Health Canada Santé Canada

Radiation Protection and Safety for Industrial X-ray Equipment

Safety Code 34

Canada

Radiation Protection and Safety for Industrial X-ray Equipment

Safety Code 34

Safe Environments Programme
Healthy Environments and Consumer Safety Branch

03-HECS-333

Our mission is to help the people of Canada
maintain and improve their health.

Health Canada

Published by authority of the
Minister of Health

Également disponible en français sous le titre :
*Les appareils de radiologie industriels :
radioprotection et sécurité*

This publication can be made available in/on computer diskette/large print/audio-cassette/braille, upon request.

Cat. H46-2/03-333E
ISBN 0-662-35570-9

Foreword

Ionizing radiations are increasingly used in a variety of applications in medicine, research and industry because of their known benefits to society. One important industrial application utilizes various sources of ionizing radiations to investigate the integrity of structures or components through radiographic images, a practice generally referred to as nondestructive radiography or industrial radiography. Industrial radiography to date is an established practice that provides benefits concurrent with radiation risks. The radiation protection objective, therefore, is to keep the risks *as low as reasonably achievable* (ALARA) while maximizing benefits.

Guidelines for ionizing radiation protection have been in existence for more than 60 years and have been subject to numerous revisions in that time. One authoritative international standard-setting organization is the International Commission on Radiological Protection (ICRP). In 1990, the ICRP reaffirmed its system of radiological protection aimed at reducing the radiation risks associated with ionizing radiation use, and recommended lower dose limits for radiation workers and the public[1]. The objectives of that system with respect to radiation exposure are twofold: to prevent the occurrence of deterministic effects, and to reduce the incidence of stochastic effects. Sharing these same goals, the International Atomic Energy Agency (IAEA) revised and updated its guidance documents[2,3] that not only reflect the 1990 recommendations of the ICRP, but also aim to lower ionizing radiation risks while not limiting the beneficial uses of ionizing radiation. The ICRP and IAEA publications are influential internationally and are used by a large number of countries to develop national regulations for radiation protection and safety.

This document is one in a series of Safety Codes published by Health Canada in accordance with Treasury Board Hazardous Substances Directive[4] to promote radiation protection and safety in the federal workplace. This Safety Code draws on the ICRP and IAEA objectives, concepts and recommendations, and provides advisory information and guidance on radiation protection and safety specific to industrial x-ray equipment. It supersedes Safety Code 27 and is intended for federal facilities. Thus, facilities subject to the Canada Labor Code Part II, Occupational Health and Safety Legislation[5] shall comply with the requirements of this Safety Code.

This Safety Code comprises an Introduction, the Management of Radiation Protection and Safety, Requirements for Industrial X-ray Equipment, Additional Guidance, References, Glossary and Appendices. The Introduction provides a background on industrial x-ray

equipment and radiation hazards, and indicates the intent and scope of the Safety Code. The Management of Radiation Protection and Safety Section specifies the responsibilities of stakeholders which are key in the management of radiation protection and safety relevant to industrial x-ray equipment. The section on Requirements for industrial X-ray Equipment specifies what is needed for regulatory compliance of equipment, for permanent and temporary work sites, and for on-site evaluations. Additional Guidance information is included for non-radiography use of industrial x-ray equipment, personnel monitoring, survey meters, emergency procedures, resale and disposal. References are provided as well as a Glossary and Appendices. The information and guidance provided in this Safety Code would be of interest to regulatory authorities, industrial x-ray equipment manufacturers, owners, operators, organizations or radiographers carrying out industrial radiography, and clients responsible for hiring such organizations.

This Safety Code may be adopted for use elsewhere. Facilities under provincial or territorial jurisdiction are advised to consult their appropriate agency for information and guidance on radiation protection and safety, since statutes and requirements could differ from one jurisdiction to the other. Relevant (provincial/territorial) contact information is available at a Health Canada website(6).

Given the diverse applications of industrial radiography, it is not possible to foresee all work situations; therefore, it is plausible that unexpected problems may occasionally occur and the guidance in this Safety Code may be insufficient to address them. For such situations, consultation with the appropriate regulatory authority is advised.

This Safety Code was drafted, prepared and finalized by H.P. Maharaj in accordance with Health Canada review and publishing criteria. Interpretation of requirements or guidance in this document should be directed to the attention of: Head, Nonmedical X-Rays, PL 6301A, 775 Brookfield Road, Ottawa, Ontario, K1A 1C1 (Facsimile number: (613) 941-1734).

Acknowledgment is extended to the following contributors for their comments and/or suggestions towards improvement and clarity of this document:

Atlas Testing Laboratories and Services Ltd.
Atlantic NDT
Bowe and Landry NDT
British Columbia Centre for Disease Control
Canadian Nuclear Safety Commission

Canadian Police College
Cancer Care Manitoba, Radiation Protection Service
CanSpec Group Inc.
Conan Quantum Inspection and testing (Division of Stavely Services Canada Inc.)
Department of National Defence
Health Canada
Insight Inspections Inc.
Labcan(1989) Ltée
Ontario Ministry of Labour, Radiation Protection Service
Pratt and Whitney Canada Ltd.
Rolls-Royce Canada Ltd.
Royal Canadian Mounted Police

Table of Contents

1. Introduction

1.1 Background

Radiation Equipment

Machines have been specifically designed to generate x rays for the purpose of investigating the integrity of structures or components through radiographic images; this application is called nondestructive radiography or industrial radiography. Three types of ionizing radiation sources are typically available for such purposes: (1) Radioactive materials that are gamma ray emitters such as iridium-192 (^{192}Ir), cesium-137(^{137}Cs) and cobalt-60(^{60}Co). (2) Neutrons that are produced in reactors or by other means (particle accelerators, radionuclides), and this application of neutrons is specifically referred to as neutron radiography. (3) X-ray tubes that are characteristic of conventional x-ray machines.

Industrial radiography machines which are x-ray tube based can produce dose rates in air of about 2 Gy per minute at one metre[7]. 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, 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.

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 byproduct 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 electron beam incident on a copper target[8]. The welding process requires the use of highly focused beams, a requirement that not only reduces the number of electrons striking the metals being bonded but also lowers the contribution of byproduct x rays potentially scattered. The operation of electron beam welders presents a potential for exposure to x rays and electrons.

Collectively, in this document, 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.

Radiation hazard

X rays and electrons are types of ionizing radiation. In general when ionizing radiation traverses matter the interaction is probabilistic, that is, there may or may not be an interaction. In the case of a medium composed of cells of living organisms, the interaction with individual cells may be *direct* or *indirect*. At the cellular level, *direct* interaction with DNA or other constituents can cause damage. In the *indirect* mechanism, reactive ions are formed due to the breakdown of the water molecules present in the cells; such ions can interact with any cellular constituent thereby leading to potential damage. Various possibilities exist for the fate of cells exposed to ionizing radiation: (1) Damaged cells are completely repaired by the body's inherent repair mechanisms. (2) Damaged cells die during their attempt to reproduce. Thus 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. (3) Damaged cells

survive the radiation insult, but are misrepaired and are 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).

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 progeny 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 retardation and congenital malformations if the amount of radiation is sufficiently high.

Exposure to ionizing radiations has the potential to cause early or late adverse health effects. This is why the radiation risks associated with industrial x-ray equipment need to be managed.

1.2 Objective

The objective of this Safety Code 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 document provides basic requirements and guidance intended for the radiation protection and safety of industrial radiographers, other users, service personnel and the public. It does not discuss industrial radiography techniques or electron beam welding processes or other requirements (e.g., electrical or explosive).

1.3 Scope

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 may have limited application in x-ray photon-based scanning systems used for cargo surveillance purposes. The characteristics of such systems include: (i) large enclosures or modular configurations which comprise shielded walls or panels, which can facilitate human intrusion, and which may be used in temporary work sites; (ii) intense x-ray beams produced by high voltage generators (greater than 450 kVp) or by accelerators; and (iii) various safety mechanisms to limit exposures to the operators and the public.

This Safety Code excludes: (i) cabinet x-ray systems; (ii) radioactive-based equipment that emits gamma rays or neutrons for use in industrial radiography; (iii) systems specifically designed for the production of neutrons which may be used in industrial radiography; and (iv) facilities that utilize high-intensity gamma ray or electron sources for food irradiation or material sterilization or material property-modification purposes, applications which require a dose on the order of kilogray.

1.4 Definitions

Some of the terms used in this document are defined in the glossary.

2. Management of Radiation Protection and Safety: Relevant Parties and Responsibilities

Mitigation of radiation risks associated with the use of industrial x-ray equipment requires the collective action of various stakeholders: the regulatory authority, the equipment manufacturers, equipment owners, equipment operators, equipment servicing personnel, organizations carrying out industrial radiography, clients responsible for hiring such organizations, and the public. The stakeholders' responsibilities and functions are indicated below.

