Manufacturing Safety Alliance of BC

X-ray Safety in the Workplace

for BC Manufacturers & Food Processors

PROGRAM GUIDE

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Acknowledgements

This guide was developed as part of a collaborative effort between Radiation Safety Institute of Canada and the Manufacturing Safety Alliance of BC, and with the support of WorkSafeBC, to bring increased attention and awareness of the risks associated with X-ray equipment in the manufacturing sector.

Manufacturing Safety Alliance of BC

The Manufacturing Safety Alliance of BC (the Alliance) provides occupational health and safety (OHS) information and support for manufacturers and food processors in BC and is committed to transforming the health and safety culture of organizations through effective OHS management systems, training and processes.

For further information, visit: safetyalliancebc.ca

Radiation Safety Institute of Canada

The Radiation Safety Institute of Canada (RSIC) is Canada's national resource centre for radiation safety information. It provides a range of radiation health and safety services to a large Canadian audience and collaborates with other organizations and agencies to facilitate the reach and impact of their services across Canada.

For further information, visit: radiationsafety.ca

WorkSafeBC

Since 1917, WorkSafeBC has helped to improve the health and safety of British Columbians in the workplace by building a sustainable, no-fault insurance system that supports both workers and employers. Working closely with employer and industry partners, they promote a workplace culture of health and safety. WorkSafeBC continues to work toward their vision of a province free from workplace injury, disease, and death.

For further information, visit: worksafebc.com

Disclaimer

The intention of this guidebook is solely as an information guide. It is not intended as a statement of the standards required in any situation. Nor is it intended that this workbook should in any way advise anyone concerning legal authority to perform any activities or procedures.

Every effort was made to ensure the accuracy and relevance of this information; however, this material may be subject to change due to various factors. These factors may include regulatory or interpretive changes, and a need to adapt the material to unique situations or procedures.

Nothing in this package and the course program absolve participants from using their sound judgment in the appropriate application of the material learned.

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Introduction

Automated X-ray equipment is a technology that uses X-rays, a type of ionizing radiation, as its source to automatically inspect features, which are typically hidden from view. It is used in a wide range of industries and applications, predominantly with two major goals:

1. Process optimization, i.e. the results of the inspection are used to optimize processing steps
2. Anomaly detection, i.e. the result of the inspection serves as a criterion to reject a part

X-ray inspection is a valuable tool in manufacturing, as it makes possible the diagnosis of physical conditions that would otherwise be difficult to identify. Its application in quality assurance and safety is of considerable benefit to the company, worker, and the public.

X-ray inspection has a wide range of applications in manufacturing. It ranges from the quality check of electronic components and non-destructive analysis of automotive parts to the detection of bone fragments in processed meat. Wherever large numbers of very similar items are produced according to a defined standard, automatic inspection using advanced X-ray imaging and pattern recognition software (Computer Vision) has become a useful tool to ensure quality and improve yield in processing and manufacturing.

However, the use of industrial X-ray equipment must be carefully managed because ionizing radiation has the potential to damage healthy cells and tissues. Although no known occurrence of cancer or genetic damage has been observed from radiation doses delivered in modern manufacturing, until more evidence is available, one should practice radiation protection with the same care as would be dictated if a hazard were known to exist.

It is generally accepted that there is no safe level of ionizing radiation dose. No matter how low the dose there is a mathematical probability of an effect. The ALARA (As Low as Reasonably Achievable) principle states that exposure to radiation, which can be decreased without loss of critical information and without too much expense or inconvenience, should be reduced. Furthermore, any exposure, no matter how low, which can be avoided altogether without unfavorable consequences, should be avoided.

In the Province of British Columbia industrial X-ray equipment in manufacturing and food processing, as well as industrial lasers are governed by Division 3, section 7 of the Occupational Health and Safety Regulation ("*Regulation*"). These documents specify that employers have certain obligations to ensure the health and safety of themselves, their workers, and the public.

These obligations include:

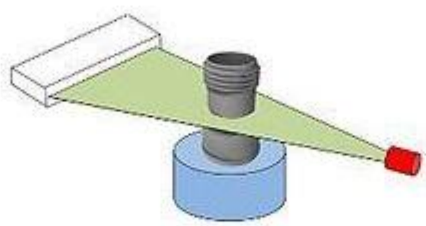
- Ensuring a healthy and safe workplace for workers, contractors, and visitors
- Keeping equipment registration information and exposure records
- Developing an X-ray safety program and policies
- Ensuring the safe installation and operation of equipment
- Complying with specific standards
- Preventative maintenance and dosimetry monitoring

This guide has been developed to assist industrial facilities with meeting these obligations.

Principle of Operation

X-ray inspection transmits X-rays through the object and records gray scale images of the shadows cast. The image is then processed by image processing software that detects the position and size/shape of expected features (for process optimization) or presence/absence of unexpected/unintended objects or features (for anomaly detection).

X-rays are generated by an X-ray tube, usually located directly above or below the object under inspection. A detector located the opposite side of the object records an image of the X-rays transmitted through the object. The detector either converts the X-rays first into visible light, which is imaged by an optical camera or detects directly using an X-ray sensor array. The object under inspection may be imaged at higher magnification by moving the object closer to the X-ray tube, or at lower magnification closer to the detector.



Line beam scanning is the traditional process of industrial CT scanning. X-rays are produced and the beam is collimated to create a line. The X-ray line beam is then translated across the part, and data is collected by the detector. The data is then reconstructed to create a 3-D volume rendering of the part.

Since the image is produced due to the different absorption of X-rays when passing through the object, it can reveal structures inside the object that are hidden from outside view.

X-ray Radiation Biological Hazards

X-rays and electrons are types of ionizing radiation. In general, when ionizing radiation crosses matter, there may or may not be an interaction. Biological effects of X-rays can be classified as direct or indirect, acute or delayed, and as deterministic or stochastic.

When radiation is absorbed inside the cells the action is called direct action. The critical target is the DNA molecule. X-rays can break this molecule and the cell can be damaged resulting in cell death or in cell function alteration. The altered cells can be repaired or can be transformed. Depending on the level of radiation, the cell death or alterations can be dangerous.

When radiation is absorbed in atoms or molecules other than biological material (for example in a water molecule) the interaction with the body is called indirect action. Ions and free radicals can result from these interactions. Depending on the chemical reactions, these ions and free radicals can be dangerous for the human body.

Among acute effects of skin overexposure to X-rays are erythema (skin reddening), changes in pigmentation, epilation, blistering, necrosis, and ulceration. If an overexposure of the whole body occurs above 2000 mSv, depending on the level, acute radiation syndromes (hemopoietic, gastrointestinal, and central nervous system) can result. Blood changes, nausea, vomiting, malaise, and fatigue, or increased temperature of the body can accompany these syndromes.

Delayed effects of radiation may be due either to a single large overexposure or continuing low-level overexposures to X-rays. The delayed consequences of overexposure to X-rays include cancer, genetic effects, mental delay in development of children who have been irradiated in utero, shortening of life span, and cataracts.

Deterministic effects are effects in which a clear connection between the person that suffered the overexposure to radiation and the effect can be made. In these cases, there is a causal relationship between dose and effect on a particular individual. To cause a deterministic effect a certain minimum dose must be exceeded, and the severity of the effect increases with the dose. Deterministic effects can be acute or delayed.

Stochastic effects are effects that occur by chance, and their probability of occurrence increases with an increase in dose received by a large population. The stochastic effects has no threshold dose and are delayed.

Various possibilities exist for the fate of cells exposed to ionizing radiation:

- Damaged cells are completely repaired by the body's inherent repair mechanisms.
- Damaged cells die during their attempt to reproduce. Consequently, tissues and organs in which there is substantial cell loss may become functionally impaired. There is a "threshold" dose for each organ and tissue above which functional impairment will manifest as a clinically observable adverse outcome. Exceeding the threshold dose increases the level of harm. Such outcomes are called deterministic effects and occur at high doses.
- Damaged cells survive the radiation insult but are badly repaired and able to undergo subsequent divisions. These cells, with the progression of time, may be transformed by external agents (e.g., chemicals, diet, radiation exposure, lifestyle habits, etc.). After a latency period of years, they may develop into leukemia or a solid tumor (cancer). Such latent effects are called stochastic (or random).

