency and higher energy. X-rays can penetrate far through most materials. However, by using an appropriate material, such as lead, they can be effectively shielded. This is discussed in more detail later in the handbook.

X-rays are most often produced artificially by machines. When these machines are turned on, that doesn't mean they are producing x-rays. The operator of the machine has to give the machine a specific command (push a button, flick a switch, step on a mat or press a pedal) for it to create x-rays.

Unlike other types of radiation, x-rays cannot cause objects in their path to become radioactive. Think of an x-ray as being similar to a light beam. Once the light source is turned off, the light beam is gone and it is dark. Screening officers therefore do not face any risk of accidentally bringing radioactive contamination (e.g., dust-like radioactive sources) home at the end of the work day.

What are ionizing radiation and non-ionizing radiation?

Ionizing radiation is radiation with enough energy to remove electrons from atoms exposed to it. Losing electrons in this way causes the atom to become charged or ionized. Ionized atoms are highly reactive and can damage the cells of the body, potentially resulting in adverse health effects. X-rays are a type of ionizing radiation.

Non-ionizing radiation, such as radio waves or visible light, does not have enough energy to ionize atoms and therefore poses little or no possibility of adverse health effects. An example of a man-made source of non-ionizing radiation is a typical body scanner.

The electromagnetic spectrum, illustrated in ***Figure 2***, shows some of the most familiar forms of electromagnetic radiation. As the illustration shows, the energy of the radiation increases from left to right, with gamma rays being the highest energy electromagnetic radiation.

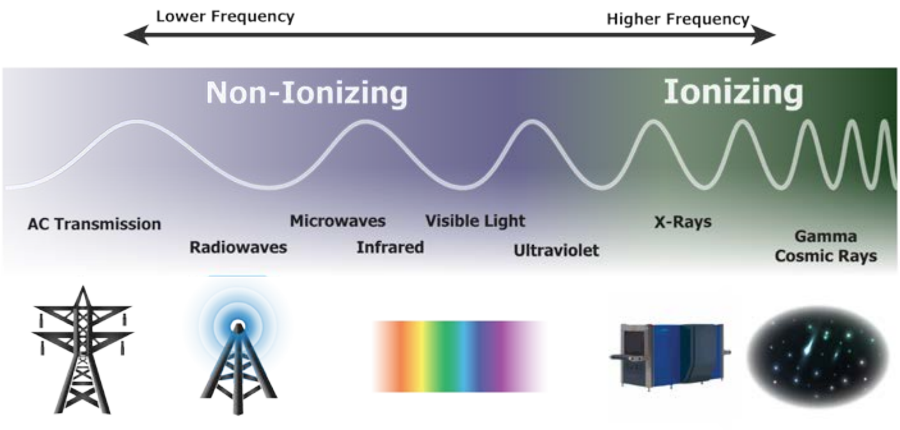

Figure 2: The electromagnetic spectrum

▶ 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 another direction – this is called "scatter" (***Figure 3***). 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 4***).

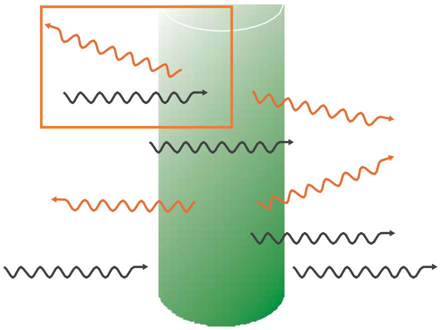

Figure 3: X-ray scatter. When x-rays encounter an object, some will interact and be scattered in different directions while others will travel through the object unimpeded. In this diagram, the scattered x-rays are shown in red.

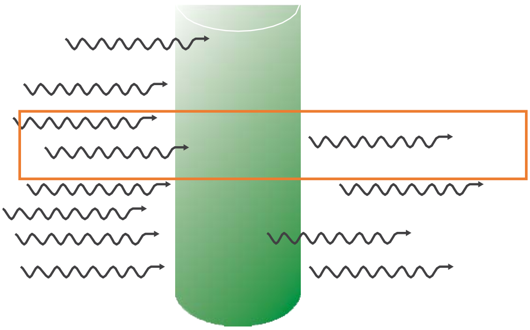

Figure 4: X-ray attenuation. When an x-ray beam encounters an object, some of the x-rays will interact with the atoms in the object and lose all of their energy. As a result, fewer x-rays make it out the other side of the object.