2.1 Regulatory Authority

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

In accord with its health protection mandate, the regulatory authority has the powers to enforce compliance with this Safety Code, to make or authorize measurements that would facilitate evaluation for compliance with the requirements of this Safety Code or to require an operating organization or facility to modify or correct any procedure, practice, system or component to ensure safety. It can issue directives prohibiting use of industrial x-ray equipment, depending on the hazards and risks presented by deviations of procedures or by safety violations, and can annul the confirmation of registration.

2.2 Industrial X-ray Equipment Owner

Only products that are compliant with the *RED Act*[9] shall be procured. **The owner of industrial x-ray equipment is ultimately responsible for the radiation safety of that equipment**, and for ensuring that it is used in accordance with all legislation and regulations, including conformance with other safety standards (e.g.,

electrical, explosive) that might be applicable for the safe use of the equipment in the intended workplace. This responsibility requires a strong commitment to safety by the owner of the industrial x-ray equipment, demonstrated by the establishment and use of a radiation safety program.

The owner **shall** appoint a Radiation Safety Officer (RSO) to oversee and implement the radiation safety program at each facility in which industrial radiography is carried out, **and shall** provide adequate financial and physical resources for the incumbent duties and actions. A facility-designated RSO, by appointment to the position, is empowered to undertake necessary supervision of radiation protection activities, stop unsafe practices, implement safety directives and enforce prohibitions issued by the regulatory authority pursuant to this Safety Code. An RSO shall be a certified industrial radiographer at the NDT Level 1, or higher, as described in Section 2.2.1.12. of this Safety Code.

The owner of industrial x-ray equipment that is to be operated in a facility under federal jurisdiction shall ensure that the equipment is duly registered as described in Section 3.2 of this Safety Code and that there is a valid confirmation of registration before the equipment is used. A federal facility that operates industrial x-ray equipment without a valid confirmation of registration is in contravention of legislation[5].

2.2.1 Radiation Safety Officer

Prior to procurement of industrial x-ray equipment, the RSO must receive written confirmation from the equipment manufacturer or its authorized marketing agent that the product complies with the *RED Act* (refer to Section 4.1 of this Safety Code). The onus is on the equipment manufacturer to show proof of or demonstrate regulatory compliance. Only products that are compliant with the *RED Act* shall be procured. The RSO must ensure that (i) the industrial x-ray equipment and the facility(ies) in which it will be in use meet all applicable radiation safety and regulatory requirements in this Safety Code, including conformance with other applicable standards (e.g., electrical, explosive); and (ii) industrial radiography is performed in accordance with safety procedures consistent with those of the practice. In a case for which noncompliance is identified after the equipment has left the manufacturer's premises, guidance to ensure regulatory compliance of the equipment is given in Section 2.4 of this Safety Code.

The specific and incumbent actions required of an RSO are:

1. To register all industrial x-ray equipment with the regulatory authority and obtain a valid confirmation of registration which must be posted conspicuously at that facility. For equipment installed inside a permanent installation or stored in a designated key-locked room, the wall beside the main access door to the inside of such a structure would suffice for posting the confirmation of registration. Where a facility has portable industrial x-ray equipment for use off site, the industrial radiographer tasked with operating the equipment at the off-site location shall have appropriate documentation attesting that the equipment is duly registered. Non-registered equipment shall not be used.
2. To prepare or review all safety, ALARA and radiation accident or overexposure response procedures and submit them to the regulatory authority for review.
3. To ensure that all protective and safety equipment and materials required in the safety, ALARA, and radiation accident or overexposure response procedures are available.
4. To ensure that a program of regular maintenance is in place for all industrial x-ray equipment used at the facility.
5. To provide written notification to the regulatory authority of industrial x-ray equipment that does not comply with the requirements of Section 3.1 of this Safety Code in the event that noncompliance was identified after the equipment has been installed or in use, and clearly detail the item(s) of noncompliance.
6. To ensure that the proposed design plans for a new permanent installation or for modifications of an existing permanent installation are reviewed by the regulatory authority, before any construction or modification begins.
7. To consult and liaise with the appropriate personnel responsible for the construction of new permanent installations or of modifications to existing installations in order to ensure compliance with regulatory requirements and incorporation of recommendations of the regulatory authority.
8. To arrange for on-site evaluations associated with the pre-commissioning tests of permanent installations.
9. To identify the controlled and supervised areas at the facility.
10. To acquire a calibrated and operable survey meter at each facility where industrial x-ray equipment is in use. Such meters shall be calibrated by a national calibration ionizing radiation laboratory

(e.g., National Research Council, Ottawa, Canada; NIST, USA) or, a laboratory that has been accredited by a national laboratory to perform such calibrations. Calibrations shall be done at several photon energies to cover the range of photon energies, generated by the x-ray equipment that will be in use. Calibration frequency is once a year or after the meter has been serviced or repaired. Records of the results of survey meter calibrations shall be kept at the facility. Each facility shall have a back up radiation protection survey meter that is also calibrated and functional as indicated in this subsection.

11. To undertake reviews and modifications, as necessary, of operational procedures relevant to protection and safety to ensure radiation exposure to industrial radiographers is ALARA and public dose limits (in Appendix II, Tables 1 and 2 of this Safety Code) are not exceeded.
12. To ensure that any person operating industrial x-ray equipment for industrial radiography purposes is an industrial radiographer, with certification at the NDT Level 1, or higher, in accordance with the requirements of the Canadian General Standards Board[10]. Persons operating industrial x-ray equipment specifically for police and security radiography must be certified at Level I or higher in accordance with the Canadian General Standards Board requirements[11].
13. To ensure that individuals operating electron beam welders and other users receive radiation safety education as outlined in Section 4.3 of this Safety Code.
14. To ensure that both industrial radiographers and other users have received practical training on the proper use of the specific x-ray equipment and of the survey meter(s) present at the facility, and have received instruction on the operational, ALARA, and safety procedures applicable to the facility.
15. To conduct quarterly reviews of the industrial radiographer's signed and dated log reflecting periodic safety checks done on the industrial x-ray equipment and its safety-related components, and on the safety accessories comprising the permanent installation as described in Section 3.3.1. of this Safety Code.
16. To make decisions on reassignment of duties for declared or confirmed pregnant industrial radiographers to ensure that the pregnancy dose limit is not exceeded for the duration of the

pregnancy, and on the need for special restrictions to limit exposure of female employees in the work area. (Consultation with the regulatory authority is suggested.)

17. To arrange for training, where applicable, and briefing of industrial radiographers, other users and allied personnel on radiation safety issues or procedures, and maintain appropriate record keeping of training material and a roster of trained personnel.
18. To supervise safety procedures for industrial radiography at temporary job sites or delegate such tasks to a safety officer or an equivalent alternative as described in Section 3.3.2.3. of this Safety Code.
19. To ensure that individuals training for industrial radiographer certification are supervised by an appropriately certified industrial radiographer, and are subject to all protection, safety and dose monitoring procedures commensurate with those applicable to an industrial radiographer.
20. To develop and maintain a system of personnel monitoring that includes periodic reviews of personnel monitoring data, investigation of inconsistencies, implementation of remedial actions in a timely manner, and retention of all such documents and records.
21. To ensure that there are available sufficient passive dosimeters for the industrial radiographers, other users and allied personnel as applicable, and that passive personnel dosimeters assigned to an individual are not shared by others.
22. To acquire personnel dosimetry records from industrial radiographers who are engaged in service contractual agreements with multiple employers, then assess and ensure that their annual permissible occupational dose limit has not been exceeded, prior to undertaking the industrial radiography work at hand.
23. To investigate radiation accidents or abnormal exposures or suspected exposures to personnel and file an appropriate report with the regulatory authority within 5 calendar days of the incident.
24. To ensure that individuals accidentally exposed to ionizing radiation receive proper medical attention.
25. To ensure that service personnel are qualified and authorized by the industrial x-ray equipment manufacturer to service the

equipment, and have read and understood all radiation safety procedures applicable to the facility, before they can proceed with the impending servicing tasks.

26. To ensure that persons proximal to industrial radiography work sites are briefed on the radiography work being done, the potential hazards and radiations risks, the applicable regulations, the safety procedures that will be followed, the duration of the work, and are provided with contact information on the RSO to whom ionizing radiation-related issues or concerns may be directed. (This action is perceived as promoting a positive safety culture in the workplace.)
27. To initiate revisions of safety procedures and ensure that the facility is in compliance with the requirements of this Safety Code for as long as the facility uses, owns or stores industrial x-ray equipment.
28. To ensure that the industrial x-ray equipment is returned to the manufacturer for disposal or, if the manufacturer is no longer in business, is delivered to a company specifically contracted by the equipment owner to undertake the actions indicated in Section 4.8 of this Safety Code in order to ensure safe disposal.

