



Health Canada
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Safety Requirements and Guidance for Analytical X-Ray Equipment

Safety Code 32



Canada

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Safety Code 32*

Environmental Health Directorate
Health Protection Branch

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Foreword

While the term *analytical x-ray equipment* generally refers to all types of x-ray diffraction and spectrographic systems designed primarily for performing microscopic examinations or analyzing x-ray spectra of matter at the atomic or crystalline level, it is used in this Safety Code to mean those systems that contain an x-ray tube (or sealed demountable tower) as the source of ionizing radiation. X-ray diffraction systems disperse monochromatic radiation and are typically operated in the range of 20-60 kVp. Spectrographic systems disperse polychromatic radiation and are typically operated at potentials in the range of 25-100 kVp.

This Safety Code is prepared under authority of Treasury Board Standards⁽¹⁾ and may be used by facilities subject to Canada Labour Code Part IV.⁽²⁾ It provides information on regulatory requirements and guidance necessary to ensure that the risks from analytical x-ray equipment remain low (i.e., the same as the risks from unavoidable natural background radiation). This approach is in accordance with the 1990 International Commission on Radiological Protection (ICRP) objectives⁽³⁾ to prevent the occurrence of deterministic effects (those for which the severity of a biological effect increases with dose) and to reduce the incidence of stochastic (random) effects (those for which the probability of occurrence increases with dose but the severity does not depend on the magnitude of the absorbed dose) to acceptable levels.

This publication is intended to minimize or avoid the radiation exposures potentially associated with analytical x-ray equipment. It provides information on regulatory requirements and safety procedures, and outlines specific responsibilities for the

- equipment owner, meaning a person, organization, or institution having title to or administrative control over one or more facilities having source(s) of ionizing radiation;
- equipment users;
- maintenance personnel, meaning specifically trained persons employed by the equipment manufacturer or its authorized agent(s) to undertake service functions; and
- radiation safety specialists (analysts and inspectors as defined in the Radiation Emitting Devices (RED) Act).⁽⁴⁾

This document supersedes Safety Code 19 – Recommended safety procedures for the selection, installation and use of x-ray diffraction equipment.⁽⁵⁾

This document may be adopted for use elsewhere. Facilities should consult their appropriate regulatory authority provided in Appendix III because of differences in provincial and territorial statutes and requirements.

This publication was prepared by H.P. Maharaj in accordance with the Radiation Protection Bureau internal and external review, and approval criteria. All agencies, organizations and individuals whose comments and suggestions helped in the preparation of this publication are gratefully acknowledged.

Interpretation or elaboration on any point in this Safety Code may be obtained from the X-Ray Section, Radiation Protection Bureau, 775 Brookfield Road, Ottawa, Ontario, K1A 1C1.

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1. Introduction

X rays are short-wavelength electromagnetic radiations that can undergo various interactions with matter. Such interactions yield data which, when appropriately analyzed, can provide useful information on the materials irradiated. Machines, typically x-ray diffraction devices and x-ray spectrometers, have been designed to utilize very intense x-ray beams in order to facilitate microscopic examinations or atomic analyses of materials in industry, research laboratories and educational institutions. These machines are generally referred to in this Safety Code as analytical x-ray equipment.

X rays are ionizing radiation that can cause adverse biological effects such as cancer and leukemia. While a brief exposure to the hands in the primary beam of analytical x-ray equipment may not present any clinically observable effects over a short- or long-term period in some individuals, the effect in other individuals may result in mild skin discoloration, which subsequently could develop into a burn, dermatitis and possibly progress to a cancer. Radiation exposures may be considered acute or chronic. Acute exposures are those for which relatively large radiation doses are delivered within short time periods, and the resulting adverse biological effects are manifested in a time frame approximately in an inverse relation to the dose incurred. Chronic exposures are those for which small doses are delivered, more or less uniformly, over long time periods, and the resulting adverse biological effects are more subtle and may develop within years or decades. Recovery from radiation insult depends on many factors including but not limited to, the radiosensitivity of the tissue(s) or organ(s) irradiated, the relative biological effectiveness (RBE) of the radiation, the age and sex of the individual, the dose incurred and the time in which it was delivered. While experimental evidence suggests cellular recovery occurs for low doses incurred over long time periods, such mechanisms may be imperfect, and this could eventually lead to late health effects of radiation such as induction of cancer (carcinogenesis), degenerative diseases (e.g., cataracts), and genetically determined ill-health and developmental

abnormalities in the progeny of exposed individuals. Thus, radiation exposure could present immediate and late health effects. In common with other types of man-made ionizing radiation sources used in medicine, industry, research and consumer products, there are potential radiation hazards associated with analytical x-ray equipment.