Reproductive hazards

Germ cells are present in the ovaries and testes and are responsible for reproduction. Should they be modified by radiation, hereditary effects may occur in the children of the individuals exposed to radiation. Radiation-induced hereditary effects have not been observed in human populations, yet they have been demonstrated in animals. Exposure of the embryo or fetus to ionizing radiation could increase the risk of leukemia in infants and, during certain periods in early pregnancy, may lead to mental problems and congenital malformations if the amount of radiation is sufficiently high. In section 7.21 of the Regulation, it states:

1. The employer must ensure that every worker who exceeds, or may exceed, the action level of ionizing radiation is fully informed of any potential reproductive hazards associated with exposure to ionizing radiation.
2. When requested by a pregnant worker or by a worker intending to conceive a child, the employer must make counselling available with respect to the reproductive hazards associated with exposure to ionizing radiation.

Exposure to ionizing radiations has the potential to cause early or late adverse health effects. Therefore, the radiation risks associated with industrial X-ray equipment need to be managed

Pregnant Workers

It is well known that the foetus is more sensitive to the effects of radiation than an adult human. If an irradiation occurs in the first 30 weeks of pregnancy, delayed effects may appear in the child. These include mental and behavioural development issues, with a delay period of approximately 4 years.

Because of these possible effects, dosimetry during pregnancy differs from the usual protocol. Special attention is paid to both external and internal irradiation. An X-ray Safety Officer must review exposure control and work procedures when working around an X-ray source when a pregnant worker performs such work.

It is not possible to accurately measure the dose to the foetus and so it must be inferred from the exposure to the mother. Radiation protection principles limit exposure to the mother in order to achieve the minimum risk to the foetus.

Industrial Applications for X-ray Inspection and Scanning

With the advancement of image processing software, the number applications for automated X-ray inspection is huge and constantly growing. The first applications started off in industries where the safety aspect of components demanded a careful inspection of each part produced (e.g. welding seams for metal parts in nuclear power stations) because the technology was expectedly very expensive in the beginning. But with wider adoption of the technology, prices came down significantly and opened automated X-ray inspection up to a much wider field – partially fueled again by safety aspects (e.g. detection of metal, glass or other materials in processed food) or to increase yield and optimize processing (e.g. detection of size and location of holes in cheese to optimize slicing patterns).

In mass production of complex items (e.g. in electronics manufacturing), an early detection of defects can drastically reduce overall cost because it prevents defective parts from being used in subsequent manufacturing steps. This results in three major benefits:

- Provides feedback at the earliest possible state that materials are defective, or process parameters got out of control,
- Prevents adding value to components that are already defective and therefore reduces the overall cost of a defect, and
- Increases the likelihood of field defects of the final product, because the defect may not be detected at later stages in quality inspection or during functional testing due to the limited set of test patterns.

Industrial radiography machines, which are X-ray tube based, can produce dose rates in air of about 2 Gy per minute at one metre. They may be highly portable or mobile and convenient for use at temporary job sites. Sometimes, they can be operated by a single worker in a wide range of conditions such as at aircraft hangers, pipeline construction and deployment, food processing, fabrication facilities, offshore platform operations, bridges, or construction sites. At temporary work sites, the working conditions coupled with frequent manipulation of such high-intensity radiation sources present much potential for radiation exposure to occur. Both the worker(s) and other persons proximal to the work area can be exposed to high radiation fields which, potentially, can result in radiation accidents that could lead to serious personal injuries or death. In other work situations, X-ray tube-based devices may be installed in a shielded enclosure equipped with safety components which significantly reduce radiation risks. To date industrial radiography is an established practice that provides benefits concurrent with radiation risks.

Note: In another industrial application, there are systems specifically designed to focus intense beams of high-energy electrons that melt and bond metals under vacuum conditions, and these electron-metal interactions can produce x rays as a by-product of the bonding process. Such systems are called electron beam welders. By design, electrons are emitted from heated filaments and accelerated to several hundred kilovolts before impacting on metallic materials which are generally placed in a vacuum. In some designs, however, the electron beam passes through a series of orifices, each of which is individually evacuated while the target material is positioned within close range (few centimeters) of the last orifice. Beam currents and high voltages are typically in the range of 20-200 mA and 120- 450 kV, respectively. A device operating at 150 kV and 50 mA, for example, would yield an estimated electron dose rate in air of ~ 0.5 Gy per second at 50 cm, while the scattered X-ray radiation field at 1 metre would approximate 1 Gy per hour for a 1-cm primary

Collectively, in the Regulation and relevant Health Canada Safety Codes, X-ray tube-based machines used for industrial radiography and electron beam welders are classed as "*industrial X-ray equipment*." They present potential risks of exposure to x rays and electrons. The radiation protection objective, therefore, is to keep the risks ALARA while maximizing benefits.

Use of X-ray Inspection in the Food Industry

X-ray technology is the ideal solution to inspect food, identifying physical contaminants such as metal, glass, calcified bone, stone, and dense plastic to guarantee product safety. Simultaneously X-ray systems can also measure mass, count components, identify missing or broken products, monitor fill levels, inspect seal integrity and check for damaged products or packaging, ensuring product integrity.


Foreign body detection, fill level control, and process control are the three main areas for the use of X-ray inspection in the food industry. Especially in packaged goods at the end of the filling and packaging line the use of X-ray scanners has become the norm, rather than the exception. It is often used in combination with other quality assurance measures, especially inline weight checkers.

With increased expectations for food products of high quality and safety standards, the need for accurate, fast, and objective quality determination of certain characteristics in food products continues to grow. X-ray computer vision provides one alternative for an automated, non-destructive, and cost-effective technique to accomplish these requirements. This inspection approach based on X-ray image analysis and processing has found a variety of different applications in the food industry. Considerable applications have highlighted its potential for the inspection and grading of fruits and vegetables. Computer vision has been successfully adopted for the quality analysis of meat and fish, pizza, cheese, and bread. Similarly, grain quality and characteristics have been examined by this technique.

Most of it is limited to a good/ bad check, i.e. it produces rejects after the X-ray inspection station, but in some applications it is directly used for process control where the data from the X-ray inspection are fed to the process and can control other variables. An often-cited example is the control of the thickness of cheese slices after an X-ray inspection determined the distribution and position of 'holes' inside the cheese block (to ensure consistent total package weight).

X-ray inspection systems are considered safe. Radiation levels used by X-ray inspection systems for food are exceptionally low, while X-ray inspection equipment operates within extremely high safety limits. A study by the World Health Organisation (WHO) confirmed that radiation levels up to 10,000Sv do not affect food safety or nutritional value.

Machine operators can work in a safe operating environment because the X-ray exposure they receive from a food X-ray inspection machine is far less than the amount absorbed from naturally occurring background radiation. Natural background radiation contributes to 2,400µSv of radiation in a year from natural sources, while occupational exposure, immediately adjacent to an X-ray system, is less that 1µSv an hour.

Use of X-ray Inspection in Manufacturing

Industrial radiography and X-ray inspection are one of the most common non-destructive testing methods within the industrial sector and has been commonly used for internal inspection of components. From having the ability to inspect, quantify and qualify failures and defects to being able to access internal and external geometry, X-ray analysis has become an indispensable tool for industry. Applications vary depending on the type of material, size of part and inspection requirements, and it is commonly used for testing welds, pipe, pipeline, concrete, machined parts, and metal components, solid and flat materials. But it has also become invaluable for the testing, qualification, and verification of part components in the manufacturing cycle. Industrial radiography and industrial X-ray testing have revolutionized non-destructive methods of testing and inspection by assisting in the following areas:

- Ensures safety and reliability of part
- Identify, locate, and measure defects
- Failure analysis
- Density variations can be analyzed for structural evaluation
- Metrology
- Assembly analysis and reverse engineering applications
- Ability to use part after testing and analysis
- Qualify and approve part components
- Quick, cost effective and accurate

Analysis and Inspection Techniques

Various inspection uses and techniques include part-to-CAD comparisons, part-to-part comparisons, assembly and defect analysis, void analysis, wall thickness analysis, and generation of CAD data. The CAD data can be used for reverse engineering, geometric dimensioning and tolerance analysis, and production part approval.

Assembly

One of the most recognized forms of analysis using X-ray scanning is for assembly, or visual analysis. The X-ray scanning provides views inside components in their functioning position, without disassembly. Some software programs for industrial scanning allow for measurements to be taken from the X-ray scanner dataset volume rendering. These measurements are useful for determining the clearances between assembled parts or the dimension of an individual feature.