What are internal and external radiation exposures?

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

Radiation exposure is external if the source of the radiation is outside of the body (*see* ***Figure 5***). Exposure to x-rays is an example of an external radiation exposure. The source of the radiation, the x-ray tubes, is located outside of the body and therefore, it will never expose a person to radiation from inside the body.

Figure 5: External radiation exposure. A baggage x-ray machine is a source of external radiation exposure

Radiation exposure is internal if the source of the radiation is inside the body. This may occur if radioactive particles enter the body through eating, drinking, breathing, or through a wound contaminated with radiation. Potassium-40, a radioactive form of potassium naturally found in bananas and milk is a common example of a source of internal radiation exposure (see ***Figure 6***). 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.

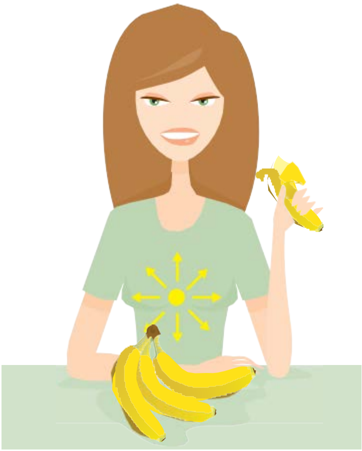

Figure 6: Internal radiation exposure. We are all exposed to radiation internally from the foods we eat. When we eat food, we take small amounts of naturally occurring radioactive atoms into our bodies

▶ 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". According to the Canadian Nuclear Safety Commission, Canadians receive doses of approximately 1.77 milli-sieverts (mSv) of radiation every year from background radiation and the total worldwide average effective dose is approximately 2.4 mSv[1]. The term *effective dose* is used to indicate that the damaging properties of different types of radiation have been taken into account when combining them to form an estimate of total dose.

[1] Dose values taken from CNSC publication, *Introduction to Radiation,* 2012.

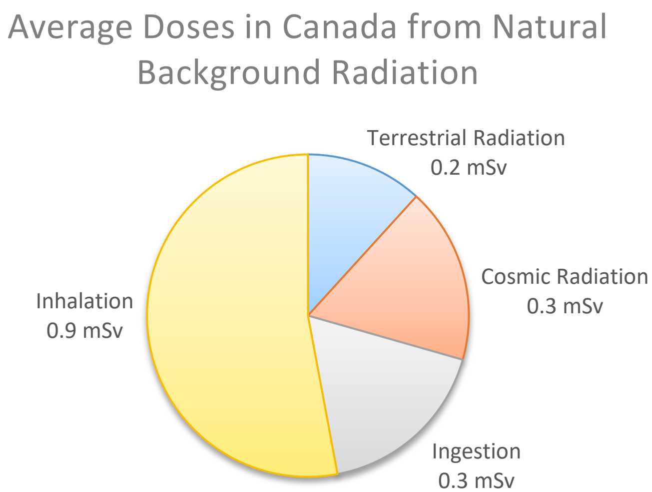

Figure 7: Average Doses in Canada from Natural Background Radiation[2]

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

Cosmic radiation

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

Terrestrial radiation

The Earth contains all types 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 that then becomes an internal source of radiation exposure.

Ingestion (e.g. food)

The Earth's food gathers nutrients and minerals from the soil. Some of these nutrients and minerals contain radioactive atoms which are incorporated into the food. When we eat the food, we consume the radioactive atoms that become an internal source of radiation. Eating bananas is one example of how

[2] Dose values taken from CNSC publication, *Introduction to Radiation,* 2012.

we receive internal radiation exposure. Carbon-14, contained in all plant and animal matter, is another example of a radioactive atom found in foods. In addition, trace amounts of radioactive minerals are naturally found in the contents of drinking water.

Inhalation

Most of our dose from natural radiation results from inhalation of radioactive gases (e.g. radon) in air. Radon is a colorless and odorless gas that is produced by the decay of uranium. Radon is usually found in igneous rock and soil and can seep into our homes, exposing the occupants.

As seen above, the dose received by a person from natural radiation depends on multiple factors. ***Figure 8*** presents an average annual effective dose from natural sources around the world.