2.3 Certified Industrial Radiographer

A certified industrial radiographer is an individual meeting the requirements as described in Section 2.2.1.12. of this Safety Code. The individual has a responsibility to carry out the radiography work in accordance with instructions and defined operating and safety procedures to ensure his or her protection and that of others. It is therefore imperative that there be strict adherence of the safety instructions, procedures and precautions provided in the operating manual of the specific industrial x-ray equipment to be used. The individual shall adopt an overall safety philosophy when doing industrial radiography and, in this context, exercise vigilance with respect to the interlocks, alarms, warning indicators and signs. A certified industrial radiographer shall:

1. carry on his or her person appropriate proof of identification and certification as an industrial radiographer whenever radiography is being conducted;
2. provide the facility RSO with appropriate evidence affirming identification, certification and training;

3. provide the facility RSO with a record of any radiation exposure history, especially if the industrial radiographer has been or is engaged in service contractual agreements with multiple employers at any time;
4. ensure that his or her annual permissible occupational equivalent dose limit (20 mSv, refer to Appendix II, Table 1 of this Safety Code) has not been exceeded, prior to undertaking industrial radiography at a facility;
5. receive safety instructions and training specific to the industrial x-ray equipment and survey meter(s) to be used at the permanent installation or temporary job site, and confirm with the facility RSO that this action has been taken;
6. keep radiation exposure to himself or herself and others ALARA, and use one of the facility's functional and calibrated survey meter to ensure radiation levels are within dose limits that would not present an undue risk to any person;
7. wear (i) a personnel radiation dosimeter (passive dosimeter) supplied by a dosimetry service provider[12, 13] which is approved by the Canadian Nuclear Safety Commission (CNSC) in accordance with CNSC regulations[14], and (ii) an electronic alarm dosimeter (active dosimeter) which shall emit an audible signal when the equivalent dose rate reaches or exceeds 5 mSv/h or where the total equivalent dose reaches or exceeds 2 mSv;
8. not wear another individual's passive radiation dosimeter;
9. perform preliminary checks on all safety devices (interlocks, warning lights, timers, shields, survey meters, personnel alarm dosimeters, etc.) for proper functioning and resolve any inadequacies identified, before undertaking industrial radiography, and maintain an appropriately signed and dated log of such checks;
10. check the inside of a permanent installation or controlled area to confirm that no person is present before initiating the generation of x-radiation;
11. follow all protection and safety rules, including procedures established for the pending radiography work at the facility;
12. notify the facility RSO of any known or suspected abnormal radiation exposure to any person, and maintain a record of such notification;

13. supervise, as delegated by the owner of the industrial x-ray equipment in collaboration with the facility RSO, any individual in training for industrial radiographer certification;
14. exercise vigilance and check, at least once a month,: (i) the x-ray tube and cables for visible damage and wear, and (ii) the warning labels and signs on the control console and radiation source assembly, including the exposure factors on the control console for legibility;
15. not use any defective industrial x-ray equipment or survey meters or radiation dosimeters or shielding; and
16. where applicable, when industrial radiography work is to be carried out at a client's facility which is off site from the facility in which the industrial radiographer is registered, brief the client as described in Section 2.5 of this Safety Code.

Due consideration shall be given to female industrial radiographers of reproductive capacity. Female industrial radiographers, whether certified or in training, who are confirmed or declared pregnant shall discuss with the facility RSO their potential occupational doses and radiation hazards for the remainder of the pregnancy. (Should private or sensitive information about the radiographer's pregnancy be divulged in the discussion, such information shall be treated in a confidential manner.) Having been made knowledgeable of the potential occupational doses and radiation hazards associated with the work, should the pregnant industrial radiographer choose to continue radiography work, personnel monitoring shall be implemented on a monthly basis and the badge readings shall be promptly reviewed by the facility RSO to ensure that the pregnancy dose limit (in Appendix II, Table 1 of this Safety Code) is not exceeded. Records of these actions shall be properly documented and retained by the facility RSO. No pregnant industrial radiographer shall be re-assigned to other duties simply on the basis of information that the individual is pregnant.

2.4 Manufacturer of Industrial X-ray Equipment

Manufacturers of industrial x-ray equipment shall acknowledge that such equipment is federally regulated in Canada (refer to Section 3.1 of this Safety Code). It is the manufacturers' responsibility to ensure that their products comply with the *RED Act*[9] before they are

imported, leased or sold in Canada. To facilitate demonstration of product compliance, manufacturers of industrial x-ray equipment or their marketing agents shall:

(i) provide written notification to the regulatory authority, Health Canada, of the particular product intended for commerce in Canada;
(ii) include with that written notification: a copy of the promotional literature, technical specifications, including installation, operational, safety, maintenance and disposal instructions in respect of that particular product, if these materials have not been previously submitted to the regulatory authority; and
(iii) provide supportive evidence that the particular product conforms with the requirements as specified in Section 3.1 of this Safety Code.

The regulatory authority may evaluate the product and provide a response to the manufacturer accordingly. (Evaluation and responses may take place 4-6 weeks following receipt of all required documentation and supportive evidence from the manufacturer.) The importation, lease or sale of industrial x-ray equipment that does not conform with the *RED Act* is unlawful. Any violation of the *RED Act* is a criminal offence.

In a case for which noncompliance is revealed after procurement or installation of the industrial x-ray equipment, the equipment manufacturer and the importer, upon **written or verbal** notification of the noncompliance by the regulatory authority or by the equipment owner, shall take the necessary actions to bring the equipment into compliance within 30 days from the date of noncompliance notification. In such situations, the equipment owner is further advised to cease using the equipment until the noncompliance issues are resolved to the satisfaction of the regulatory authority.

The manufacturer is solely responsible for providing training on the servicing, safety and radiation protection specific to the industrial x-ray equipment, and for issuing appropriately written authorizations to individuals so trained to carry out servicing.

2.4.1 Service Personnel

Personnel responsible for servicing industrial x-ray equipment in a facility or other workplace shall:

1. provide proof to the facility RSO or workplace manager, as applicable, that they have received service training specific to the industrial x-ray equipment that is to be serviced;
2. provide written evidence to the facility RSO or workplace manager, as applicable, that they are authorized by the industrial x-ray equipment manufacturer to service the industrial x-ray equipment;
3. follow all safety rules, including ALARA and accident response procedures established at the facility;
4. wear personnel monitoring devices as specified in Section 2.3.7. of this Safety Code;
5. acknowledge that, for the application of this Safety Code, 'radiation worker' dose limits apply;
6. ensure that their annual permissible occupational dose limits of 20 mSv (Appendix II, Table 1 of this Safety Code) is not exceeded; and
7. specify any unsafe conditions that could arise during operation of the industrial x-ray equipment in a written, signed and dated report which shall be submitted to the facility RSO or workplace manager as applicable.

2.5 Clients Hiring Organizations or Individuals to Perform Industrial Radiography

Before any radiography services are undertaken at a client's facility, the client shall be briefed on the industrial radiography, the potential risks and hazards that are intrinsic to the work, the safety procedures that will be followed for the client's specific work required, applicable regulations, and proof of radiography personnel certification and training. This briefing shall be done by the certified industrial radiographer hired or authorized to perform the radiographic services at the client's premises, before any such services are carried out.

The client shall acknowledge that contractual conditions must not hinder the operating organization or individuals from performing the radiographic work safely, that is, regulatory and safety requirements take precedence in industrial radiography. The client must ensure that industrial radiography is conducted in a safe manner to minimize the risk of ionizing radiation exposure to the operators and

others on site. The client shall, therefore, designate a safety officer to ensure that all safety procedures are being adhered to at the facility. Where different industrial radiography jobs on site are required, the issuance of work permits in conjunction with client supervision is necessary to reduce the likelihood of radiation accidents or abnormal exposures. Based on the foregoing, the client in conjunction with the radiography service provider shall prepare and retain a document (e.g., a checklist) which incorporates appropriate signatures and dates in order to demonstrate that the client was briefed on the safety issues relevant to the job, and is satisfied that appropriate safety actions were taken at the work site. A copy of all documents so prepared shall be kept on file at the radiographer's facility and at the client's premises where the radiography was carried out.

2.6 Unauthorized Individuals in Industrial Radiography Areas

Unauthorized individuals, other workers and staff in an organization or facility, and members of the general public, who might be in areas where industrial radiography is being carried out must adhere to all safety warnings, instructions and notices posted in such areas, and apply "common sense thinking and action" for their own protection and safety. An individual who violates this 'standard of care' and incurs harm is deemed to have acted voluntarily in a negligent manner.

3. Requirements for Industrial X-ray Equipment

This part of the Safety Code outlines the regulatory requirements for industrial x-ray equipment, respecting design, compliance evaluation and enforcement; registration; and work site practice of industrial radiography.