Void, Crack, and Defect Detection

Traditionally, determining defects, voids and cracks within an object would require destructive testing. X-ray scanning can detect internal features and flaws displaying this information in 3D without destroying the part. 3D X-ray is used to detect flaws inside a part such as porosity, an inclusion, or a crack.

Metal casting and moulded plastic components are typically prone to porosity because of cooling processes, transitions between thick and thin walls, and material properties. Void analysis can be used to locate, measure, and analyze voids inside plastic or metal components.

Regulations and Standards

Following is a list of standards which apply to industrial facilities. This Guide consolidates the important information that is required by an industrial facility on a regular basis. It is the owner's responsibility to ensure the equipment and facility comply with all requirements and regulations.

The British Columbia Occupational Health and Safety Regulation ("Regulatio*n*") is the provincial legislation which specifies the requirements to be met for X-ray applications in manufacturing. The X-ray safety regulations are under Division 3 of the Regulations. Division 3 applies to all sources of ultrasonic energy, non-ionizing and ionizing radiation, including radiation sources governed by the *Nuclear Safety and Control Act* (Canada), except as otherwise determined by the WorkSafe BC Board. The Regulations can be found at the WorkSafeBC website.

Agencies having jurisdiction over exposure to radiation include WorkSafeBC and the Canadian Nuclear Safety Commission (CNSC). The mandates of these agencies with respect to radiation are briefly described within this guideline.

WorkSafeBC

WorkSafeBC administers the Regulation, which includes provisions for protecting workers from exposure to ionizing radiation, electromagnetic fields, lasers, ultraviolet radiation, and ultrasound.

The Regulation does not differentiate between ionizing radiation in the form of X-rays or from radioactive sources - the requirements apply equally to both. This differs from the CNSC regulations, which only apply to ionizing radiation from radioactive materials or particle accelerators.

A WorkSafeBC inspection is not restricted to issues of radiation, but a WorkSafeBC prevention officer may also check for compliance with the other applicable sections of the Regulation, such as the requirement for an occupational health and safety program. The prevention officer will normally review a radioisotope license at the worksite to determine the nature and quantity of any radioactive materials at the workplace.

Canadian Nuclear Safety Commission (CNSC)

CNSC, previously known as the Atomic Energy Control Board of Canada, is a federal authority that focuses primarily on the control of the health, safety, and environmental consequences of nuclear activities. CNSC does not have a mandate for X-ray machines or for non-ionizing radiation such as radiofrequency, microwave, or ultraviolet radiation.

The CNSC replaced the Atomic Energy Control Board in May 2000 when the *Nuclear Safety and Control Act* and its regulations came into effect.

CNSC inspectors perform routine compliance inspections of organizations (referred to as "licensees") that have received a license from the CNSC to work with radioactive material. The license will state what isotopes and devices can be possessed, as well as where and how they are to be handled and maintained. The license will also list the prescribed (for example, radioactive) substances and devices to which the license applies and may specify any number of conditions with which the licensee is required to comply.

These may include conditions with respect to allowable radiation levels, signage, leak tests, dosimetry, disposal, and reporting of accidents.

The CNSC requires that the license be available at any location where the prescribed substances are used or stored. A CNSC inspector's primary responsibility is to measure compliance with the conditions on the license and with the regulations, which apply to the handling of radioactive material. These regulations include CNSC Transport of Nuclear Substances and Transportation of Dangerous Goods.

A routine inspection entails checking for and ensuring the accuracy of all records, such as inventory, leak tests, dosimetry, training, and shipping documents. Inspectors would also check that the radioactive material is stored properly and that appropriate signs are posted, such as radiation warning signs and contact details. They also check to see that the appropriate monitoring equipment is available and that it is being properly maintained. Like the process followed by WorkSafeBC prevention officers, CNSC inspectors leave a report identifying items of non-compliance and then follow up to ensure compliance is achieved.

CNCS inspectors are also involved in investigating incidents. These investigations can lead to a variety of actions, including the suspension of a license or prosecution.

Health Canada Safety Codes

Safety Code 32 - Safety Requirements and Guidance for Analytical X-ray Equipment
Safety Code 32 provides requirements and guidance intended to ensure that the radiation risks from analytical X-ray equipment remain low (i.e., the same as the risks from unavoidable natural background radiation). It provides information on regulatory requirements, standards, surveillance, monitoring and safety procedures, and outlines specific responsibilities for the:

- equipment owner, meaning a person, organization, or institution having title to or administrative control over one or more facilities having source(s) of ionizing radiation
- equipment users
- maintenance personnel, meaning specifically trained persons employed by the equipment manufacturer or its authorized agent(s) to undertake service functions
- radiation safety specialists (analysts and inspectors as defined in the Radiation Emitting Devices (RED) Act)

The words *must* and *should* in Safety Code 32 have been chosen with purpose. The word *must* indicates a requirement that is essential to meet the currently accepted standards of protection, while *should* indicates an advisory recommendation that is desirable, and which is to be implemented where feasible.

Addendum to Safety Code 32 – Portable hand-held open beam X-ray devices
This Addendum consists of several sections, including Appendices and references. It provides regulatory and user requirements, guidance, and information specific to portable, hand-held, X-ray tube based open-beam X-ray fluorescence (XRF) devices as related to non-destructive testing (NDT) applications.

Safety Code 34 – Radiation Protection and Safety for Industrial X-ray Equipment
(Supercedes Safety Code 27 in section 7 of BC Regulation)

The objective of Safety Code 34 is to present information for the radiation protection and safety of individuals operating, using, and servicing industrial radiography X-ray equipment at permanent installations or at temporary job sites, and of persons proximal to such work areas. The owners of industrial X-ray equipment, the organizations or individuals carrying out industrial radiography, and clients who hire such organizations or individuals are responsible for ensuring that all safety procedures are followed and that the work is done in a manner that does not pose undue risks to any person.

This Safety Code applies specifically to industrial X-ray equipment operating at energies up to 6 MeV for use in industrial radiography and in material melting-and-bonding applications. It therefore covers X-ray tube-based equipment, electron beam welders and low energy (≤ 6 MV) accelerators. It provides basic requirements and guidance intended for the radiation protection and safety of industrial radiographers, other users, service personnel and the public.

Health Canada Radiation Emitting Devices (RED) Act and Regulations

The *RED Act and Regulations* prescribe specific safety standards governing the design, construction and function of radiation emitting equipment and are generally used by manufacturers and Authorized Radiation Protection Agencies when doing compliance verifications. The part of the regulations applicable to cabinet X-ray equipment commonly used in manufacturing applications is the RED Regulations under Schedule II, Part XV: Cabinet X-ray Equipment.

As radiation emitting devices have the potential to harm human health and safety, they must meet the general requirements of Sections 4 and 5 of the Radiation Emitting Devices Act and Regulations (RED Act) as well legislative requirements set out elsewhere in the Act and the Regulations.

Certification of compliance with a foreign radiation safety standard is not a substitution for compliance with the RED Act and its regulations.

Registration of Designated Radiation Equipment

Considerations

Some industrial X-ray equipment is not registerable because it does not meet the standards for design, construction, or function. Although this is more prevalent with older equipment, particularly 50 and 60 kVp units, new equipment may not be registerable if the manufacturer has not ensured that the equipment complies with the federal Radiation Emitting Devices Act and Regulation. Before the purchase of equipment, it is recommended that an industrial supply representative be consulted to ensure that the equipment being purchased complies to all aspects of the Radiation Emitting Devices Act.

Registration of X-ray Sources

There are two primary reasons for preparing and maintaining a record of all X-ray sources. These are:

- To identify areas where X-ray sources are present so that appropriate administrative and engineering controls may be put in place
- To enable the X-ray sources to be inspected on a regular basis for compliance with the employer's X-ray safety program

The employer is responsible for the registration of all X-ray sources and deregistration of decommissioned ones.

When, after the installation of an X-ray in a permanent location, there is a change that may result in an increase in the exposure of a worker, contractor or visitors, the employer shall conduct another complete approval process. Examples of situations where this applies is:

- The installation or use of the X-ray source
- The use of the rooms or areas adjacent, horizontally, or vertically, to the X-ray source
- Any shielding of the X-ray source

The XSO is responsible for the preparation and maintenance of the X-ray sources registry.