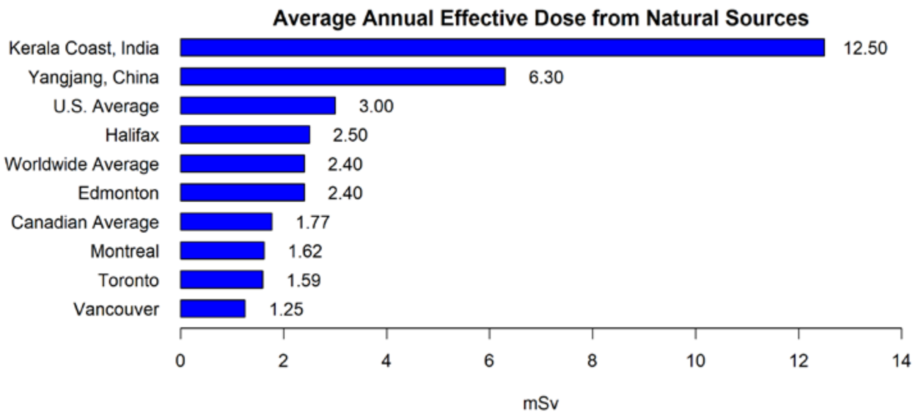

Figure 8: Average Annual Effective Dose from Natural Sources[3]

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 minimize 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.

[3] Dose values taken from CNSC publication, *Introduction to Radiation,* 2012.

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).

How much does radiation increase my risk of cancer?

The Canadian Cancer Society estimates Canadians face an overall probability of dying from cancer of approximately 25%. To illustrate the significance of cancer risks incurred from radiation, imagine a group of Canadians who engage in some occupation or activity that increases their annual radiation doses by 1 mSv. For each year at the increased dose, the risk of an eventual death from cancer for the members of this group increases by 0.005%. The table below shows the effect of 10, 20, 30 and 40 years of the additional annual 1 mSv doses on the cancer risks faced by the members of this group.

Number of years of exposure resulting in an annual dose of 1 mSv	Original risk of Canadians dying from cancer	Additional risk of dying from cancer due to the annual dose of 1 mSv	New overall risk of dying from cancer with an annual exposure dose of 1 mSv
10	25%	+0.05%	25.05%
20		+0.10%	25.10%
30		+0.15%	25.15%
40		+0.20%	25.20%

Table 1: Cancer risk from an annual exposure dose of 1 mSv

Table 1 shows us that if annual doses are increased by 1 mSv, the risk of fatal-cancer increases from 25% to 25.2% after 40 years of exposure.

Unlike the members of the hypothetical group above, baggage x-ray machine operators receive no more dose than what they would receive from background radiation while not at work. Testing of a CATSA x-ray machines (aTiX 6040, aTiX 7555, CTX 5800, and 620 DV) demonstrates that dose rates received at operator positions (due to the x-ray machine and background sources combined) are indistinguishable from dose rates from natural background radiation alone. In other words, operation of the x-ray machine does not result in additional dose to operators above what they are already receiving from background exposure. Screening officers face negligible additional radiation exposure when operating baggage x-ray machines.

▶ Does long-term exposure to baggage x-ray machines pose risks to fertility?

Radiation exposure from baggage x-ray machines is much too low to cause infertility. Only exposure to high levels of ionizing radiation (including x-rays) may have effects on fertility. It is estimated by the US National Academy of Sciences that the dose to cause temporary sterility in the adult human testis is 150 mSv, and for permanent sterility, a single exposure of 3,500 mSv must be received. For permanent sterility in the adult ovary, the dose that must be received is 2,500-6,000 mSv in a single exposure and 6,000 mSv when received over long periods of time. Single exposures at these levels may also cause death. Clearly, these doses are much larger than those received by operators of baggage x-ray machines throughout their careers. The risk of becoming infertile from x-ray radiation emitted by baggage machines is negligible.

▶ What are the effects of radiation on a fetus?

Radiation effects to a fetus are detectable for doses greater than 100 mSv (e.g. higher risk of deficit in cognitive abilities and childhood leukemia). For doses of about 10 mSv, no correlation with reduced cognitive abilities has been shown, however the risk of childhood leukemia is estimated to increase by approximately 0.06%. Below 1 mSv, there is no known correlation between dose and health effects.