3.1 Industrial X-ray Equipment Design Standards

X-ray equipment is federally regulated in Canada under the *Radiation Emitting Devices (RED) Act*[9] and companion regulations. The *RED Act* provides the authority to write regulations for specific classes of x-ray equipment. Where specific *RED Act* regulations are not available for a class of x-ray equipment, the general provisions of the *RED Act* respecting prohibition, deception and notification apply within the scope of ensuring worker and public safety. This is the case for industrial x-ray equipment. Thus, the importation, lease or sale of industrial x-ray equipment that does not conform with the *RED Act* is contrary to Canadian law. It is the manufacturer's and the importer's responsibility to ensure that the x-ray equipment available for commerce in Canada complies with the *RED Act*. Any violation of the *RED Act* is a criminal offence.

Re-sale industrial x-ray equipment shall also comply with the *RED Act* at time of sale. The seller is responsible for ensuring regulatory compliance of the equipment, for bearing the associated costs of compliance, and for notifying the buyer of his or her safety obligations upon acquisition of the equipment. Additional information is provided in Section 4.7 of this Safety Code.

Industrial x-ray equipment that is designed and constructed to conform with the following minimum requirements would meet the general provisions of the *RED Act*:

(1) a control console that is equipped with:
  (i) a power switch;
  (ii) an illuminated 'power on' indicator;
  (iii) a red illuminated failsafe 'x-ray on' indicator;
  (iv) indicators of the operational high voltage and beam current in respect of the ionizing radiation source;
  (v) a lock of a type that requires the insertion of a key before ionizing radiation can be produced and for which the removal of the key terminates the production of ionizing radiation;
  (vi) a device that controls the duration of ionizing radiation generation;
  (vii) a radiation ON/OFF control that requires activation by the operator for ionizing radiation production;
  (viii) an emergency switch which, when activated, de-energizes the ionizing radiation source;
  (ix) appropriate provisions for the connections of interlock systems and of remotely positioned warning devices that provide visible and audible warnings during ionizing radiation generation;
  (x) a warning sign, next to the key lock, which (a) indicates that hazardous ionizing radiation emissions are produced when the device is operating, and (b) prohibits unauthorized use;
  (xi) a radiation warning sign that reflects the x-ray tube logo shown in Appendix I of this Safety Code; and
  (xii) an identification label, respecting the industrial x-ray equipment, which indicates the name and business address of the manufacturer, the model number, the serial number, the date of manufacture and the country of manufacture.

(2) A radiation-shielded assembly that contains the ionizing radiation source and is equipped with a simple battery operated laser alignment device or a suitable alternative that aids radiography set-up procedures.

(3) Labels affixed on the external surface of the radiation-shielded assembly that
  (i) identify the electrical connections or means that facilitate activation of audible and visible warning devices positioned on the periphery of controlled areas during ionizing radiation generation at a temporary site;
  (ii) display the x-ray tube logo shown in Appendix I of this Safety Code; and

(iii) identify the name and business address of the manufacturer of the industrial x-ray equipment, the equipment model number, the serial number, the date of manufacture and the country of manufacture.

(4) All marks, labels and signs required on the control console and on the radiation-shielded assembly that are securely affixed and are clearly visible.

(5) All controls, lights, meters or other indicators on the control console and on the radiation-shielded assembly that are clearly marked as to function and conform to the following illumination and colour codes:

State or condition	*Colour*
Radiation ON	Red
Emergency	Red
Warning (stand-by)	Amber or yellow
Radiation OFF (safe)	Green
Information	Blue

(6) Installation, operational, safety, maintenance, and disposal instructions that are provided by the manufacturer of the equipment such that, when followed, will enable the equipment to operate within the standards of functioning and performance specified for it, and to be disposed of in a safe and environmentally responsible manner.

(7) Portable and mobile industrial x-ray equipment, in addition to meeting all of the above requirements, that is designed to be equipped with:

(i) means (e.g., cables of sufficient length, radiofrequency mechanisms or other accessories) for enabling activation of the radiation "ON/OFF" control from a location external to a controlled area that is established for temporary sites in accordance with Section 3.3.2. of this Safety Code;

(ii) adequate support for the radiation-shielded assembly to prevent tipping, drifting or vibration during operation of the equipment; and

(iii) an automatic radiation warning alarm system either comprising a beacon light/siren device, or an alternative that provides an equivalent function.

All texts respecting radiation warning signs and labels required in this part shall be in black on a yellow background and be written in both English and French.

3.2 Legal Registration of Industrial X-ray Equipment in Federal Facilities

Any activity that might involve an assembled or ready-to-use industrial x-ray equipment carries an element of radiation risk. To ensure that the associated risks remain low, a system of control necessitating industrial x-ray equipment evaluation and operational review must be in place. This requirement exists in the Canada Labour Code Part II, Occupational Safety and Health Regulations, Part X, Section 10.26[5]: essentially, all federal departments and agencies under federal jurisdiction must register their x-ray equipment with the regulatory authority, Health Canada.

The registration process involves:

(i) a submission of (a) a filled-in registration form that requires details on various elements (e.g., the facility, x-ray equipment, trained personnel, maintenance provider, personnel dosimetry services, radiation survey meters), and (b) supportive documentation on emergency, safety and disposal procedures;

(ii) an evaluation of the submitted material by the regulatory authority; and

(iii) the issuance by the regulatory authority of a confirmation of registration valid for 3 years.

Where a confirmation of registration has been granted to a federal facility in accordance with Section 3.2.(iii) of this Safety Code and the facility subsequently makes a material change to the industrial radiography operation, safety procedures, permanent installation or to the industrial x-ray equipment, a supplementary report that clearly describes the change shall be submitted to the regulatory authority, Health Canada, for review within 14 calendar days of the said change. In this context, industrial x-ray equipment that has been re-sold, removed from service or transferred to other users or to another facility shall be reported. Failure to file such a supplementary report would automatically invalidate the confirmation of registration.

Re-registration shall occur every three years, unless specified otherwise. A facility that operates industrial x-ray equipment without a valid confirmation of registration would be in contravention of the federal Occupational Safety and Health Regulations[5].

3.3 Job Site Requirements for Industrial Radiography

Radiography may be carried out in a permanent installation site and/or at a temporary job site. These sites are characterized by differences in work conditions and therefore hazard reduction strategies must integrate both the industrial x-ray equipment and human factors.

3.3.1 Permanent installation

In the majority of cases industrial radiography is carried out in a shielded enclosure. When a shielded enclosure is properly designed and constructed using sound engineering principles and operated within the design limitations, no 'Controlled Area' external to it is created. However, if conditions do not merit a controlled area, the occupational exposure conditions need to be kept under review by the RSO. This scenario would constitute a 'Supervised Area' for which the following actions are required: (i) delineate the supervised area by suitable means; (ii) display suitable and sufficient signs in appropriate positions of the area to warn of the radiation sources and the associated risks; and (iii) conduct periodic review of conditions to determine a need for protective measures or safety provisions or changes to the boundaries defining the area.

The planning of a permanent installation should follow life-cycle management concepts. Though not exhaustive, a number of factors need to be considered: siting, location, construction, commissioning, operation, maintenance and decommissioning based on present and foreseeable future needs. Drawings of the enclosure and its surroundings should be prepared; entrances should be identified; and dimensions and personnel occupancy areas need to be specified as well. Heating, lighting, ventilation and utility requirements also merit attention. Shielding, interlocks, warning indicators, emergency activators, and radiation control systems and stations require in-depth consideration because of their importance to radiation safety. Generally, limitation of external radiation exposure to personnel, due to the use of ionizing radiation sources present inside the installation, requires shielding. Estimates of shielding thickness may be determined using established methods[15]; users of this reference should ensure appropriate dose limits are used when determining shielding estimates. Often, depending on the nature of the work or location of the installation, penetration of the shielding will be necessary for various reasons, such as, to place or remove heavy test objects in

the primary beam using overhead cranes, robots or conveyor; to provide in the enclosure access for personnel entry and exit; to facilitate passage of utility pipes and x-ray control or imaging cables; to affix lights; and to provide essential heating and ventilation duct systems. Inadequate shielding at such discontinuities might lead to unacceptable levels of stray radiation, which potentially could expose personnel or the public, thereby increasing radiation risks. Guidance for effective shielding at such discontinuities is available[15]. Though infrequent, operational demands may involve the replacement of an existing radiation source with one of a higher beam penetration capability (that is, higher energy x rays), and this may require changes to the installation shielding or re-consideration of primary and secondary barriers or to occupancy of surrounding areas.

Based on the foregoing, it is essential that a radiation protection adviser be consulted (or hired) to advise on matters relevant to radiation safety. The expert may be a consultant who is competent in the field of ionizing radiation protection and safety and has several years experience in the design of ionizing radiation shielded facilities. However, responsibility for compliance with the relevant regulations and standards remains with the organization or agency having ownership of the permanent installation.