In recognition of the widespread applications of ionizing radiation to mankind worldwide and the potential adverse human health effects, the International Commission on Radiological Protection (ICRP 1991)⁽³⁾ has recommended a system of radiological protection which, when followed, would ensure that the risks from ionizing radiation use remain low. The ICRP recommended dose equivalent limits (Appendix I) are based on the prevention of deterministic effects by keeping radiation doses below the relevant threshold, and on the demand that all reasonable steps be taken to reduce the incidence of stochastic effects to acceptable levels. (Deterministic effects are those for which the severity of a biological effect increases with dose; and stochastic effects are those for which the probability of occurrences increases with absorbed dose, but the severity does not depend on the dose.) In this context, analytical x-ray equipment must be designed and constructed to conform with regulatory standards, and persons who install, use and maintain them *must* know the x-ray hazards inherent with such equipment and adhere to recommended procedures.

2. Intent of This Safety Code

This Safety Code provides requirements and guidance intended to ensure that the radiation risks from analytical x-ray equipment remain low (i.e., the same as the risks from unavoidable natural background radiation). Specific responsibilities for the equipment owner (defined in the foreword), user and maintenance personnel are outlined. Information on safety procedures, standards, surveillance and monitoring is also provided.

3. Radiation Safety Requirements and Responsibilities

Within the scope of the 1990 ICRP objectives, analytical x-ray equipment must conform with applicable regulatory standards and facility requirements, and persons associated with the equipment ownership, use and maintenance must strictly adhere to their respective responsibilities.

3.1 Regulatory Standards and New Equipment

All new analytical x-ray equipment sold in Canada *must* conform to the Radiation Emitting Devices (RED) Regulations⁽⁶⁾ at the time of sale. Depending on the analytical x-ray equipment design, Part XIV or Part XV of Schedule II of the RED Regulations may apply. These regulations are promulgated under the RED Act,⁽⁴⁾ and it is the responsibility of the manufacturer or distributor to ensure that the equipment conforms to the applicable regulations. Since the regulations are subject to amendments in order to reflect changes in technology, information on their current applicability may be obtained by contacting the X-Ray Section, Radiation Protection Bureau, 775 Brookfield Road, Ottawa, Ontario, K1A 1C1.

When selecting or procuring analytical x-ray equipment, the equipment owner is well advised to obtain a copy of the most recent regulations to familiarize oneself with the requirements, and to enquire of the intended manufacturer or importer if the product complies with those current regulations. (These actions may eliminate or minimize the need for modifications to the equipment. Such modifications may be costly and cause considerable inconvenience because of disruption in service.)

3.2 Requirements for Used Equipment*

Equipment manufactured prior to the advent of design guidelines presents a number of safety deficiencies when compared to current standards,⁽⁷⁾ and some equipment has been decommissioned as a result. Although equipment presented with fewer deficiencies is in general less costly and often practical to upgrade, absolute safety cannot be assured; however, a reasonable level of safety can be achieved by following the operational instructions specified in the equipment manual and the safe working procedures and guidelines outlined in this Code. In addition, operationally used equipment must be equipped with the following minimum requirements:

1. Control panel
 - (i) A keylock control switch or an alternate device must be installed to prevent unauthorized use.
 - (ii) A power ON/OFF switch must be installed to energize the equipment.
 - (iii) A warning sign that reads “Caution x rays. This equipment produces high intensity x rays when energized. To be used and serviced by qualified personnel only.” and where appropriate, its French equivalent: “ Attention Rayons X. Cet équipement émet un rayonnement X de haute intensité. Il ne doit être utilisé que par du personnel qualifié.” The sign(s) should be placed, preferably, next to the power ON/OFF switch and must be clearly legible at a distance of 2 metres and be clearly visible at any time.
 - (iv) An x-ray ON/OFF switch must be installed.
 - (v) All lights, meters, controls and other indicators must be properly labelled and marked as to function.
 - (vi) Separate fail-safe light indicators must be present to indicate when the x-ray tube is energized and when x rays are being produced. For equipment designed with a single control panel that operates more than one x-ray tube, each tube must be equipped with its separate fail-safe light indicators (of the type just described) to show when it is energized and producing x rays. Tubes not in use must be disconnected to prevent them from becoming energized or be removed from the equipment.