▶ What is the maximum amount of radiation for pregnant workers?

For members of the public, which includes screening officers, the maximum annual dose for pregnant women recommended by the ICRP remains 1 mSv. Potential health effects to either the mother or fetus at doses this low are negligible. As seen previously, screening officers are receiving occupational doses far below the annual limit of 1 mSv. There is no additional risk to pregnant screening officers and no specific precautions are required.

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 ionizing 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, including Canada, adopt the recommendations of the ICRP.

What is the ALARA principle?

ALARA is an acronym representing the principle that radiation exposures should be maintained 'As Low As Reasonably Achievable, economic and social considerations being taken into account'. The ALARA principle refers to the idea that one should always seek practical ways to further reduce exposure.
ALARA urges 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 optimize doses as low 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 reduce exposure to radiation are by applying the following three principles of radiation protection: time, distance, and shielding. These principles are illustrated in ***Figure 9***.

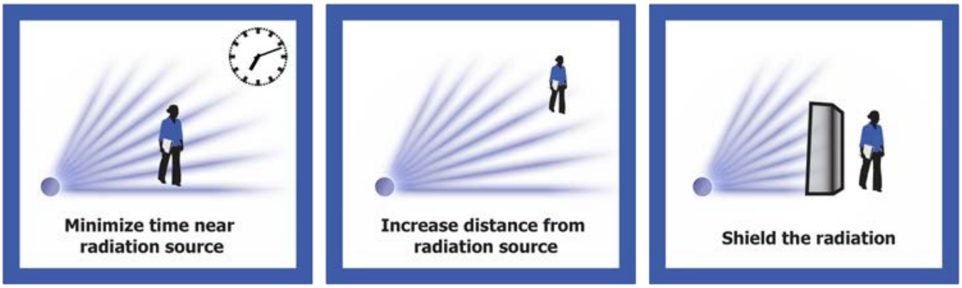

Figure 9: Radiation Protection Principles: Time, Distance and Shielding

How does time impact radiation exposure?

The longer a person is exposed to radiation, the more energy the body will absorb from the radiation. The principle is logical: the less time you are next to something emitting x-rays, the less radiation you will be exposed to.

The time principle is applied to baggage x-ray machines as x-rays are emitted only when bags are moving through the machine.

How does distance impact radiation exposure?

This principle is just as simple: the further you are from a radiation source, the less radiation you can be exposed to. A source emitting x-rays is represented in ***Figure 10***. When standing closer to the x-ray source, the person's body is exposed to more x-rays than when standing further away from the x-ray source.

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.

Figure 10: The distance principle of radiation protection

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.

How does shielding impact radiation exposure?

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 the material. The type of material used for shielding will determine how effective it is. The denser and thicker the material is, the better it is at attenuating x-rays. As radiation travels through shielding, its intensity is reduced. However, no amount of shielding can completely stop all x-rays. The x-ray machines are therefore designed so that the built-in shielding is sufficient to reduce the number of x-rays escaping from the machine to a negligible level.

To demonstrate real application of ALARA principles at the checkpoint, consider the following:

Time: X-rays are only produced when needed
Distance: Shrouds are in place to maintain distance
Shielding: Presence of lead shields and curtains

The PBS x-ray machines only produce x-rays when a bag is moving through them (an application of the time principle), and the shrouds at the entrance and exit of the machines prevent both the public and screening officers from getting too close to the moving curtains (an application of the distance principle).

What kinds of shielding are best used against radiation?

The best materials for shielding against x-rays are ones that are dense.
The denser the material is, the better it is at blocking x-rays. An effective and commonly used material for shielding against x-rays is lead.

Baggage X-Ray Machines

▶ What is a cabinet 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” and is designed for “the examination of carry-on baggage, personal items, sealed mail, etc.”

X-ray machines are designed to produce radiation and the radiation is controlled by the operator of the machine. Electricity is used to supply energy to the machine so that the radiation, the x-rays, can be created. X-rays are the only type of radiation produced by x-ray machines (they do not emit nuclear radiation).