The minimum requirements for a permanent installation are:

1. shielding of sufficient thickness that assures protection of individuals surrounding the installation;
2. warning signs of the type shown in Appendix I of this Safety Code that are affixed on all doors or panels or openings which provide partial- or whole-body entry into the permanent installation;
3. a radiation control station that (i) is suitably designed and positioned external to the permanent installation, (ii) contains the ionizing radiation source control console, (iii) provides for the operator direct visual or electronic surveillance of the interior of the permanent installation during radiography, and (iv) facilitates real-time imaging display and assessment capabilities;
4. two independent interlocks that are affixed on the main door which is nearest the control console and which provides whole-body entry to the permanent installation, and they shall be designed in such a manner that, when activated, they shall promptly terminate x-ray production and require a manual reset at the control console to resume x-radiation generation;

5. one interlock, which trips a safety relay thereby removing power from the x-ray generator, shall be affixed on all remaining doors that provide whole-body entry to the installation, including any panel that permits partial-body entry to the permanent installation;
6. clearly visible red 'radiation-on' warning indicators that are failsafe and that illuminate when x-radiation is generated: one indicator shall be prominently positioned inside the permanent installation on a fixed vertical structure at a height of 2 metres above the installation floor and, at least one indicator on the outside of the permanent installation, near each entry door or panel that provides access to the interior of that installation;
7. clearly visible yellow or amber 'stand-by' warning indicators that illuminate when ionizing radiation is not generated: one indicator shall be prominently positioned inside the permanent installation on a fixed vertical structure at a height of 2 metres above the installation floor and, at least one indicator on the outside of the permanent installation, near each entry door or panel that provides access to the interior of the permanent installation;
8. inside the permanent installation, an audible warning signal that (i) is distinct and loud enough to gain the attention of an individual, and (ii) is initiated for at least 5 seconds preceding ionizing radiation generation;
9. clearly labelled red 'emergency' activators that (i) are installed inside the permanent installation at 1 metre above the floor in such a way that they can be activated without passing through the primary beam, and (ii) function in a manner that when any such activator is activated it shall: (a) promptly terminate ionizing radiation generation; (b) automatically open the main door, referred to in Section 3.3.1.4. of this Safety Code, which is nearest the control console and which provides whole-body entry to the permanent installation; and (c) require a manual reset within the permanent installation, before ionizing radiation generation can be resumed at the control console; and
10. all controls, lights, warning signals or other indicators associated with the permanent installation must: (i) be clearly labelled, (ii) be imbedded with the appropriate warning text, and (iii) be in conformance with the following illumination and colour coding:

State or condition	*Colour*
Radiation ON	Red
Emergency	Red
Warning (stand-by)	Amber or yellow
Radiation OFF (safe)	Green
Information	Blue

All texts respecting radiation warning signs and labels required in this part shall be in black on a yellow background and be written in both English and French. Before a newly constructed or modified permanent installation is commissioned for use, an on-site evaluation must be conducted.

3.3.2 Temporary job site

The use of engineering controls at temporary job sites is limited. Consequently, strict adherence to administrative measures is necessary to reduce the likelihood of radiation accidents and unintentional exposures. Individuals must therefore receive training and instructions commensurate with the work procedures, and they must be committed to safety. To the extent practical, radiography should be performed at times when personnel occupancy of the ambient area is low or zero. Use should be made of collimators and secondary shielding (walls, shielded enclosures, vehicles unoccupied by humans, mobile lead screens), where practical, to reduce dose levels.

The minimum requirements for radiography at a temporary job site are:

1. A controlled area must be established to facilitate the radiographic work required. It shall be clearly designated by
   (i) written warnings and safety instructions that are strategically posted external to the controlled area to warn against unauthorized entry; and
   (ii) barriers that prevent entry into any area within which the equivalent dose rate exceeds 0.1 mSv per hour[14] as a result of use of the industrial x-ray equipment.
2. Appropriate signals (visible from at least 10 metres) and audible warnings (loudspeaker, horns) that alert unauthorized personnel of radiography in the designated controlled area.
3. At least two individuals, authorized by the RSO, are required to monitor or patrol the boundary of the established controlled area and to ensure unauthorized individuals do not enter inside the controlled area during ionizing radiation generation. One of the authorized personnel shall be a certified industrial radiographer

and the other should be a safety officer or an equivalent designate who have read and understood the safety procedures relevant to industrial radiography at temporary job sites. The RSO can also function as the other authorized individual.

4. A calibrated and functional survey meter(s), as outlined in Section 2.2.1.10. of this Safety Code, shall be used to ensure that the equivalent dose rate at the boundary of the designated controlled area, where authorized personnel might be present does not exceed 0.1 mSv per hour[14].
5. Protocols that specify work set-up procedures, such as repositioning of the radiography test object or the radiation source or its support assembly or the image receptor procedures, are completed before x-radiation is generated.
6. A temporary radiation control station that is positioned external to the designated controlled area for the initiation, generation or termination of ionizing radiation and for real-time image acquisition and assessment. Every effort must be made to establish such a control station.
7. The attendant industrial radiographer must have appropriate documentation which substantiates that the portable x-ray equipment that is used on site has been duly registered. In cases where portable industrial x-ray equipment registered at a specific facility (resident facility) is used elsewhere, the resident facility RSO shall provide the attendant industrial radiographer with written confirmation that the portable x-ray equipment has been duly registered in conformity with the validated confirmation of registration.
8. All controls, lights, warning signals or other indicators associated with industrial radiography at a temporary site must: (i) be clearly labelled, (ii) be imbedded with the appropriate warning text, and (iii) be in conformance with the following illumination and colour coding:

State or condition	*Colour*
Radiation ON	Red
Emergency	Red
Warning (stand-by)	Amber or yellow
Radiation OFF (safe)	Green
Information	Blue

All texts respecting radiation warning signs and labels required in this part shall be in black on a yellow background and be written in both English and French.

3.4 Facility On-site Evaluation

On-site evaluation is intended to ensure compliance with the requirements of this Safety Code. It must be conducted by the regulatory authority; equivalents may be permitted provided that prior consent has been obtained from the regulatory authority. Such an evaluation should confirm that

(i) permanent installations are adequately constructed;
(ii) safety systems and components function as intended;
(iii) warning signs are appropriate and are correctly deployed;
(iv) emergency procedures are clearly posted at the control console and are understood by all industrial radiographers, other users and allied personnel associated with the industrial radiography operation;
(v) stray radiation levels external to the permanent installation are within limits to ensure that no undue risks are presented;
(vi) radiographers, other users and allied personnel are trained and are competent to use the radiation survey meter(s);
(vii) radiographers and other users are trained to conduct checks that establish the proper functioning of safety components associated with the ionizing radiation producing equipment or the permanent facility or the temporary job site; and
(viii) personnel monitoring and control are in accordance with the requirements of Sections 2.2.1.16.; 2.2.1. 20-24.; and 2.3.6-8. of this Safety Code.

On-site evaluations may be conducted periodically or at any time.

4. Additional Guidance

This section provides information for guidance purposes.

4.1 Industrial Radiography Accelerators

Accelerators used for industrial radiography produce photons in the MeV range at high dose rates. For example, a 3 MV-Linatron accelerator can produce a dose rate of 3 Gy per minute at 1 metre and a similar device operating at 9 MV can yield a dose rate of 30 Gy per minute at the same distance[16].

High-energy (MeV) photons can interact with atomic nuclei, causing nuclei transformation and release of energy in the form of photons or energetic particles or a combination of both. One such particle can be a neutron. The interaction process is called photodisintegration. This reaction is energetically feasible whenever the photon energy exceeds the binding energy of a proton or neutron in the atom nucleus. For materials heavier than hydrogen, except beryllium, the photon threshold energy for such reactions is generally >5 MeV[17]. For accelerators operating at <6 MV, the neutron yield from photodisintegration reactions would be extremely low and therefore would not be a concern as a radiation hazard[18].

4.2 Industrial Radiography Underwater

This procedure normally employs radioactive-based sources. The procedure, practice or radiation source is beyond the scope of this Safety Code.

4.3 Non-Radiography Uses of Industrial X-ray Equipment

Industrial x-ray equipment may occasionally be used for purposes other than industrial radiography. In a facility in which this is the case, it is the responsibility of the industrial x-ray machine owner in that facility to (a) ensure that individuals using the x-ray equipment for non-radiography purposes have the appropriate education, training and competence; and (b) determine the individuals' suitability for the particular job intended.