* The term ‘used equipment’ means equipment not under the original manufacturer’s warranty issued at the time of initial purchase.

2. Shutters and beam ports
 - (i) Warning indicators must be installed to indicate the open/shut status of shutters. Shutter mechanisms must be interlocked with x-ray production. Shutters should normally be in the closed position and positive action required to open them, and unused shutters must be secured to prevent casual opening. Unused beam ports should be permanently blocked-off with lead.
3. Shields
 - (i) Primary beams transmitted beyond the detector must be attenuated by a beam stop or trap or other permanent shield that is positioned closest to the equipment to confine the beam, and that does not permit radiation levels to exceed 0.5 mR [$\sim 4.39 \mu\text{Gy}$ air kerma] per hour at 5.0 centimetres from its external surface.
 - (ii) For any equipment operating under open beam configurations (i.e., where the primary beam may be incident on the extremities or organs in the upper chest and facial regions, and where stray radiation fields are in excess of permissible limits) access to such radiation fields must be restricted. In addition to the facility safeguard requirements in section 3.3, such equipment may need to be placed in a physical enclosure that contains:
 - (a) lead-glass or equivalent material (e.g., lead-acrylic copolymer) of sufficient thickness to attenuate existing radiation levels to 0.5 mR [$\sim 4.39 \mu\text{Gy}$ air kerma] per hour at 5.0 centimetres from all externally accessible surfaces of the enclosure, when the equipment is operated at its maximum ratings;
 - (b) sliding door(s) or similar access openings to facilitate safe set-up procedures;
 - (c) an automatic shut-off or appropriate audible alarm to alert personnel of intrusion into a high radiation zone when any sliding door(s) or similar access opening is not in the closed position; and
 - (d) a warning sign of the type described in section 3.2.(1)(iii), that is clearly visible at any time on a part of the sliding door(s) or similar access opening.
4. Interlocks
 - (i) Where appropriate and feasible, fail-safe interlocks should be installed on accessories or components for which their removal would cause direct access to the primary beam or to high radiation areas on the equipment.

3.3 Facility Safeguards Requirements

Potential sources of stray radiation have been identified through surveys to be defective parts, poorly fitting accessories causing unshielded gaps, and tube rectifiers on x-ray diffraction devices, especially amongst equipment manufactured before regulatory control was imposed; often the levels are orders of magnitude higher than permissible limits. In a number of cases equipment presented with such problems was improperly secured and/or identified, and this potentially increases the risk of unnecessary radiation exposure.

In order to achieve an acceptable standard of protection, facilities must include the following safeguards:

1. Proper isolation and designation of analytical x-ray equipment
 - (i) Allocate a room, or portion thereof, for the equipment.
 - (ii) Permanently affix on the outside of the room, on the door that provides access to the equipment, the appropriate x-ray warning sign shown below. The sign must be clearly legible and visible at a distance of 2 metres to personnel approaching the room door.



2. Restricted access

Access to rooms in which analytical x-ray equipment is in use must be restricted strictly to the equipment users and other authorized personnel.

3.3.1 Pre-operational and Maintenance Measures

The reliability and safety of any physical system decreases with age and use because of component wear or corrosion effects.^(8,9) In order to ensure safe and reliable operation of analytical x-ray equipment in every facility, the user must routinely conduct certain pre-operational safety checks on components critical to x-ray safety, and the equipment owner or designee must establish and implement a suitable preventive maintenance program. These measures should account for the age and frequency of use of the specific equipment.

3.3.1.1 Pre-operational Safety Checks

When analytical x-ray equipment is installed and whenever maintenance functions are performed on it or on its accessory components, the user must consult section 3.4.2 of this Code, and conduct examinations or tests that ensure:

- (i) the proper functioning of all protective and safety devices;
- (ii) the proper assembly and functioning of all radiation shields, beam ports, accessories and fittings;
- (iii) the ambient radiation levels are within the permissible regulatory limit (0.5 mR [$\sim 4.39 \mu\text{Gy}$ air kerma] per hour at 5.0 centimetres from all the external surfaces of the equipment) by using an appropriate survey meter (see Appendix II for guidance) provided by the equipment owner or the designee; and
- (iv) any safety by-pass procedures are of the one time actuation and revert back to a fail-safe situation at start-up time of the x-ray generator.