Baggage x-ray machines, defined by *Safety Code 29*, includes all baggage x-ray inspection systems deployed in Canada and at CATSA. These include, for example, the Hi-Scan systems (***Figure 11***), the VIS/VDS systems (***Figure 12***), CTX systems (***Figure 13***, ***Figure 14***) x-ray systems, the 620 DV system (***Figure 15***), and the aTix systems (***Figure 16***).

Figure 11: Hi-Scan x-ray machine (pictured without shrouds) used at pre-board screening

Figure 12: VIS-108 and VDS-108 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

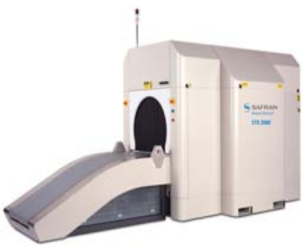

Figure 13: The CTX 2500 x-ray machine

Figure 14: The CTX 5800 x-ray machine

Figure 15: The 620DV x-ray machine

Figure 16: The 6040/7555 aTiX 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 radiation energy. 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 affecting 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 an x-ray generator, located within the cabinet of the machine.

When a bag is being inspected, the x-ray system works as follows:

1) An x-ray beam is generated that is directed at the bag.
2) 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 than will exit out of the opposite side of the bag. Thicker and denser materials within the bag will result in a higher attenuation of the x-ray beam.
3) An image is generated by a sensor (similar to camera sensors) located on the side opposite the x-ray generator. The image is generated based on the intensity of the x-rays. Items that cause greater attenuation of the beam appear darker than items that cause very little attenuation. 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. In fact, the part of the patient's body being investigated is placed directly in the x-ray beam. This application is very different from that of baggage x-ray systems, in which people are never directly exposed to the x-ray beam and are shielded from x-rays on all sides of the machine. Because of these differences, medical and dental x-ray machines have their own specific regulatory requirements and safety codes.

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. 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 2*** below shows the average annual doses received by various types of workers.

Occupation	Average annual radiation dose for 2006 (mSv)
Aircrew	0.50
Dentist	0.01
Medical radiation technologist	0.09
Radiologist (diagnostic)	0.20
Radiologist (therapeutic)	0.12

Table 2: Annual radiation doses for various occupations (values obtained from Health Canada)

Figure 17 below shows doses received for certain activities, based on information from the Canadian Nuclear Safety Commission (CNSC) website.

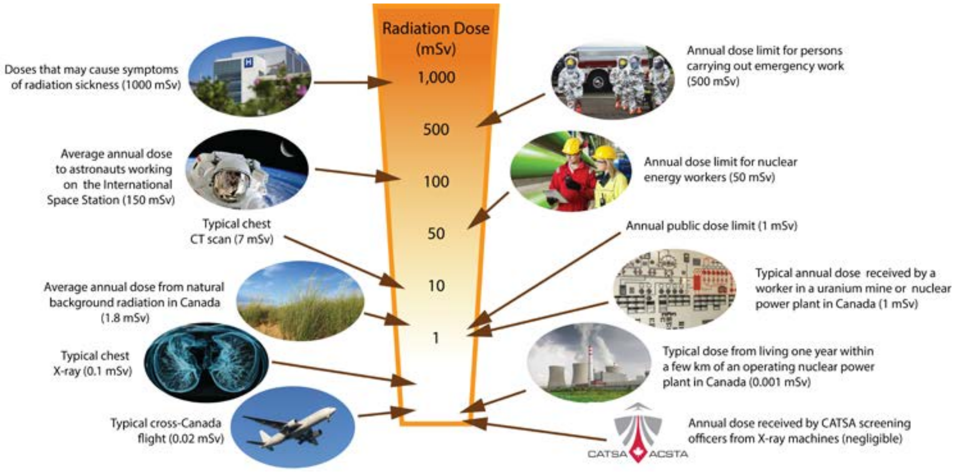

Figure 17: Radiation dose examples

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

CATSA uses a number of different x-ray machines throughout airports in Canada. Models currently used include the following:

- Smiths Detection Hi-Scan 6040a, 6040i and 7555i
- Smiths Detection aTiX 6040 and 7555
- Smiths Detection CTX 2500, 5800, 9000, 9400 and 9800
- Rapiscan 620 DV
- Leidos CT-80 and CT-80 DR
- L3 VIS 108/VDS 108
- L3 eXaminer XLB
- L3 MVT-HR
- L3 3DX

Hi-Scan, aTiX, and 620 DV x-ray machines are used primarily for pre-board screening of carry-on baggage (the 620 DV is also be used in non-passenger screening). The VIS, CTX 9000, CTX 9400 CTX 9800, MVT-HR, XLB and 3DX are used in hold-baggage screening. The CTX-2500, CTX 5800, VDS, and occasionally 7555aTiX units are used to examine oversized baggage.