Radiation safety education should be consistent with that of a Radiation Safety Course, such as the one administered by the NDE Institute of Canada[19] or equivalent. The training and education should include: (i) basic atomic and radiation physics; (ii) a knowledge of x-ray production and interaction of ionizing radiation with matter; (iii) radiation detection and measurement methods, including survey meters; (iv) basic understanding of biological effects of ionizing radiation; (v) personnel monitoring devices; (vi) fundamentals of radiation protection: time, distance, shielding; (vii) ICRP principles and applicable radiation dose limits to workers and the public; (viii) applicable regulations and operational standards for the specific industrial x-ray machine; (ix) instructions on the operation, radiation hazards and safety specific to the industrial x-ray machine to be used; (x) discussion of the relevant radiation surveys and results specific to the industrial x-ray machine(s); and (xi) emergency procedures.

The RSO shall identify the subset of industrial x-ray equipment users who are engaged in non-radiography work, and ensure that they have the necessary education and training and have demonstrated competence before undertaking the job in question. Except for the certification criterion, the requirements of Section 2.3 of this Safety Code shall apply to that subset of industrial x-ray machine users.

4.4 Personnel Monitoring

Personnel monitoring devices are needed to record and control whole-body exposures to ensure occupational limits are not exceeded in accordance with the ICRP recommendations (Appendix II of this Safety Code). For external dose monitoring purposes, devices should be worn on the clothing closest to the body either at the waist or chest level. **Patented and state-of-the-art personnel monitoring systems, capable of registering and reporting dose levels as low as 0.01 mSv, are readily available**[12]; older technology also exists[13]. As a general guide to users of ionizing radiation sources, it is extremely important to **notify your dosimetry service provider of the radiation sources you are using or likely to use, seek the appropriate passive dosimeters, and ensure that your occupational doses reported, correctly reflect the contribution from the various radiation sources you are using.**

Industrial radiographers and other users must wear photon-sensitive passive dosimeters as well as instantaneous reading electronic alarm dosimeters. Each passive personal dosimeter must be worn by only one individual. It is advised that passive detectors be stored in a secure, properly shielded location between periods of use to avoid registering exposures from extraneous sources. Personnel monitoring data need to be retained as a permanent record and be made readily available for review by industrial radiography personnel, other users of the equipment and the regulatory authority.

Computation of occupational doses for purposes of assessment against worker dose limits recommended by the ICRP (refer to Appendix II in this Safety Code) must be based on the summation of all exposures incurred by the individual from the ionizing radiation sources used in industrial radiography. Photon-sensitive passive detectors collectively record x-ray and gamma-ray components. Natural background radiation or medical radiation contributions are not computed as occupational exposures.

An electronic personnel dosimeter not only provides direct dose reading capability, but also is designed to emit an audible signal intended to provide instantaneous feedback to its wearer about the radiation conditions prevailing in an area. The alarm set point may be for a dose rate or an integrated dose. Electronic alarm dosimeters shall (i) be checked to ensure proper functioning before use; (ii) be set to give an alarm at a preset dose equivalent rate of 5 mSv/h or an integrated dose of 2 mSv[14], with an accuracy of ± 20 % of the true radiation dose; (iii) be calibrated at periods not exceeding 12 months; and (iv) require special means to change the preset alarm function. Following activation of the alarm, the dosimeter wearer is obligated to exercise appropriate radiation control measures to reduce his or her occupational dose. Such dosimeters work reasonably well for conventional x-ray (and gamma-ray) sources. However, there are radiation sources that produce very high x-ray levels in a time frame in the order of microseconds (e.g., flash x-ray sources[20]) and the electronic personnel dosimeter may not have sufficient time to respond within that time frame; this sub-optimal dosimeter response could be falsely interpreted to mean the absence of x rays. Thus, an alternative dosimeter that provides direct dose reading display capability should be used, provided that it has been tested to provide reliable results and the wearer must be aware of any inherent limitations thereof. Direct dose-reading dosimeter results shall be recorded for individual wearers.

4.5 Survey Meter

4.5.1 Information relevant to x-ray tube based systems and electron beam welders

To avoid underestimation of the exposure rate from industrial x-ray equipment, the cross-sectional area of the radiation beam must be larger than the sensitive area of the survey meter detector. For routine survey work the meter should yield readings that are accurate to ± 20%. The energy response should be flat to within ± 20% over the desired photon energy range to be encountered. Survey meters that utilize an ionization chamber must be calibrated over the energy range for which they are to be used; calibration factors shall be used to convert the meter readings to appropriate dose values. A meter having several measurement ranges provides greater flexibility. A meter that provides maximum scale readings in the range of 10 μSv/h to 10 mSv/h (or the equivalent in exposure or dose units) is suggested. The detector response time ***must*** be short enough for an accurate radiation measurement. The meter must not exhibit "fold-back" under any circumstances. Fold-back is said to occur when an instrument is exposed to an exposure (or dose) rate or cumulative exposure (or absorbed dose) in excess of its display range and shows a lower or zero reading. Ideally, a meter that is designed against fold-back should show an off-scale deflection or, in the case of a digital display, show an overload condition when it is exposed to ionizing radiation fields that exceed the measurement range. In work areas where radio frequency (RF) fields might be present ensure that the survey meter ***is not*** sensitive to the ambient RF fields (by wrapping the meter in metallic gauze).

Several web sites may be consulted regarding radiation protection instrumentation[21].

4.6 Emergency Response for Unintentional Radiation Exposures

Unintentional exposure to radiation may be caused by equipment failure or human error or a combination of both. Radiation accident victims must receive prompt medical attention by a physician. In addition, the root cause of the incident must be investigated and remedial measures taken to prevent recurrence at the facility.

To address such situations, the facility is responsible for developing an emergency response plan and having the capabilities to

implement the plan. Personnel must be trained to handle emergency equipment and to follow written procedures. The plan shall be tested and validated, and deficiencies shall be identified and corrected. The facility needs to liaise with the various personnel identified in the emergency procedures.

As a guide, the generic emergency response plan should include:

(1) Response initiator – a person who initiates the response and performs actions to mitigate the accident at the scene. Usually this is the attendant radiographer or the first responder on the scene.

(2) Emergency response manager – a person who is in charge of the overall plan, manages the priorities and ensures protection of other workers, emergency workers and the public. This person could be a safety officer or manager or senior staff member in the facility.

(3) Radiological assessor – a person who is responsible for conducting radiation surveys and dose assessment, and for providing radiation protection support to emergency workers and advice to the facility. This person is usually the RSO or a hired consultant with relevant expertise.

Emergency procedures should incorporate the following criteria:

(i) be concise and easy to follow;
(ii) include what situations are indicative of requiring emergency action;
(iii) specify the immediate action to be taken to deliver prompt medical attention to radiation accident victims or those suspect; it is advised that the attendant physician be a radiation oncologist or be knowledgeable in the biological effects of ionizing radiation on humans;
(iv) specify the immediate action to be taken to minimize radiation exposure to persons in the vicinity of the radiation source;
(v) specify the names and telephone numbers of the RSO, the physician or relevant medical institution, the equipment manufacturer, the qualified expert, emergency services and the regulatory authority, and ensure that such information is up to date;
(vi) notify the regulatory authority of the incident as soon as possible, and provide accurate and complete information.

The facility shall prepare a written report that contains: a description of the accident; methods used to protect other workers and the public; assessments of exposures to the accident victims, workers, emergency services personnel and members of the public; cause of the accident and corrective actions. That report shall be submitted (by the RSO) to the regulatory authority for review and follow up within 5 calendar days after the incident (see Section 2.2.1.23. of this Safety Code).

4.7 Resale of X-ray Equipment

X-ray equipment intended for resale shall also comply with the *RED Act* and regulations at time of sale. The seller is responsible for

(i) ensuring regulatory compliance of the product and for bearing the associated costs, and
(ii) notifying the purchaser that it is the purchaser's responsibility to make certain that the following requirements are met before the x-ray machine can be used:
(a) the x-ray machine must be installed by trained and authorized maintenance personnel;
(b) the x-ray machine must be inspected by a radiation safety inspector authorized by the federal regulatory authority, Health Canada, and a corresponding report prepared;
(c) all operators must receive radiation safety training specific to the x-ray machine, prior to its use; and
(d) the x-ray machine shall conform to the operating rules commensurate with those of the appropriate regulatory authority that has jurisdiction of the facility in which the x-ray machine will be in use.

If the purchaser's facility is under federal jurisdiction, the Nonmedical X-Ray Unit, Consumer and Clinical Radiation Protection Bureau, Health Canada shall be contacted and the facility shall adopt this Safety Code. Otherwise, the appropriate provincial or territorial radiation protection authority shall be contacted to determine the applicable operational requirements for the x-ray machine.

4.8 Disposal of X-ray Equipment

For the disposal of an x-ray machine, the RSO shall observe the instructions provided by the manufacturer in the product manual or contact the manufacturer for information and guidance. In a case where a manufacturer is no longer in the business of manufacturing, selling or servicing industrial x-ray equipment, the following procedures shall be followed:

(i) the vacuum in the x-ray tube must be breached;
(ii) the x-ray tube window should be investigated to determine whether or not it contains beryllium, and if it does, special disposal procedures must apply since beryllium presents a toxic ingestion or inhalation hazard;
(iii) the transformer oil, if this exists, must be disposed of in accordance with pertinent environmental legislation; and
(iv) the lead must be recycled accordingly.