3.3.1.2 Maintenance Measures

Hazardous x-ray exposures can be significantly reduced or eliminated when maintenance procedures are in accordance with the manufacturer's guidelines specified in the service manual. Maintenance personnel must observe the following procedures while ensuring that unauthorized individuals are not near the x-ray equipment during servicing:

- (i) test all protective and safety devices and ensure their proper functioning. If by-passing a safety device is deemed essential to facilitate a specific maintenance task, the following requirements are **mandatory**:
 - (a) install a flashing red light or intermittent sound signal that is clearly visible or audible to a person with normal or corrected vision and hearing proximal to that part of the equipment where the safety device was altered,
 - (b) attach, near the flashing red light or intermittent sound signal, a written notice that indicates explicitly what safety device was altered,
 - (c) use an appropriate survey meter if radiation emissions are potentially associated with the intended task, and ensure that the permissible limits are not exceeded (see section 3.4.3 for guidance reference levels for body organs), and

- (d) ensure that the safety device is re-established and any shielding removed or modified to facilitate the intended task is replaced after the task is completed;
- (ii) examine all radiation shields, beam ports, shutters, accessories and fittings for proper installation and function; and
- (iii) monitor the radiation levels nearest that part of the equipment where maintenance functions will be carried out, before and after the maintenance function(s). Use an appropriate survey meter (either provided by the equipment owner or oneself), and observe the guidance reference limits suggested in section 3.4.3 for body organs and the permissible levels established for the performance of the equipment (see section 3.3.1.1(iii)).

3.4 Human Considerations

If radiation risks are to remain low in conformity with the ICRP objectives, personnel in every facility at which analytical x-ray equipment is installed for use must strictly adhere to the responsibilities charged to them. The respective responsibilities affecting equipment ownership, use and maintenance are indicated below.

3.4.1 Equipment Owner Responsibilities

The ultimate responsibility for the radiation safety of analytical x-ray equipment rests with the equipment owner. **The equipment owner is defined as a person, organization, or institution having title to or administrative control over one or more facilities having source(s) of ionizing radiation.** The equipment owner must ensure that the analytical x-ray equipment meets all applicable radiation safety standards. For some applications, this responsibility may be delegated to staff (e.g., a senior user or the facility health and safety officer, henceforth, called the equipment owner designee). In every facility where analytical x-ray equipment is in use, the equipment owner or designee is responsible for:

1. ensuring that the equipment is installed in accordance with the requirements set out in section 3.3 of this Safety Code;
2. ensuring that all users have received training on the proper operation and x-ray hazards appropriate to the analytical x-ray equipment installed;

3. prescribing and posting prominently near the x-ray equipment radiation safety rules, and safe operating and emergency procedures which shall include address information and contact details of a hospital or clinic where medical treatment can be administered;
4. making readily available a copy of this Safety Code for reference by users and maintenance personnel;
5. implementing a system of verification, supervision and periodic review to ensure that all users and maintenance personnel have received adequate training, and have read and understood the relevant parts of this Safety Code, the applicable radiation safety rules, safe operating and emergency procedures before using and servicing the analytical x-ray equipment;
6. establishing a maintenance program, taking into account the age and frequency of use, that ensures all safety devices and components critical to both x-ray production and shielding, are routinely checked and defective parts replaced or repaired;
7. providing an appropriate survey meter, and ensuring that it is in a working and functional condition at all times for use by users and maintenance personnel;
8. conducting prompt investigations of all radiation overexposures and accidents, and submitting appropriate reports to the equipment owner or designee and to the appropriate radiation protection regulatory authority within 5 calendar days;
9. ensuring that victims of radiation overexposures receive specialized medical attention (e.g., consultation with a radiation oncologist or physician knowledgeable in human biological effects of ionizing radiation);
10. determining the appropriate corrective measures following radiation overexposures, unsafe events and accidents, and ensuring that such measures are implemented effectively; and
11. ensuring that, during a radiation protection survey, a copy of the most recent survey report including summaries of corrective measures recommended and instituted on the equipment, is readily available to the radiation inspector.