CATSA also employs Computer 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. The models used are Morpho Detection's CTX 2500 and CTX 9000, Reveal Imaging's CT-80, and L3's eXaminer.

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

No. PBS x-ray machines 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. X-rays are only produced when the x-ray generator is on. Depending on the specific model of x-ray machine, this occurs when bags are passing through the machine, or when an operator manually activates the generator using a switch (e.g., a push-button or foot pedal). 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 failsafe features that do not allow x-rays to be generated under certain conditions, especially those that are operated manually by a screening officer. These failsafe features include:

Footmats and Foot Pedals

If an operator is not standing on the footmat or pressing on the foot pedal, 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 oversize checkpoints), the operator stands next to the x-ray machine and controls when x-rays are produced. Other machines (e.g., in-line machines of the automatic conveyance systems in HBS) are typically operated remotely.

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

Based on manufacturer specifications, it has been assessed that during a typical scan, a bag will receive a radiation dose of approximately 0.002 mSv from the Heimann x-ray units.

▶ Does radiation accumulate in a screening checkpoint from scatter etc. (.i.e. the more machines, the more x-ray radiation?

Theoretically, x-ray radiation emitted from multiple sources adds together. However, at positions occupied by operators, no detectable radiation above natural background levels has been measured. Exposures to an operator from other machines (e.g., machines in a different lanes which are being operated by other screening officers) would not be detectable since the distance between those machines and the operator is much greater. The total radiation field from all operating machines at any single operator's position therefore remains negligible.

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

Yes, enough shielding is provided by CATSA's baggage x-ray machines to protect screening officers and members of the public at all times from x-ray radiation. 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 0.005 mSv/h. A dose rate at this distance from the machine results in negligible doses to operators or members of the public who are in the vicinity. X-ray machines used by CATSA are designed and manufactured with enough shielding (either lead or steel) to meet this criterion.

Also, in compliance with *Safety Code 29*, CATSA'S x-ray machines are 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 0.005 mSv/h limit throughout the service life of the machine.

▶ Is there radiation leaking when maintenance technicians open up the panels to conduct maintenance?

No. Maintenance procedures require technicians to shut down the x-ray machines before opening the panels. There is no radiation leaking when the x-ray machines are turned off. If the generator was somehow erroneously operating with a panel off, the effect on radiation leakage would be negligible since the panels are not relied on as part of the shielding for the x-ray machines.

▶ 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 radiation leakage. This is one of the main reasons (in addition to care and control of the bag through the screening process) why the shrouds are in place – to prevent people from getting too close to these openings.

CATSA's x-ray baggage machines are all equipped with shrouds of at least 0.5 metres when deployed at PBS or NPS checkpoints. This means that screening officers, as well as individuals whose baggage or other belongings are being screened, remain at least 0.5 m from the entry and exit openings of the x-ray machines.

▶ 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 considerably 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 composed of lead and are thick enough to provide an effective shield against the x-rays produced by the machine.

What is the exposure risk from parted curtains as bags move through the x-ray, versus closed curtains?

The curtains are designed to part as bags move through the x-ray machine, and still provide a safe environment for the screening officers.

X-ray machines have been tested under realistic conditions, with bags moving and curtains parting to allow the bags through. When the curtains are completely closed, they provide maximum attenuation to the x-rays. When the curtains are parted by bags moving through the x-ray machine while x-rays are on, then there is a higher risk for randomly scattered x-rays to escape (x-ray leakage). Measurements over a five-minute period show that, beyond the shrouds, the radiation levels at the operator position are indistinguishable from the natural background.

The shrouds are in place to maintain a safe distance from the source to the operators and public. Operators can ensure their doses from the x-ray machines remain negligible by not reaching into the shrouds while the x-rays are on.

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 effect 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 would I receive if I worked 40 hours a week at a distance of 5 cm from a baggage x-ray machine?