References

1. International Commission on Radiological Protection. *1990 Recommendations of the International Commission on Radiological Protection.* Oxford: Pergamon Press; ICRP Publication 60;1991.

2. International Atomic Energy Agency. *International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources.* Vienna, IAEA; Safety Series 115;1996.

3. International Atomic Energy Agency. Radiation Protection and Safety in Industrial Radiography. Vienna, IAEA; Safety Series 13;1999.

4. Treasury Board of Canada Secretariat. *Occupational Safety and Health: Hazardous Substances Directive*. Available at: http://www.tbs-sct.gc.ca/Pubs_pol/hrpubs/TBM_119/hazl_e.html Accessed 19 April 2002.

5. Human Resources Development Canada. *Canada Occupational Safety and Health Regulations*. Ottawa: Queen's Printer; Canada Gazette; Revised Statutes of Canada, SOR/2000-374; 2000. Available at: http://laws.justice.gc.ca/en/L-2/sor-86-304/text.html Accessed 26 February 2002.

6. Listing of provincial and territorial contacts. *Information on radiation protection and safety.* Available at: http://www.hc-sc.gc.ca/hecs-sesc/rpb/fptrpc_members.html Accessed 23 April 2002.

7. Maharaj, H.P. *Radiation output and beam quality measurements of industrial x-ray tubes*. CSNDT Journal, 19:36-41; 1998.

8. Information on health risks to persons using electron beam welders. Available at:
http://www.hps.org/publicinformation/ateq143.html

9. Department of National Health and Welfare. *Radiation Emitting Devices Act, Chapter 34 (1st Supplement)*, Revised Statutes of Canada. Ottawa, Queen's Printer, Canada Gazette; 1984. Available at: http://www.canlii.org/ca/regu/crc1370
Accessed 10 March 2003.

10. Canada General Standards Board. *Non-Destructive Testing – Qualification and Certification of Personnel (ISO 9712: 1999,MOD)*. Ottawa: Canada General Standards Board; National Standards of Canada, CAN/CGSB – 48.9712-2000; 2000.

11. Canada General Standards Board. *Certificate of Nondestructive Testing Personnel (Police and Security Radiography Method)*. Ottawa: Canada General Standards Board; National Standards of Canada, CAN/CGSB – 48.20-94; 1994.

12. Website on radiation dosimetry services.
http://www.landauerinc.com
Accessed 15 April 2002.

13. Websites that provide information on radiation dosimetry services.
http://www.dosimetry.com; http://www.hc-sc.gc.ca
Accessed 15 April 2002.

14. Canadian Nuclear Safety Commission. *Nuclear Substances and Radiation Devices Regulations*. Ottawa; *Nuclear Safety and Control Act*. SOR/2000-207. 2000. Available at:
http://laws.justice.gc.ca/en/N-28.3/SOR-2000-207/144272.html
Accessed 02 July 2001.

15. National Council on Radiation Protection and Measurements. *Structural Shielding Design and Evaluation for Medical Use of X rays and Gamma rays of Energies Up to 10 MeV.* Bethesda. MD; NCRP, Report 49, 1976.

16. Varian Medical Systems. *Industrial Products: Field Portable X-ray Systems*.2001. Available at :
http://varian.com/ind/lnm000a.html
Accessed 26 July 2001.

17. Choppin, G.R., Rydberg, J. *Nuclear Chemistry*. Pergamon Press: Toronto;1980.

18. National Council on Radiation Protection and Measurements. *Neutron Contamination from Medical Accelerators*. Bethesda. MD; NCRP, Report 79, 1984.

19. Web site that provides information on radiation safety course. Available at:
http://www.ndeinst.org/courses/rad-safety.shtml
Accessed 17 December 2002.

20. Physics International Company. *Selection Guide for Flash X-ray Systems*. San Leandro, California. Technical Bulletin 5952-6701, 1995. Available from: Olin Corporation Aerospace Division, 2700 Merced St., San Leandro, Ca 94577-0599, USA.

21. Websites that provide information on Radiation Protection Instrumentation.
http://www. inovision.com; http://www. eberline.com
http://www.ludlums.com
http://www.thermo.com/rpm
http://www.cardinal.com
Accessed 27 February 2002.

Glossary

The following definitions apply to this Safety Code.

Accident. An event which leads to or could lead to unplanned or inadvertent irradiations of humans.

ALARA. Acronym for As Low As Reasonably Achievable. It is a concept that means the design and use of radiation sources and the practices associated therewith must be such as to ensure that exposures to radiation are kept as low as reasonably achievable with social and economic factors taken into account.

Allied personnel. Safety personnel or other staff in the vicinity of radiography work areas of a facility.

Alpha particle. A helium nucleus made up of two neutrons and two protons. An alpha particle can be stopped in a piece of paper a few microns thick. It produces substantially more ions than an x ray or gamma ray or an electron and, therefore, the potential for cellular damage is greater.

Atom. Basic component of matter. It is the smallest part of an element that has all the chemical properties of that element. It consists of a nucleus and electrons around the nucleus.

Background radiation. Radiation arising from natural sources present in the environment, solar and cosmic radiation in outer space, and naturally occurring radioactive elements present in the atmosphere, the ground, building materials and the human body. The background radiation level varies from place to place. An individual residing in North America would incur an average radiation dose value of about 2.4 mSv (240 mrem) per year.

Binding energy. A general term that refers to the minimum energy required to remove a proton or a neutron or an electron from an atom.

Cabinet x-ray system. An x-ray system designed to contain an x-ray tube and generator, detectors and space for the examination of materials within an enclosure that is independent of existing architectural structures of a building except the floor on which it may be placed, provides radiation attenuation, and excludes personnel from its interior during generation of ionizing radiation.

Cancer. A general term used to indicate any of the various types of malignant neoplasms.

Certified industrial radiographer. An industrial radiographer qualified in accordance with the national standards of Canada or equivalent; the Canadian General Standards Board standards are national. An individual who is a certified exposure device operator in accordance with Canadian Nuclear Safety Commission regulations is also considered a certified industrial radiographer for the purposes of this Safety Code.

Collimator. A shield placed in the path of a primary beam to restrict the size of that radiation beam.

Congenital. Existing at birth or acquired during in-utero development and not through heredity.

Controlled area. A defined area within which industrial radiography is carried out and where dose levels are likely to exceed 0.3 mSv in a week. It shall be under the supervision of a radiation safety officer (RSO).

DNA. Deoxyribonucleic acid. The genetic material of cells.

Deterministic effect. An adverse biological effect for which a threshold dose generally exists. The severity of the effect increases with dose. Below the threshold dose the effect is not detected clinically.

Dose. The quotient, expressed in gray, of the energy absorbed through exposure to ionizing radiation and the mass of the body or that part of the body that absorbed the radiation. (1 gray (Gy) = 100 rad.)

Dose equivalent. The product of dose and a radiation weighting factor. For x rays and gamma rays the radiation weighting factor is 1. Dose equivalent can be expressed in rem. 1 rem ~ 1 rad for soft tissue. In 1990, the ICRP proposed using the term 'equivalent dose' instead of dose equivalent.

Dose limit: Applies in relation to persons and refers to the limit on effective dose or equivalent dose specified in Appendix II.

Effective dose. It is the sum of the products, obtained by multiplying the equivalent dose of radiation received by each tissue or organ listed in Table 3 of Appendix II and the corresponding tissue or organ weighting factor given in column 2 of the same Table. The unit is the seivert (Sv).

Electromagnetic radiation. Radiation considered as a wave of electric and magnetic energy traveling through a medium. In space it travels at the speed of light. It includes x rays and gamma rays.

Electron beam welder. A machine that produces high-intensity focused electron beams for melting and bonding materials in vacuum conditions.

Embryo. A developing human organism from conception to the end of the sixth week of gestation.

Ensure. To make certain.

Equivalent dose. It is the product of dose and a radiation weighting factor expressed in seivert. It is the term recommended by the ICRP in 1990 to replace the dose equivalent. (One seivert (Sv) = 100 rem.)

Facility. A site where industrial radiography is carried out.

Failsafe. Having the property that any failure causes an action or actions which always result in a safe situation.

Flash x-ray source. A device capable of producing extremely high levels of x rays within very short time frames in the order of microseconds or less. Such sources are used for studying dynamic events associated with ballistics, explosives, implosions or detonators.

Gamma ray. High-energy, short wavelength electromagnetic radiation emitted in the radioactive decay of an unstable atom.

Gray. International Standard (SI) unit for dose. 1 gray (Gy) = 100 rad.