3.4.2 User Responsibilities

All users of analytical x-ray equipment must:

1. receive training, authorized or approved by the equipment owner or designee, on the operation and x-ray hazards relevant to the particular analytical x-ray equipment intended for use;
2. have read, understood and follow all applicable radiation safety rules and emergency procedures that are prescribed by the equipment owner or designee and by the appropriate radiation protection regulatory authority, before operating the analytical x-ray equipment;
3. wear personal radiation monitors consistent with the equipment design and operation (see section 3.7 of this Code) and as recommended by the regulatory radiation protection authority;
4. perform regular reviews of their own personal dosimetry data and identify unexpected radiation exposures, investigate them as to root cause(s) and implement appropriate corrective action(s);
5. use an appropriate survey meter to identify and monitor radiation levels at critical areas (tube housing, beam ports, shutters, analysis accessories, etc.) of the equipment during set up and beam alignment procedures, and following modifications and alterations to the device or its accessories, and to ensure that compliance with the regulatory limit (0.5 mR [\sim 4.39 μ Gy air kerma] per hour at 5.0 cm from any external surface of the equipment) is maintained, and that the guidance levels (indicated in section 3.6) including the permissible dose limits (Appendix I) would not be exceeded under routine operational conditions of the equipment;
6. conduct the pre-operational safety checks indicated in section 3.3.1.1 of this Code; and
7. stop the operation of the analytical x-ray equipment if any unsafe operational conditions arise, and immediately notify the equipment owner or designee of such conditions.

3.4.3 Maintenance Personnel Responsibilities

All personnel responsible for the maintenance of analytical x-ray equipment must:

1. be adequately trained in the proper maintenance and repair of the various analytical x-ray equipment for which they are responsible, with emphasis on maintenance operations that may require x-ray production;

2. have read, understood and follow all radiation safety rules, requirements and emergency procedures applicable to the analytical x-ray equipment and the facility, including sections 3.6 and 3.7 of this Code;
3. wear personal radiation dosimeters to monitor separately whole body and extremity doses as deemed appropriate for the operation(s) being undertaken;
4. use a properly functioning radiation survey meter (supplied by the equipment owner or oneself) to identify and monitor the radiation levels at critical areas (tube housing, beam ports, shutters, analysis accessories, etc.) of the equipment during set up, beam alignment and maintenance procedures, and following modifications and alterations to the device or its accessories;
5. undertake precautionary measures to eliminate or reduce radiation levels (measured according to clause 3.4.3.4) to ensure that the regulatory limit (0.5 mR [\sim 4.39 μ Gy air kerma] per hour at 5.0 cm from any external surface of the equipment) is met, and that the guidance levels (indicated in section 3.6) including the permissible dose limits (Appendix I) would not be exceeded during routine operational conditions of the equipment;
6. perform regular reviews of their own personal dosimetry data and identify unexpected radiation exposures, investigate them as to root cause(s) and implement appropriate corrective action(s) as may be necessary;
7. provide the user and the equipment owner or designee with a written report that specifies explicitly any user procedure or action that could lead to an x-ray safety hazard, as soon as such a procedure or action is identified;
8. consult and adhere to the maintenance procedures indicated in section 3.3.1.2 of this Code;
9. supervise the work of maintenance personnel in training; and
10. prevent the operation of the analytical x-ray equipment if any unsafe operational conditions arise, and immediately notify the equipment owner or designee of such conditions.

3.5 Radiation Protection Surveys

A radiation protection survey of analytical x-ray equipment is intended to determine whether the equipment functions according to applicable design and performance standards and is used and maintained in a way that provides maximum x-ray safety to all persons. In order to achieve these objectives, the following requirements apply to all facilities:

1. Analytical x-ray equipment must be surveyed when it is initially installed, and when maintenance, modification, damage and overexposure accidents have occurred on it.
2. Surveys must be performed by the appropriate radiation protection regulatory agency. However, authorized equivalents may be permitted provided that prior approval has been obtained from the appropriate regulatory authority.
3. Routine surveys of analytical x-ray equipment should be conducted at a frequency that depends on the particular equipment design, conditions of use, and performance history. The survey frequency may be based on consultation with the appropriate radiation protection regulatory authority.
4. Surveys of analytical x-ray equipment must include:
 - (i) a thorough inspection of all safety devices and radiation shields;
 - (ii) stray radiation measurements carried out under worst-case (if feasible) user conditions around the system;
 - (iii) proper quantification of stray radiation levels above the regulatory limit and their exact distance specification of the area or location on the x-ray equipment where they were found;
 - (iv) an assessment of occupational and public exposures when radiation levels have exceeded the regulatory limit;
 - (v) audits on:
 - the availability of a copy of this Safety code, applicable radiation safety rules, safe operating and emergency procedures at or near the analytical x-ray equipment,
 - the maintenance program established and followed by the equipment owner or designee,
 - reports of unsafe operational conditions, overexposure incidents and accidents; and
 - (vi) review and assessment of personal dosimetry records.
5. Survey reports must state the following:
 - (i) an identification of the analytical x-ray equipment that sets out the manufacturer, brand name, model number, serial number and the date of manufacture;
 - (ii) an assessment of the safety devices, radiation shields, occupational exposures, and personal dosimetry records and the deficiencies observed;

- (iii) specific corrective actions necessary for compliance with this Safety Code and RED Regulations, including the completion deadlines; and
 - (iv) safety recommendations (if any).
6. After analytical x-ray equipment has been decommissioned, all survey reports pertaining to that equipment must be retained for a period of five years by the last responsible user.

3.6 Guidance on Operational Safety

Unattended x-ray equipment is not considered a potential hazard unless there is human intervention. In order to reduce the probability and severity of radiation accidents and overexposures, strict adherence to operating and maintenance procedures recommended by the analytical x-ray equipment manufacturer must be observed in addition to those indicated in this Code. The following general guidance should also be observed and incorporated where feasible:

1. For operations not requiring constant user supervision or surveillance, the analytical x-ray equipment must be adequately secured to prevent access by unauthorized individuals.
2. Personnel must not expose any part of the body in the primary beam. If and when alignment of analysis accessories requires the use of an open x-ray beam, specific precautions must be exercised to reduce or eliminate radiation exposures to the extremities and other parts of the body. Long-handle forceps or remote handling devices, low x-ray tube current, and fluorescent beam-definers of higher radiation sensitivity should be employed.
3. While it may be necessary, under some circumstances, for maintenance operations to be performed with stray radiation fields above the regulatory limit (0.5 mR [\sim 4.39 μ Gy air kerma] per hour), every effort must be made to minimize exposures to organs or parts of the body that could be affected, so as to minimize the likelihood of long-term risks. The ICRP recommended maximum permissible dose equivalent limits (Appendix I) must not be exceeded by any maintenance personnel.

A practical guide, based on a busy maintenance worker performing, on average, one job per week under such conditions, would be to assume 1/50th of the annual permissible dose limit for each individual maintenance worker per week. This translates to a weekly working reference level of 10 mSv(1000 mrem) for the hands and other organs in the chest and upper facial regions,

except the lens of the eye for which the limit would be 3 mSv (300 mrem). **Nonetheless, all efforts must be made to reduce radiation exposure.**

4. All protective apparel and safeguards, including the radiation survey meter(s), must be tested regularly to ensure that they are in proper working and functional condition and are not defective; and proper documentation that such tests were carried out should be maintained.

3.7 Personal Exposure Monitoring

Personal dosimeters are intended to monitor occupational doses thereby providing a mechanism for restricting future radiation exposures to an individual, so that the recommended maximum permissible limits indicated in Appendix I are not exceeded. For the general application of this Safety Code, users and maintenance personnel are considered radiation workers and the applicable limits are indicated in column 2, Appendix I.

Depending on the analytical x-ray system design, monitoring the extremity doses as well as the whole body doses may be required. For extremity measurements, which typically would be the case for alignment procedures that involve open x-ray beams and systems potentially capable of irradiating the extremities, at least two finger monitors should be worn on the hand nearest the beam; one monitor should be worn on the dorsal surface of the finger and the other on the palmar surface, so as to detect exposures from narrow beams. For whole body monitoring, the monitor should be worn at chest level for work situations above bench height, enabling estimates of the dose to the breast and possibly facial organs; otherwise, wearing the monitor at waist level is satisfactory. Dosimetry records must reflect separate extremity and whole-body cumulative doses, where applicable, in order to facilitate better control on doses approaching the respective permissible limits.