Any regulated employer that owns designated radiation equipment must register with the CNSC.

The owner is responsible for:

- proper installation of equipment
- registration and compliance verification/inspection
- operation and maintenance of the equipment
- education of the operators
- maintenance of accompanying software
- storage of records
- development of a Code of Practice and a Quality Assurance Program
- dosimeter monitoring

When to Register

Registration of X-ray equipment for manufacturing or food processing purposes depends on the Province or Territory where the equipment is being utilized.

Very few X-ray generating systems for manufacturing meet the requirements for registration and licensing with the CNSC.

Presently, WorkSafeBC has no registration requirements for X-ray sources in a manufacturing application. X-ray generating analytical equipment used in medical, veterinary, and dental applications are registered through their respective professional colleges. However, all X-ray generating systems are required to have manufacturer/importer documentation that shows they meet the federal Radiation Emitting Devices Act (RED Act) regulation safety requirements. The employer should keep this documentation on file for presentation in case of WorkSafeBC or CNSC inspection.

Food processing and manufacturing X-ray systems are regulated under the Health and Safety regulations of the Province of BC (Sec. 7).

If there is a circumstance under which specific X-ray equipment requires a CNSC license, the owner has been delegated the responsibility for registering industrial X-ray and laser equipment.

Registration is required in the following situations:

- Installation of equipment or industrial laser in a new or existing industrial facility regardless of how the equipment or industrial laser was obtained (purchased, leased, gifted) or how old the equipment is (new or resale).
- Relocation within the facility or to another facility.
- Modification of the characteristics of the radiation emitted from the equipment or industrial laser, or the protective properties of the facility. Note that shielding calculations are based in part on the occupancy of adjacent rooms. If a facility is redesigned and the walls are not altered but the occupancy changes (i.e. storage room becomes assembly room), registration of the equipment is still required.

How to Register
To register designated radiation equipment and industrial lasers, submit a completed Application for Registration of Designated Radiation Equipment form that can be found on the CNSC website (https://nuclearsafety.gc.ca/eng/).

The application must be signed by the owner of the facility and a compliance verification report from an Authorized Radiation Protection Agency must be submitted prior to the use of the radiation equipment or industrial laser.

Owner Responsibility to Update

The owner(s) of the facility is responsible for ensuring that all obligations under the BC Occupational Health and Safety Regulation, and Health Canada Safety Codes, are met. You must advise the CNSC if the owner(s) of the facility changes.

Compliance Verifications

Compliance verifications of X-ray equipment, industrial lasers and facilities should be performed to ensure the safety of all workers.

Verifications ensure that:

- that the facility complies with current legislation
- equipment has been installed correctly and is functioning properly
- shielding has been calculated and installed correctly
- the principle of ALARA has been utilized within the facility work process design
- worker doses are within the limits specified by the BC *Regulation* (sec. 7.19)
- evidence that the manufacturer continues to support the equipment and software

To assist the owner with obtaining the services of an Authorized Radiation Protection Agency, a list of these agencies may be obtained from the CNSC website (https://nuclearsafety.gc.ca/eng/)

Exposure Control Plan

Safety Code 32 and Section 7.20(1) of the BC Regulation indicates that "if a worker exceeds or may exceed an action level" for ionizing radiation, the employer must develop and implement an exposure control plan meeting the requirements of section 5.54(2).

The instructions to workers developed under subsection (1) above must be posted or otherwise available in the work area or near the applicable equipment controls.

The employer is responsible for the safe use of all X-ray sources under their jurisdiction and must ensure that X-ray sources users are competent to use X-ray sources in a safe manner, that an X-ray sources hazard evaluation is performed and that adequate controls are in place, before using X-ray sources.

The employer has the responsibility to ensure the implementing, updating, and auditing of the X-ray Safety Program and will appoint one employee as the X-ray Safety Officer (it is recommended the employer consult with the Joint Health and Safety Committee or Safety Representative).

The X-ray Exposure Control Program is intended to assist the employer in the effective control of X-ray hazards.

The basic elements of an X-ray control program are:

- X-ray permit system
- registration of all X-ray machine and X-ray sources
- inspections of X-ray machines and X-ray sources
- training and education of X-ray workers
- reporting accidents/incidents involving X-ray machines and X-ray workers
- personal dosimetry
- engineering controls
- administrative and procedural controls
- auditing the implementation and effectiveness of the program

Personal Dosimetry

Also, Regulation section 7.22 states that "if a worker exceeds or may exceed the action level of ionizing radiation", the employer must ensure the worker is provided with and properly uses a personal dosimeter acceptable to the Board and a facility policy on dosimetry must be incorporated into the Code of Practice or Standard Operating Procedures.

BC's Regulation respecting X-ray Safety (section 7) specify that personal monitoring is required for each X-ray worker who has a reasonable probability of receiving a radiation dose of 1 mSv/year (whole body) or greater.

When proper procedures are followed, X-ray cabinet operators generally would not require dosimetry, as doses are not expected to approach 1 mSv per year. As well, when not in use, and in most emergencies, the X-ray source is shut off (not energized) so radiation exposure is not possible.

Personal Dosimetry Monitoring

The dose received by a person working with or near an open X-ray source can be measured by a personal dosimeter. There are basically two different types of personal dosimeters: one that indicates the dose received immediately and one that stores the information inside the dosimeter. In the last case, the stored dose is read later.

A personal electronic dosimeter (PED) is an example of the first type. This instrument can indicate the shallow dose (dose received by the surface of the skin up to the depth of 0.007cm) and the deep dose (dose received by a person up to one cm depth inside the tissue). It can also be set-up to alert, through an alarm system, when a certain dose or dose rate is reached.

A few examples of the second type of personal dosimeters are film, a thermo-luminescent dosimeter (TLD), and optically stimulated luminescence (OSL) dosimeter. The X-ray energy is deposited inside the dosimeter's material and can be read later by a method specific to each type of dosimeter.

- All operators of X-ray equipment, together with personnel who routinely participate in X-ray analytical procedures, must wear personnel worker if their exposure exceeds or may exceed the action level of ionizing radiation.
- It is recommended that industrial facilities also have a control badge issued by the Dosimetry Service, to differentiate elevated exposures that may have occurred at the facility from those that may have occurred during shipping of the dosimeter badge.
- It is the Radiation Program policy that each dosimeter badge registered within a facility remains at that one facility and is not used or transferred by any means to another facility. If an employer owns more than one facility, each facility must register, utilize and monitor its own dosimeter badges. An employer and/or their staff cannot use the badge(s) for multiple facilities.

Engineering Controls

Engineering controls are physical barriers designated to keep the risks of using X-ray sources under control. When, due to the nature of the device these engineering controls are not applicable, the employer has the obligation to ensure that equivalent controls are in place. These controls should offer equal or greater protection than the ones described here.

Shielding

To reduce the dose received by X-ray workers according to ALARA and under the permissible limits, structural or other shielding shall be installed as is necessary.

The XSO will assist in calculating the thickness of the shielding for each individual application when asked by the employer.

If a lead apron and gloves are required when using an X-ray machine the material will provide a shielding equivalent to at least 0.5 mm of lead.

Diaphragms, Cones, Collimators

Diaphragms, cones and adjustable collimators or other suitable devices shall be provided and used as are necessary to limit the dimensions of the useful X-ray beam.

Each port shall be designed in such a way that the X-ray beam can emerge only when a camera or other recording device is in its proper position, wherever applicable.

All unused ports shall be secured in such a way as to prevent inadvertent opening.

Locks, Interlocks

When the air kerma in an area may exceed 100 µGy in one hour, access to the area should be controlled by:

- Locks or interlocks if the X-ray source is installed in a permanent location
- Barriers and X-ray warning signs if the X-ray source is portable or mobile and is being so used
- A guard or interlock which prevents entry of any part of the body into the primary beam path shall be used, wherever applicable
- When an interlock terminates an exposure, it shall only be possible to restart the exposure from the control panel

Shutter

A shutter is a mechanical device installed near the exit of the X-ray tube capable of blocking the beam when is necessary. The shutter may be used in connection with an interlock to stop the beam.

Administrative and Procedural Controls

Engineering controls must be given primary consideration in instituting a control measure program for limiting access to X-ray source radiation. If some of these engineering controls are impractical or inadequate, then administrative, and procedural controls that provide equivalent protection shall be used.