High radiation field. A qualitative indication of the equivalent dose rates that exist in a particular area. Areas with equivalent dose rates in excess of 1 mSv per hour should be regarded as high radiation fields.

IAEA. International Atomic Energy Agency. An agency formed in 1954 within the United Nations to create and apply international safeguards consistent with the peaceful uses of atomic energy. It has issued internationally agreed radiation protection standards based on the recommendations of the ICRP.

ICRP. International Commission on Radiological Protection. An independent group of experts from a wide range of scientific disciplines which have published recommendations for the protection of radiation workers and the public against ionizing radiation for more than 50 years.

Ionizing radiation. Radiation that has enough energy to dislodge an electron of an atom. It includes x rays, gamma rays, alpha particles, neutrons, protons and electrons.

Industrial radiographer. A person having the academic and professional training to use radiation equipment for industrial radiography. A certified industrial radiographer is within the scope of this definition.

Industrial radiography. Examination of the structure of materials by nondestructive methods in which ionizing radiation is used to make radiographic images.

Industrial x-ray equipment. X-ray machines used for industrial radiography and electron beam welders used for melting and bonding materials.

Industrial x-ray equipment owner. A person, organization or institution having title to or administrative control of one or more permanent installations or radiation sources used for industrial radiography.

Isotope. Atoms of the same element but different mass numbers. The mass number refers to the sum of the number of protons and neutrons in the nucleus of the atom.

Interlock. A device that precludes radiation exposure to an individual by preventing entry to a hazardous area or by automatically removing the hazard.

Ion. An atom or group of atoms that carries a positive or negative charge as a result of having lost or gained one or more electrons.

Irradiation. Exposure of a living being or matter to x-radiation or electrons.

Leakage radiation. All radiation, except the primary radiation, coming from an ionizing radiation source.

Leukemia. A disease in humans characterized by an abnormal increase in the number of white blood cells in tissue or blood.

Malignant. Resistant to treatment and occurring in severe form and frequently fatal.

MeV. Million electron volts. The kinetic energy acquired by an electron in traveling through a potential difference of 1 million volts.

Muon. A particle that has a mass about one-tenth that of a proton or about 200 times heavier than an electron.

MV. The potential to which accelerating particles is subjected.

Neutron. One of the three basic particles of all atoms heavier than hydrogen. Neutrons have no electrical charge, are located in the nucleus of the atom and each has a mass approximately equal to a proton.

Nuclide. A general term used to describe a family of isotopes.

Occupational. The exposure of an individual to ionizing radiation incurred in the course of employment by virtue of the normal duties of the individual in the workplace.

Other user. An individual age 18 or older who uses industrial x-ray equipment for a purpose other than industrial radiography or material fusion (melting and bonding).

Permanent installation. A shielded enclosure in a fixed location.

Photon. A quantum of electromagnetic radiation equal to a constant (Planck's constant which is: 6.61×10^{-34}J s) times the frequency of radiation (unit is the hertz), applicable to x rays and gamma rays.

Primary radiation. Radiation that emanates from a radiation source or target and passes through the radiation source assembly via a collimator or other beam shaping device. A synonym for primary beam.

Proton. One of the three basic particles of an atom. Protons have a positive electrical charge, are located in the nucleus of the atom and each has a mass approximately equal to a neutron.

Rad. Unit of absorbed dose. One rad = 100 erg of energy absorbed per gram of material. 1 rad equals 1 centigray.

Radiation equipment owner. A person, organization, or institution having title to or administrative control over one or more facilities having source(s) of ionizing radiation.

Radiation protection adviser. A person having the specialized knowledge, training and experience necessary to perform the task of giving advice and guidance in ionizing radiation safety in a competent and professional manner.

RSO. Radiation Safety Officer. An individual having the responsibility for the overall radiation safety program on behalf of the owner of the industrial x-ray equipment and meeting the requirements of Section 2.2 of this Safety Code. (An individual recognized as an RSO in accordance with CNSC requirements would suffice for purposes of this Safety Code.)

Radiation source. A sealed gamma ray source or other source emitting ionizing radiation.

Radioactive. Release of energy in the form of particles or gamma rays emitted by the disintegration of the nuclei of atoms.

Radioactive isotope. Element that emits ionizing radiation when it decays.

Radiography. Use of ionizing radiation to produce radiographic images on film, fluorescent material or an image display device.

Radionuclide. Any species of an atom that is radioactive.

Regulatory authority. An authority designated or otherwise recognized by a government for regulatory purposes in connection with protection and safety.

Roentgen. Unit of exposure to x rays or gamma rays having energies < 3 MeV. One roentgen = 2.58×10^{-4} coulomb per kilogram of air.

Secondary radiation. Ionizing radiation emitted by matter as a result of the interaction of primary radiation with that matter.

Sell. An offer for sale, or advertising a product for the purpose of sale, or delivering or distributing a product for sale or lease.

Service personnel. Specifically trained persons, authorized by the industrial x-ray equipment manufacturer or its agent(s), to undertake service functions.

Shielded enclosure. An enclosed space that contains a radiation source and is engineered with safety components to provide adequate shielding and protection from ionizing radiations.

Shielding. Material used to protect people or living things or items from ionizing radiation.

Sievert. Unit of equivalent dose. One sievert (Sv) = 100 rem.

Stochastic effects. An adverse biological effect for which the probability of occurrence increases with dose but the severity does not depend on the magnitude of the absorbed dose. There is no dose threshold for such effects to occur.

Stray radiation. The sum of secondary and leakage radiations.

Supervised area. Any area not designated a controlled area but which requires the occupational exposure conditions to be kept under review.

Survey meter. A portable instrument that measures exposure or dose or equivalent dose rate.

Target. Part of an x-ray tube or material surface onto which is directed a beam of accelerated particles to produce x rays.

X rays. Electromagnetic radiation that is more energetic than visible light.

X-radiation. A beam of x rays.

Appendix I
X-ray Warning Sign

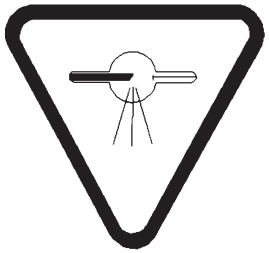
The X-ray warning sign referred to in this Safety Code is a sign that:

a. has a yellow background and black text;

b. is of a size appropriate to the size of the device or of the area, door, wall, installation or other item in respect of which it is posted;

c. bears the words "CAUTION, X-RAYS : NO UNAUTHORIZED USE " and "ATTENTION, RAYONS X: UTILISATION NON AUTORISEE"; and

d. is designed in accordance with the following diagram:



Appendix II
Recommended Dose Limits for Ionizing Radiation

In its 1990 Publication 60[1], the International Commission on Radiological Protection (ICRP) **recommended** dose limits for ionizing radiation. The dose limits do not include medical and natural background ionizing radiation exposures and are indicated below.

Table 1. Effective dose limits

Person	Period	Effective Dose (mSv)
Radiation worker	(a) One year	(a) 20 (average) 50 (special circumstances)
	(b) 5-year period	(b) 100
Pregnant radiation worker[§]	Remainder of pregnancy	**2**
Public	One year	**1**

[§] In the case of a female radiation worker who is pregnant, the fetus must be protected from radiation exposure for the remainder of the pregnancy once pregnancy has been diagnosed.

Table 2. Equivalent dose limits

Tissue or Organ	Person	Period	Equivalent dose (mSv)
Skin	(a) Radiation worker	One year	500
	(b) Public	One year	50
Lens of the eye	(a) Radiation worker	One year	150
	(b) Public	One year	15
Hands and feet	(a) Radiation worker	One year	500
	(b) Public	One year	50

Table 3. Organ or tissue weighting factors

Organ or Tissue	Weighting Factor, w_T
Gonads (testes or ovaries)	0.2
Red bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder organs mean all organs and tissues, excluding the twelve listed above, and include: adrenals, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus and uterus¶	0.05
Whole body	1

¶ In those rare cases in which one of these remainder organs receives an equivalent dose that exceeds the equivalent dose received by any one of the preceding 12 organs listed, a weighting factor of 0.025 shall be applied to that organ or tissue and a weighting factor of 0.025 shall be applied to the average equivalent dose received by the remainder organs and tissues.

Table 4. Radiation weighting factors

Radiation type and energy	Radiation weighting factor, w_R
Photons, all energies	1
Electrons and muons, all energies§	1
Neutrons of energy < 10 keV	5
Neutrons of energy 10 keV to 100 keV	10
Neutrons of energy >100 keV to 2 MeV	20
Neutrons of energy > 2 MeV to 20 MeV	10
Neutrons of energy > 20 MeV	5
Protons, other than recoil protons, of energy > 2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

§ Refer to Table S-1 in ICRP 1990 Publication 60[1] for specific notes on radiation types and energy.