According to manufacturer's measurements, leakage radiation from baggage x-ray machines at a distance of 5 cm is normally less than 0.0001 mSv/h after accounting for (subtracting) natural background radiation.

Using a dose rate of 0.0001 mSv/h, if you worked for 40 hours a week while standing within 5 cm of the side of the baggage x-ray machine, with it constantly producing x-rays, you would receive a weekly dose of 0.004 mSv. If you worked for 50 weeks in the year, your annual x-ray dose would be 0.2 mSv.

In reality, the doses calculated above are an overestimation. Generally, you will not spend your entire shift working within 5 cm of the side of the x-ray machine. 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 far below 0.2 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.

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.

▶ What is *Safety Code 29*?

Safety Code 29 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 related to the health and safety of the general public as well as the operators of the x-ray machines. The safety code presents procedures that must be followed in order to minimize 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.

▶ 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, averaged over a 5 year period (100 mSv in 5 years), with the further provision that the effective dose should not exceed 50 mSv in any single 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, the 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.

▶ 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 recognize 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.

How does CATSA and my employer ensure that I receive less than 1 mSv per year?

The established regulatory requirements ensure that baggage x-ray machine operators will receive much less than 1 mSv per year. To ensure you receive less than 1 mSv per year, CATSA adheres to regulatory requirements and implements dose minimizing measures by:

- Defining qualifications, training and performance criteria for screening officers and maintenance personnel;
- Ensuring all staff receive appropriate training on safe work procedures and radiation risks prior to working near or with x-ray machines;
- Providing standard operating procedures which include:
    - Safety features of, and requirements for operation of the x-ray machines;
    - Instructions for startup tasks, operation, shutdown tasks and end-of-day procedures;
    - Responses to unplanned or emergency situations;
    - Responsibilities for reporting issues to management or human resources.

- Implementing a maintenance program, including procedures for performing radiation surveys and other system verification tests to ensure the machines operate as designed and in compliance with Canada's regulations and standards;
- Providing daily checklists with pass criteria to be completed by screening officers to verify the machines are functioning properly;
- Ensure computer controls are placed away from the entrance and exit of the x-ray baggage machines.

CATSA authorizes screening contractors to deliver screening services at airports. As an authorized screening contractor, your employer is responsible for assessing your qualifications, providing training, and monitoring your performance to ensure you meet all criteria set by CATSA.

▶ 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 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.

▶ What is a radiation survey test and how is it conducted?

A radiation survey is a procedure used to measure external or ambient ionizing radiation in some area of interest. The surveys performed around CATSA x-ray machines allow the surveyor to determine whether radiation emissions from x-ray machines are below the regulatory limits.

To conduct a radiation survey of an x-ray machine, the surveyor insets dense material (e.g., wood, plexiglass) as a substitute for baggage inside the machine to maximize x-ray scatter. The x-ray generator is then turned on at full power and, using a calibrated radiation meter, the radiation emitted at 5 cm from every surface of the machine is measured. In order for the radiation survey test to pass, the radiation measurements must not exceed the regulatory limit of 0.005 mSv/h at 5.0 cm from any external surface of the x-ray machine.

What is a radiation survey meter?

A radiation survey meter is an instrument that is capable of detecting ionizing radiation, such as x-rays. The meter itself will either be equipped with a "window" which allows radiation to enter the detector or an external probe which detects the radiation. In either case, the level of radiation is registered by the meter. The selection of a meter or 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 18***) will generally measure the radiation exposure rate in mR/h (old units) or it will give an indication of the radiation dose rate in mSv/h. Where 1 mR/h is approximately equivalent to 0.01 mSv/h.

Figure 18: Example of a typical radiation survey meter (Ludlum 9DP)

What is the frequency of radiation surveys?

Radiation surveys are conducted on a yearly basis for PBS x-ray machines in service. Survey are also conducted:

- When the x-ray generator is replaced;
- When the lead curtains are replaced;
- When the x-ray unit has been moved over a certain distance; and
- At any other time an issue which may affect radiation leakage is detected.

How do I know that the testing was completed properly and that the equipment is safe?

Radiation surveys are always performed by trained and qualified maintenance personnel and using properly calibrated tools and equipment. In addition, all the measurements are documented and retained. If an x-ray machine fails to pass a radiation survey, it is taken out of service and remediated. Once remediated, another radiation survey must be passed before the machine is brought back into service.