Administrative and procedural controls are methods or instructions which specify rules, or work practices or both, which implement or supplement engineering controls and which may specify the use of personal protective equipment.

Standard Operating Procedures (SOPs)

Standard operating procedures (SOPs) for X-ray equipment shall be maintained with the X-ray equipment and must always be available as a reference for all X-ray workers; SOPs may include the X-ray sources instruction manual (prepared by the manufacturer) and as appropriate, additional written information to ensure compliance with good work practices and safety.

General X-ray Safety Practices

The following are guidelines for the safe use of all X-ray equipment in general:

- The equipment shall be used under the guidance and supervision of a qualified person who is also responsible for the safe use of the equipment.
- X-ray warning signs shall be posted on the doors of all X-ray rooms, and X-ray warning labels shall be affixed to all X-ray equipment.
- All work should be planned before carrying out maintenance or making an adjustment.
- Persons who are classified as X-ray workers shall all wear personal dosimeters, as required by the employer.

- Persons wearing lead aprons should wear their personal dosimeter under lead aprons to avoid false high readings.
- All equipment capable of producing X-rays shall be lead shielded or installed in a protective lead enclosure. The area in which this equipment is used shall be marked with warning signs to indicate that X-ray radiation may be present.
- Energized equipment shall not be left unattended in a location with unrestricted access.
- High voltage power supplies using rectifier tubes should be housed in protective lead enclosures.
- A radiation survey of a new or modified X-ray installation and its vicinity shall be carried out before it is put into operation, to ensure compliance with regulatory requirements.
- Protection of workers or contractors working in areas surrounding an X-ray machine should be achieved by means of lead barriers, which absorb the scattered, leakage, or transmitted radiation. The barriers shall be positioned as close as possible to the equipment.
- The primary beam shall be directed towards an unoccupied area (i.e. an area to which access is not permitted) or towards a wall containing adequate shielding. The beam should be well collimated so that it covers only the minimum area necessary for the nature of work being undertaken.
- Personal Protective Equipment shall be inspected annually to ensure that they remain in good condition.
- A mobile X-ray machine used routinely in one location should be considered as a permanent installation and be lead or lead-equivalent shielded accordingly.
- A mobile X-ray machine should be used only in an unoccupied area with restricted access. If the equipment must be used in an area with unrestricted access, a lead shield shall be provided to prevent persons present in the surrounding areas from being exposed to radiation. The operator shall remain behind the protective lead screen during all exposures.
- Prior to any major change/modification of the approved X-ray installation, or the use of the X-ray machine, which may result in an increase in the exposure of the machine user, a risk analysis shall be prepared and submitted to the joint health and safety committee and employer for pre-approval.
- Early submission to the joint health and safety committee and workers for any new project using an X-ray source would ensure that any problems could be considered and discussed in advance. A radiation survey shall be carried out prior to any X-ray work commencing.
- The joint health and safety committee should be provided with written notice in advance of any purchase of new X-ray equipment, or the sale, relocation, or disposal of an existing X-ray machine or source.
- The X-ray tube shall not be energized during adjustments or repairs or when any protective safety cover is removed.
- No interlock or another safety device shall be deliberately defeated or bypassed.
- Any defect in a piece of X-ray equipment shall be reported immediately to the authority responsible for the radiation safety of the equipment.

Roles and Responsibilities

Employer/Equipment Owner Responsibilities

- To identify all supervisors/managers under his/her authority that have X-ray equipment in their departments and ensure that they clearly understand their duties and responsibilities as individuals with principal authority for X-ray equipment;
- assure that all X-rays and X-ray systems have been labeled by the manufacturer to indicate the appropriate hazard classification
- ensure that the product is properly classified and that the correct classification label is affixed (if this classification or label is not available or the system has been modified)
- ensure that a hazard evaluation of the X-ray control area has been performed prior to X-ray operation.
- immediately inform the user of imminent danger from an X-ray hazard
- ensure that control measures are in effect; and periodically evaluate the effectiveness of the selected controls.
- ensure that all components of the X-ray Safety Program are implemented in the company.
- ensure registration all X-ray equipment before use, and to deregister the decommissioned ones with the CNSC
- ensure that X-ray equipment supervisors and workers participate in the Company's X-ray safety program training prior to operating or working in proximity to any X-ray equipment
- provide and enforce the use of appropriate personal protective equipment when required
- provide and enforce the wearing of a personal dosimeter by all X-ray workers when necessary
- provide written standard operating procedures (SOPs) for X-ray equipment and to ensure that each X-ray source is used only under conditions and in locations which meet the requirements of the SOP(s)
- ensure that each X-ray equipment supervisor/worker is trained in the safe operation of the specific X-ray equipment that he/she will operate
- ensure that all X-ray machines and X-ray equipment are stored securely and safely when not in use so that they are not usable by unauthorized personnel or under unauthorized conditions
- permit only trained X-ray equipment supervisors/workers to operate or work in proximity of an X-ray source
- ensure that all administrative and engineering controls are implemented and followed
- correct unsafe conditions in a timely manner
- ensure that all workers, contractors, maintenance personnel and visitors are properly informed of, and protected from, potential X-ray equipment hazards
- cancel X-ray equipment supervisor/worker privileges until satisfied that he/she fully meets the requirements of this control program
- report immediately known or suspected accidents to the CNSC and/or WorkSafeBC.

General Safety and Responsibility

- assure that all X-rays and X-ray systems have been labeled by the manufacturer to indicate the appropriate hazard classification
- ensure that the product is properly classified and that the correct classification label is affixed (if this classification or label is not available or the system has been modified)
- ensure that a hazard evaluation of the X-ray control area has been performed prior to X-ray operation.
- immediately inform the user of imminent danger from an X-ray hazard
- ensure that control measures are in effect; and periodically evaluate the effectiveness of the selected controls.
- establish and enforce standard operating procedures
- ensure that protective equipment is available, in good working order and is used correctly.
- ensure that the wording on area signs and equipment labels are accurate and appropriate
- conduct hazard evaluations of modifications to existing facilities or X-ray equipment
- ensure that maintenance and service is carried out by qualified personnel
- ensure that appropriate safety education and training is provided to all personnel associated with X-rays
- provide safety instructions, which shall be incorporated into the standard operating procedure for the X-ray (if manufacturer's labeling safety information does not exist and cannot be obtained from the manufacturer or the distributor of the X-ray system)
- maintain necessary records

X-ray Supervisor Responsibilities

An individual who has been delegated supervisory responsibilities for X-ray equipment and X-ray workers by the Employer. He/she has the following responsibilities:

- participate in the Company's X-ray safety program training prior to operating or working in proximity to X-ray equipment
- be familiar with all operational procedures and specific safety hazards of the X-ray equipment that he/she will operate/oversee
- ensure authorized workers operate X-ray equipment safely and in a manner consistent with safe X-ray equipment practices, requirements, and written SOPs
- ensure authorized workers operate X-ray equipment only under the conditions authorized by the employer
- report all unsafe conditions to the Employer
- As directed by the Employer, provide instruction and supervision to X-ray workers
- As directed by the Employer, conduct other activities associated with the company's X-ray safety program
- promptly report known or suspected accidents and unsafe conditions to the Employer

Authorized Operator Responsibilities

The authorized operator is one who operates an X-ray source. He/she has the following responsibilities:

- participate in the company's X-ray safety program training prior to operating or working in proximity to an X-ray source
- be familiar with all operational procedures and specific safety hazards of the X-ray equipment that he/she will operate
- operate X-ray equipment safely and in a manner consistent with safe X-ray equipment practices, requirements, and written SOPs
- operate X-ray equipment only under the conditions authorized by the X-ray equipment supervisor/Employer
- report all unsafe conditions to the X-ray equipment supervisor/Employer
- promptly report known or suspected accidents and unsafe conditions to the X-ray equipment supervisor/Employer

X-ray Safety Officer responsibilities

The X-ray Safety Officer (XSO) is one who is directed by the Employer and is knowledgeable in the evaluation and control of X-ray sources hazards.

The XSO has the following responsibilities regarding X-ray equipment in his/her jurisdiction:

- Hazard evaluation of X-ray equipment work area
- Approval, or recommending for approval, the beginning of work for new facilities involving the usage of X-ray equipment, commissioning and decommissioning the X-ray equipment
- Developing and maintaining policies and procedures for engineering and administrative control of X-ray equipment hazards. The XSO is also responsible for ensuring that the prescribed controls are in effect
- Approval of procedures connected with X-ray equipment operation that may be subject to administrative and procedural control
- Inspection of X-ray equipment according to the X-ray safety program
- Recommendation and approval of protective equipment, X-ray equipment working area signs and equipment labels
- Ensuring safe operation through the authority to suspend, restrict or terminate operations
- stopping individual work when the safety of workers, the public or the environment is at risk documenting the technical reasons for the above decision, and reporting to the supervisor
- Investigation of the X-ray equipment related incidents and accidents, analysis of the causes, ensuring corrective actions are taken as required
- Maintenance and updating X-ray Safety Database
    - X-ray equipment registrations
    - Inspection reports
    - Training records
- Provides the appropriate X-ray safety training to all categories of personnel according to the X-ray safety program
- Verifies the quarterly personal dosimeter reports and investigates all the exposure reports that do not appear to be reasonable and appropriate. The results that are over the regulatory limits

will be communicated to WorkSafeBC and CNSC. If a record indicates a value above 0.4 mSv in one quarter and the investigation yields a real result, the XSO will recommend measures to reduce any further exposure

- Reports on all aspects of the X-ray safety program to the Joint Health and Safety Committee and Employer on a regular basis

Note: Data Storage and Retention of Records. The data volumes that are generated must be kept for the period that is stipulated by the CNSC Standard of Practice: Worker Records for record retention as this data is part of the worker record. Storage and transfer of this data is must comply with any Health Information Act in British Columbia.

Joint Health and Safety Committee (JHSC)

Roles and Responsibilities of the JHSC include:

- Receive appropriate X-ray safety training
- Conduct monthly inspections of all X-ray source equipment
- Investigate all complaints regarding the exposure control program, equipment malfunctions that may have resulted in increased radiation levels or overexposure or safety procedure non-compliance
- Incident investigations and reporting regarding exposure to X-ray radiation and safety and security policy breeches
- Oversight of all X-ray level surveys of equipment or facilities and exposure monitoring of personnel
- Receive exposure, survey and incident reports regarding X-ray equipment
- Review training and exposure records to ensure they are adequate and up to date
- Follow-up on all action items regarding the X-ray exposure program

Signage

Warning signs posted in the vicinity of the X-ray-controlled area shall:

- identify the X-ray-controlled area
- establish the nature of the hazard by specifying the wavelength and class of X-ray being used
- be posted on all means of access to the area
- only be posted or illuminated when the system is powered on or in standby
- indicate that personal protective equipment shall be worn.

Maintenance Program

The employer shall ensure that a maintenance program for manufacturing X-ray equipment is in place and that personnel are appropriately qualified, whether in-house services or contracted services are used.

Educational Requirements

Training programs shall be evaluated by the employer for applicability to the facility's practice. Successful completion of the program for all personnel responsible for working with X-ray equipment shall be documented.

All employers, supervisors and workers operating ionizing radiation equipment shall be knowledgeable about the operational parameters of the equipment and their influence on radiation dose.

The equipment operator must have a thorough understanding and have completed training for safe working methods and appropriate techniques and procedures. It is also acceptable to send staff to training facilities that offer training for the equipment that has been installed or modified. This training must be documented, and the records retained.

X-ray equipment operators must complete training in the safe operation of the equipment at the time of purchase/installation. New employers and staff, who join the facility after the installation and initial training, must receive similar training.

Safety Program

The owner or employer is responsible for having available a safety program to provide information to workers and other persons concerning the safe operation of radiation facilities and radiation equipment.

All Facility owners, employers or non employers, all support staff, all managerial staff and anyone involved in the procurement, installation, maintenance, and operation of radiation equipment must be knowledgeable in issues relating to the operation the unit, must be aware of the OHS Regulations (section 7) of BC pertaining to ionizing radiation equipment, the relevant Health Canada Safety Codes and any Health Information Act governing the transferring of worker health information in British Columbia.

All staff must undergo initial training. An ongoing training schedule must also be developed to accommodate changes in the X-ray equipment's operation and maintain consistency of the operators over time.

Above outlining the general safety obligations, the written safety manual addresses topics described in the following sections.

Informing Staff

The owner informs staff, who is likely to be exposed to radiation, of the potential hazards of the radiation and the precautions to be taken to protect themselves and other persons from the hazards.

Information includes:

- the worker's responsibilities and duties under the Radiation Protection Act and the regulations
- the type of radiation source the worker will be working with
- radiation protection principles and X-ray exposure limits appropriate to the type of radiation
- the uses and limitations of the radiation facility, equipment, and source
- known or suspected health hazards associated with the form of radiation emitted by the radiation source

X-ray Operator Competency

All tasks which involve the use or operation of radiation equipment must be performed by competent, authorized workers.

A competent worker is an individual who is adequately qualified by registration or licensure, suitably trained and sufficiently experienced to perform safely the assigned task without supervision, or with minimal supervision.

Maintenance of Radiation Equipment

The owner maintains all radiation equipment in a condition that will not endanger the health or safety of persons operating or affected by the operation of the equipment, and a preventive maintenance program is required.

Radiation Exposure Limits

The owner takes all reasonable precautions to ensure the radiation exposure of persons is kept as low as reasonably achievable and the X-ray exposure limits described in Appendix B are not exceeded.

Reasonable precautions would include Sections 8 and 9 of Safety Code 32.

Notice of Incidents and Overexposures

The WorkSafeBC must be notified of any overexposures or incidents that have the potential of causing an overexposure. Therefore, it is important that staff inform the owner immediately of any such incidents and that the incidents be recorded including resolutions.

Workers are responsible for following all procedures, working with an awareness of radiation health and safety, and cooperating in working towards improved radiation health and safety conditions at work.

Workers will take all reasonable precautions to ensure their own safety and the safety of their colleagues and maintain their knowledge by appropriate continuing education.

Pregnant Workers

Pregnant workers must inform the owner as soon as they are aware of the pregnancy. This will assist the owner in ensuring that radiation exposure to the fetus does not exceed the limit specified.

Operation of Non-Compliant Equipment

A worker must not operate equipment which is in a condition that will endanger the health or safety of themselves or others. If such equipment is under their control, they must notify the owner immediately.

X-ray Safety Inspections

Periodic inspections of X-ray sources are an integral part of the X-ray safety program; inspections provide some indication as to whether or not these X-ray sources are being operated in a safe manner. The employer will be informed about the results of the inspection (a copy of the check sheet will be sent to the employer and joint health and safety committee) and of the necessary measures to improve the safe use of the X-ray source.

The XSO is responsible for inspecting all new X-ray sources and, at least annually, all X-ray equipment for compliance with the company's X-ray Safety Program and to report to management and the joint health and safety committee.

Training and Education

All X-ray equipment workers and their supervisors must participate in the company's X-ray Safety Program training prior to operating or working in proximity to X-ray equipment.

This training will include the following:

- X-ray basics
- X-ray hazards, bio-effects
- Engineering and administrative control measures
- X-ray safety regulations and company X-ray safety program
- Responsibilities
- Causes of accidents
- X-ray accident reports
- Quiz

All X-ray equipment supervisors must also be familiar with all standard operating procedures and specific safety hazards of the X-ray equipment that they will operate/oversee.

All X-ray workers must also be familiar with all standard operating procedures and specific safety hazards of the X-ray machines that they will operate.

To use X-ray mobile equipment, the Xray worker needs to obtain the corresponding certificate of the Natural Resources Canada (X-ray Fluorescence Analyzer Operator Certification)

The XSO is responsible for maintaining records of all X-ray supervisors and X-ray workers who have participated in the X-ray safety program training and for notifying employers of this participation.

All persons using X-ray equipment shall participate every 3 years at the refresher training sessions organized by the company. The refresher training will include:

- X-ray safety news
- Changes in X-ray safety legislation
- Changes in the company X-ray safety program
- Responsibilities
- Results of X-ray safety inspections
- Quiz

Incident Reporting and Emergency Response

Company policy requires the reporting of all accidents/incidents, which result in or have the potential to result in personal injury.

Reporting of accidents involving death, critical injury, lost time, or health care is required for employees under the Workers Compensation Act and OHS Regulation, while Company policy requires the reporting of accidents/incidents involving visitors and other persons on company premises. Therefore, reportable accidents/incidents are those which:

- Result in personal injury (including those requiring first aid) or property damage; or
- Have the potential to result in significant personal injury or property damage even though no injury or damage occurred; or
- Occur to any person on company premises; or
- Occur to a company employee during his/her work either on or off company premises.