What is a dosimeter?

A dosimeter is an instrument that measures and records the radiation dose received by the worker during the course of their work. There are different types of dosimeters depending on the kind of radiation that the person is exposed to, as well as other factors (e.g., operation environment).

Should I wear a 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 responsibilities of baggage x-ray operators described in section 3.2 of *Safety Code 29;*
- Read and follow the safe operating guidelines in section 4.2.1 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;
- Operate the x-ray machines in accordance with CATSA's standard operating procedures.

The above list is not detailed or exhaustive. Please refer to *Safety Code 29*, section 3.2 and 4.2.1 for more information. These requirements are also covered in greater depth in your training.

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 bears 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 CATSA's x-ray machine maintenance program?

CATSA implements a preventative maintenance program to ensure the x-ray machines meet all safety requirements for operation. Preventative maintenance activities are based on regulatory requirements and the manufacturer's maintenance procedures.

The maintenance guidelines in *Safety Code 29* are achieved by System Verification Tests, which ensure all safety, functional, and performance criteria are met for the baggage inspection x-ray devices. The System Verification Tests are performed prior to placing a machine into operation, routinely as part of preventative maintenance, and following corrective maintenance or equipment relocation to ensure each x-ray machine is verified fully functional with all safety features operating properly before being returned to operation.

Radiation surveys are one example of a System Verification Test. Other System Verification Tests include verification of shielding (e.g., no structural damage), inspection of lead curtains to ensure integrity and appropriate spacing, functionality of x-ray lights (which indicate operation), and tests to ensure x-ray generator is correctly functioning.

Maintenance on CATSA's baggage x-ray scanning devices may be performed only by trained and qualified maintenance personnel and using properly calibrated tools and equipment.

In addition to the maintenance program, a daily checklist is executed by screening officers at the start of each business day in order to verify the machines are functioning properly. This check provides the opportunity to identify any functional issues that may have resulted from normal daily operations. Machines that do not pass the checklist criteria are not placed into operation until corrective maintenance has been performed and the machine verified ready to return to service.

Acronyms

ALARA	As Low As Reasonably Achievable
CATSA	Canadian Air Transport Security Authority
CT	Computed Tomography (scan)
DNA	Deoxyribonucleic acid
ICRP	International Commission on Radiological Protection
keV	kilo-electron volt
RED	Radiation Emitting Devices
Sv	sievert

Glossary of Terms

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.

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.

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.

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

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 summarizes the quantities and units.

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

Table 3: 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 an older unit, still used when measuring the amount of radiation coming from the x-ray machine. 104 mR is equivalent to a radiation dose of 1 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. 104 mR/h is equivalent to 1 mSv/h.

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.

References

Berrington de Gonzalez, A., Darby, S., *Risk of cancer from diagnostic X-rays: estimates for the UK and 14 other countries*, The Lancet journal, Volume 363, No. 9406, pp345-351, 2004.

Canadian Cancer Society's Advisory Committee on Cancer Statistics, *Canadian Cancer Statistics 2017.* Canadian Cancer Society, 2017.

Canadian Nuclear Safety Commission, *Introduction to Dosimetry*, INFO-0827. Canada Minister of Public Works and Government Services Canada, 2011.

Canadian Nuclear Safety Commission, *Introduction to Radiation*. Canada Minister of Public Works and Government Services Canada, 2012.

Cember, H., *Introduction to Health Physics*, 2nd edition. Toronto: Pergamon Press, 1989.

Health Canada, *2005 Report on Occupational Radiation Exposures in Canada*, 2006.

Health Canada, *Requirements for the Safe Use of Baggage X-Ray Inspection Systems Safety Code 29*, 1993.

International Commission on Radiological Protection, *Recommendations of the International Commission on Radiological Protection*, Elsevier, 2007

National Research Council, *Health Effects of Exposure to Low Levels of Ionizing Radiation: BEIR V*, The National Academies Press, 1990.

Maharaj, Harri. Personal interview. November, 2006.

National Research Council. Personal interview. November, 2006.

Shleien, B., Slaback Jr, L. A. and **Birky, B. K.**, *Handbook of Health Physics and Radiological Health*, 3rd edition. Baltimore: Williams and Wilkins, 1998.