The employer is responsible for reporting all accidents/incidents involving X-ray sources to the XSO.

For incidents involving employees, the principal investigator must complete, and sign, the Company "Accident/Incident Report form for Employees"

Where a worker has received a dose in excess of the annual exposure limit (see Appendix B) set out in Section 7.19 of the BC Regulation, the XSO will investigate the cause of exposure and will provide a report in writing to the WorkSafeBC and to the joint health and safety committee of the findings and of the corrective actions taken.

All reportable incidents must be reported to the employer within 24 hours so that the appropriate report is filed with WorkSafeBC.

When a known or suspected incident is reported to the employer or supervisor with a suspected injury, they will be referred to the appropriate Health Service or hospital.

Personal Dosimetry

All X-ray workers, supervisors or employers working with or within the vicinity of an open beam X-ray source shall wear whole-body and ring personal dosimeters. If the X-ray source is enclosed in a cabinet, no radiation dosimeter is required.

A Canadian Nuclear Safety Commission (CNSC) certified dosimetry service should be used to provide the dosimetry service for the company.

The XSO will verify that the dose recorded by the personal dosimeter is reasonable and appropriate in the circumstances and will notify an inspector of WorkSafeBC of any dose that is above the regulatory limits.

The employer will retain the personal dosimeter records for a period of 10 years. The National Dose Registry of Health Canada keeps lifetime exposure records.

Each declared X-ray pregnant worker will be provided with a Personal Electronic Dosimeter. The weekly readings of the dosimeter will be communicated to the XSO at the end of each working week. Any unusual reading and anytime the alarm sounds will be communicated to the XSO immediately.

Preventative Maintenance

The following procedures should be considered for all radiation equipment.

Daily Procedures
Assess the functioning of:

- kVp meter for equipment with adjustable kV
- mA meter for equipment with adjustable mA
- mAs meter for equipment with adjustable mAs
- exposure indicators
- deadman timer
- tube movement and stability

Annual Procedures

- Clean interior of view boxes
- Check mechanical operation of all moving parts
- Examine integrity of all electrical cables
- Check operation of interlocks where applicable
- Check condition of protective clothing

Considerations
If the owner has the equipment calibrated it is important to ensure quality service.

- Ask the service company about its training programs for service personnel - most manufacturers of equipment offer factory training courses
- Ensure the service personnel are qualified to work on the type of units installed in the facility
- Ensure the reports state numerical results not just check marks
- Discuss the results and control limits with the service personnel

Appendix A: Information on Health Effects from Exposure to Ionizing Radiation

Radiation is one of the best-investigated hazardous agents. Because of the vast accumulation of quantitative dose-response data, scientists have been able to set environmental radiation levels so that applications of radiation and X-ray technologies may continue at a level of risk that is much less than with many other technologies. Consequently, machine operators of X-ray food inspection systems and cabinets can feel confident of working in a safe operating environment when standard exposure controls are followed because: 1) X-ray systems must meet rigorous safety standards before being sold and used in Canada; and 2), typical X-ray exposures to operators of X-ray machines in manufacturing and food processing are much less than the radiation exposure Canadians receive from naturally occurring background radiation.

According to the regulation, if a worker has the potential to receive more than 1mSv per year, they are classified as an "X-ray Worker" and therefore has additional monitoring and protocols required described in Regulation section 7.20 (1) "Exposure Control Plan" .

Health Canada estimates that Canadians receive on average 2-4 mSv of radiation dose each year from *background radiation*. Background radiation is radiation which is always all around us. Most background radiation is from natural sources, such as the Sun (cosmic radiation), radioactive particles like uranium, radium, and radon, found in soil or emanating from the soil (terrestrial radiation), and radioactive particles, like potassium-40 and carbon-14, found in food (internal radiation). This type of radiation exposure has never been shown to lead to adverse health effects.

A single accidental exposure to a high dose of radiation during a short period of time is referred to as an acute exposure and may produce biological effects within a short period after exposure. These effects include:

- Skin damage
- Nausea and vomiting
- Malaise and fatigue
- Increased temperature
- Blood changes
- Bone marrow damage
- Damage to cells lining the small intestine
- Damage to blood vessels in the brain

The above list is given for information purposes only. The doses that can produce such effects are extremely unlikely even in the event of an accident at work.

The delayed effects of radiation are due to both acute exposure and continuous exposure (chronic exposure). In this case, the negative effects may not be apparent for years. Chronic exposure is likely to be the result of improper or inadequate protective measures.

The most common delayed effects are various forms of cancer (leukemia, bone cancer, thyroid cancer, lung cancer) and genetic defects (malformations in children born to parents exposed to radiation). In any radiological situation involving the induction of cancer, there is a certain period between the exposure to radiation and the onset of disease. This is known as the "latency period" and is an interval in which no symptoms of the disease are present. The minimum latency period for leukemia produced by radiation is 2 years and can be up to 10 years or more for other types of cancer.

The connection between the effects of exposure to radiation and dose (i.e., dose-response relationship) is classified into 2 categories, deterministic and stochastic.

The deterministic effects, also referred to as tissues and organs effects, are specific to each exposed individual. They are characterized by:

- A certain minimum dose must be exceeded before the effect is observed. Because of this minimum dose, the deterministic effects are also called Threshold Effects. The threshold may differ from individual to individual
- The magnitude of the effect increases with the size of the dose received by the individual
- There is a clear relationship between exposure to radiation and the observed effect on the individual

Stochastic effects are those that occur by chance. They are more difficult to identify since the same type of effects may appear among individuals not working with radioactive materials. The main stochastic effects are cancer and genetic defects. According to current knowledge of molecular biology, a cancer is initiated by damaging chromosomes in a somatic cell. Genetic defects are caused by damage to chromosomes in a germ cell (sperm or ovum). There is no known existing threshold for stochastic effects. One single photon or electron can produce the effect. For these reasons, a stochastic effect is called a Linear or Zero-Threshold Dose-Response Effect.

Stochastic effects can also be caused by many other factors, not only by radiation. Since everybody is exposed to natural radiation, and to other factors, stochastic effects can arise in all of us regardless of the type of work (working with radiation or not). Whether or not an individual develops the effect is simply a question of chance.

There is a stochastic correlation between the number of cases of cancers developed inside a population and the dose received by the population at relatively large levels of radiation. Attempts have been made to extrapolate the data from these levels of dose to low levels of dose (close to the levels received from background radiation). There is no scientific evidence to prove the results of these attempts.

Since there is no evidence of a lower threshold for the appearance of Stochastic Effects, the prudent course of action is to ensure that all radiation exposures follow a principle known as ALARA (As Low As Reasonably Achievable).

The International Commission on Radiological Protection (ICRP, an independent organization of scientist) estimates that for every 1000 mSv of radiation dose, accumulated over 50 years, the risk of getting a fatal cancer increases by 4%. This number was used to create the dose limits for nuclear energy workers in Canada.

Finally, an acute exposure to a large amount of radiation can lead to immediate health effects, such as nausea, fatigue, and even death. A person would need to receive around 1000 mSv of radiation dose within a short period of time to feel any such immediate effects. The severity of the effect would then increase with increasing dose. Between 1000 and 2000 mSv, a person would expect to have radiation sickness, characterized by fatigue, nausea, possible diarrhea, and general malaise. Receiving 3500 mSv of radiation dose suddenly will be lethal for 50% of the people exposed, if untreated. Other effects, such as effects on embryos and specific organs in the body, also require doses far above the limits on radiation dose to nuclear energy workers.

Typically, workers in a manufacturing setting are not expected to reach the 1 mSv action level.

Pregnant Workers

It is well known that the fetus is more sensitive to the effects of radiation than an adult human. If an irradiation occurs in the first 30 weeks of pregnancy, delayed effects may appear in the child. These include mental and behavioural development issues, with a delay period of approximately 4 years.

Because of these possible effects, dosimetry during pregnancy differs from the usual protocol. Special attention is paid to both external and internal irradiation. An X-ray Safety Officer must review exposure control and work procedures when working around an X-ray source when a pregnant worker performs such work.

Appendix B –BC worker X-ray exposure limit table

Typically, an authorized worker operating a food X-ray inspection machine or an X-ray cabinet in a manufacturing operation is not expected to receive exposures above 1mSv per year. This is below normal background levels of approximately 2 – 4 mSv per year (ref. CNSC website).

If a worker has the potential to exceed the 1mSv action limit, the employer is required to have an "Exposure Control Program" (sec. 7.20 (1)) and personal monitoring (sec. 7.22).

PART OF BODY IRRADIATED	EXPOSURE CONDITIONS AND COMMENTS	EXPOSURE LIMIT (mSv)
Whole body or trunk of body	Uniform irradiation	20
Lens of eye	Irradiated alone or with other organs or tissues	150
Skin	The limit applies to the mean dose equivalent averaged over any area of skin of 1 cm^2, at a nominal depth of $7mg/cm^2$	500
Individual organs or tissues other than lens of eye or skin (eg. Hands and feet)	The limit on effective dose equivalent applies, with an overriding limit on the dose equivalent to the individual organ or tissue	500

If a worker declares her pregnancy to the employer, her effective dose limit for the duration of the pregnancy is 4mSv.

Appendix C – Notification of X-ray Worker Status

Following is an example letter to use for notification to an employee of their X-ray Worker Status. The worker would be given this letter by the employer. It is suggested that the employer retain a copy of the letter for his/her files which has been signed by the worker.

If this example is used, it should be printed with the Exposure Limit Table in Appendix B.

ABCD Manufacturing Canada Inc.
123 Any Street
City, Province, Canada
Postal Code

Dear______________________________(worker name)

As required by the X-ray Regulations respecting X-ray Safety made under the Occupational Health and Safety Act, Division 3 section 7.19 , I hereby inform you that you subject to the employer's Exposure Control Program under section 7.20 (1).

Section 7.19 of the regulation imposes limits as to the radiation exposure that you may receive as part of your employment. They are that doses are to be kept as low as reasonably achievable; in any case, as an X-ray worker you shall not receive a dose equivalent in excess of the annual limits.

If applicable, your employer shall take every precaution reasonable in the circumstances to ensure that the mean dose equivalent received by the abdomen of a pregnant X-ray worker does not exceed five millisieverts during the full term of the pregnancy.

Sincerely,

____ dated ____________________________

(Name of employer or employer's rep)

____ dated ______________________

(worker signature)

Appendix D: Standard Preventative Maintenance on X-ray machines

This document lists standard items to be reviewed during preventative maintenance service. Often, this work would be conducted by a qualified contractor. This list is a reference for the employer and/or XSO for understanding what should be included in preventative maintenance work.

A standard Preventative Maintenance visit usually consists of the following:

- Clean, inspect X-ray Tubes, replace O-rings, and adjust to manufacturers specs.
- Clean, inspect, reapply dielectric grease to high voltage (HV) cables and set compression.
- Clean, inspect and lubricate manipulator.
- Clean cooler, test flow, and check temperature switches.
- Clean and verify adjustments on the HV generators to prolong tube filament life.
- Test and adjust Safety Interlocks and Safety Lamps.
- Test power supplies and adjust to factory specifications.
- Test and adjust shutter.
- Service vacuum system.
- Inspect for proper cable drape.
- Verify emergency stop operation.
- Perform a Radiation Safety Survey with documentation.

After going through these checkpoints, a service technician will typically go through potential wear on specific parts of the system and may make recommendations on repairing or replacing specific components. This may include parts that need to be replaced as soon as possible, or parts that are recommended to keep on hand to reduce total downtime. This helps ensure that the system is kept in working order and minimizes wear over the course of time

Appendix E: Radiation Protection Survey

This document lists the standard measurements taken during a Radiation Protection Survey. This work would be conducted by a qualified contractor or the XSO. This list is a reference for the employer and/or XSO for understanding what measurements could be included when conducting the survey.

Radiation Protection Survey of (Equipment Name), (Model #), (Serial number #)

kVp (typical/max):_____/______ mA (typical/max):_____/______

Scatter medium:_________________________________

Survey meter used (make, model, serial number):______________________________________

Calibration date of survey meter:____

Measurement Results (expressed in micrograys per hour at 5 cm from the external surface at typical/maximum operating conditions, as stated above)

Measurement Location	Result @ 5cm from surface For Typical / Maximum Operating Conditions			
	Instrument units Specify units: ___________		Converted (if needed) µGy/h	
	Typical	Maximum	Typical	Maximum
Front				
Back				
Left Side				
Right Side				
Bottom				
Top				

Verified that interlock is functional and can only be reset at control screen after tripped and closed:______(initial)

"X-ray on" warning device conspicuously placed on or near equipment so that it can be seen from any position:______(initial)

Date of Survey:____________________Operator:_____________________________________

Appendix F: X-ray Equipment-Specific Emergency Procedures

In the event of an emergency affecting the X-ray equipment, such as the X-ray beam remaining on when the cover is opened, or if damage to the shielding occurs, the following steps are to be followed:

1. Turn off the X-ray source/machine and unplug it from the power source.
2. Identify and isolate all workers and persons who may be exposed
3. Secure the incident site to prevent entry.
4. The X-ray Safety Officer is to be informed immediately of the incident.
5. The X-ray Safety Officer will immediately notify WorkSafeBC and make a preliminary verbal report of the incident. WorkSafeBC is to be told of the details of the situation (including location and circumstances of the situation), and any action that the employer has taken or proposes to take with respect to it.
6. Get assistance from the manufacturer or a qualified radiation safety professional as required.
7. Record all event details chronologically.
8. Activate authorized follow-up procedures.
9. The XSO is to submit a written report to WorkSafeBC within 48 hours with contents of the report describing the circumstances of the accident or failure of equipment that may have resulted in a worker receiving a dose in excess of the annual limits.

Notes:

If the shielding has been damaged, the equipment must be tagged out of service, repaired, and surveyed for leakage before it can be returned to service.

Appendix G: Hand-held X-ray devices

Technological innovations that barely existed about a decade ago resulted in the development of specific X-ray tube-based X-ray fluorescence (XRF) devices used for *in situ* elemental or chemical analyses of materials, components, or systems by industry. The defining characteristics of such devices typically include:

- An X-ray tube as the source of ionizing radiation, capable of operating up to ~50 kV and a few hundred microampere (µA);
- An open port from which a collimated primary beam of high intensity emerges (beam port);
- Inherent filter(s) for modifying the intensity or quality of primary or characteristic radiation;
- An internally positioned sensitive radiation detector that picks up, through the open port, fluorescent X-rays created by the irradiated materials;
- Appropriate internal electronics coupled with software that process the detected signals to yield real-time analytical data within short irradiation times (on the order of a few tens of seconds); and
- Portability and of low enough weight to be hand-held for use utilizing an X-ray on/off switch, which incorporates a failsafe feature in that positive pressure is applied via the operator's finger to generate and sustain X-ray generation for the duration of the test and removal of that pressure promptly stops X-ray generation.

Such devices are defined as portable, hand-held, X-ray tube based open-beam XRF devices and are limited to maximum designed operational ratings of 50 kV and 4 W.

Analyses are performed when the devices, hand-held by the operator, are taken to the location of the test material and activated to provide a high intensity primary beam that bombards the test material at close range. In the past several years, these devices have been particularly useful to industry while gaining acceptance in a wide array of industrial applications, such as alloy analysis, mining and exploration, lead (Pb) testing in toys, sorting and recycling of scrap metal, and identification of materials. These applications constitute an analytical technique or test method that is not only repetitive or automated, but also falls within the scope of limited industrial non-destructive testing (NDT).

XRF devices possessing the above characteristics that are not limited to the maximum operational ratings specified in this section must not be used in an open-beam or hand-held mode.

Appendix H: Facility Floor Plan

[insert floor plan showing the placement of the X-ray equipment]

manufacturing
Safety Alliance of BC

About us

The Manufacturing Safety Alliance of BC is the industry-led, nonprofit health and safety association that helps BC manufacturers and food processors build and certify safety programs that protect workers and cut costs.

The Alliance is also the WorkSafeBC Certifying Partner for the Occupational Safety Standard of Excellence (OSSE), the health and safety Certificate of Recognition for BC manufacturers.

The Alliance offers safety certification, OHS consulting and advisory services, and broad selection of classroom and online training. Our vision is to partner with BC's industry leaders to achieve cultural change that ensures safe workplaces for all employees.

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