The need for personal dosimeters should be determined by the appropriate radiation protection regulatory authority on the basis of survey results and the particular analytical x-ray equipment in use. Given the historic injuries, effective lines of defense against radiation exposure to the body are the application of shielding and the proper use of a survey meter in the work area of the equipment, during beam alignment and set up procedures, as well as following modifications and alterations to the equipment or its accessories; personal monitoring should be used as confirmation rather than control.

Dosimetry records should be maintained at the facility for at least 5 years after a user has terminated working with such equipment.

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Appendix I Recommended Maximum Permissible Dose Equivalent Limits for Ionizing Radiation

For the purpose of radiation protection, individuals may be classified in one of two groups: radiation worker* or member of the public. The former group refers to individuals exposed to ionizing radiation during the course of their work, excluding medical and natural background ionizing radiation exposures. The latter group refers to those individuals who are not radiation workers. The following table summarizes the 1990 ICRP **recommended** dose equivalent limits for ionizing radiation.⁽³⁾

Applicable body organ or tissue	Maximum permissible dose equivalent	
	Limits in a year ^a	
	Radiation worker ^b	Member of the public
Whole body	20 mSv ^c	1 mSv
Lens of the eye	150 mSv	15 mSv
Skin (1 cm ²)	500 mSv	50 mSv
All organs	500 mSv	

a These limits are intended to prevent deterministic effects by keeping doses below the relevant threshold, and to reduce the incidence of stochastic effects to acceptable levels by demanding that all reasonable steps be taken to lower doses. For further details, consult the source, ICRP 1991.⁽³⁾

b For women who are or may be pregnant, the fetus must be protected from radiation exposure once pregnancy has been diagnosed. For the remainder of the pregnancy, the dose equivalent limit from radiation sources external to the body is 2 mSv applied to the surface of the abdomen, and the limit for radionuclides taken internally by the body is 1/20th of the allowable annual intake. If a woman is exposed to both internal and external sources, both limits apply separately and the total limit shall not exceed 1 mSv (since the fetus is considered a member of the public).

c While dose equivalents up to 50 mSv may be permitted in a single year for special circumstances, a total limit of 100 mSv over a five-year period is recommended by the ICRP. This translates into an average annual limit of 20 mSv y⁻¹.

* For purposes of this Safety Code, users and maintenance personnel of analytical x-ray equipment are considered radiation workers.

Appendix II Guidance on Survey Instrumentation

Survey meters that utilize ionization in a gas remain one of the most common instruments used for determining radiation levels around analytical x-ray equipment. General guidance information is provided below and is intended to assist in choosing instruments and interpreting their measurements.

1. In order to be detected or measured, the ionizing radiation must enter the sensitive volume of the detector. Alpha, beta, gamma and x rays, and neutrons are ionizing radiations with different penetration characteristics. This means that an instrument designed for detecting and measuring alpha particles, for example, will not be appropriate for gamma and x rays. For instruments that are not intentionally designed to measure x rays but are designed to measure alpha, beta and gamma radiation, the user should obtain the manufacturer's specifications to see if the instrument will measure x rays used in analytical x-ray equipment.
2. A given instrument intended for performing quantitative measurements will respond differently to various energies of a given radiation. That is, the energy dependence of the instrument must be known and accounted for in order to make accurate quantitative measurements. Two instruments of the same model may not necessarily yield identical results (because of internal variations in electrodes, electric fields, noise, internal components, etc.); the difference would be much larger if they were of different designs. Thus, to compare the measured exposure rates at a particular point using differently designed detectors, both detectors must be calibrated at the radiation energy at which the measurements are being made.
3. The instrument should be calibrated for the energy range intended if the readings are to be relied upon. This means, if quantification of the radiation is intended, that the instrument reading must be corrected for the corresponding energy calibration factor.

4. The range of the instruments must be compatible with the range of radiation exposures to be measured. This means the instrument must be capable of measuring sufficiently low levels to establish whether or not the analytical x-ray equipment meets the regulatory limit (0.5 mR [$\sim 4.39 \mu\text{Gy}$ air kerma] per hour at 5.0 cm from any external surface of the equipment).
5. While instrument calibration is done under well defined and highly reproducible conditions in a standardization laboratory, or one accredited by or traceable to such a laboratory, the radiation encountered in the field may come from different and often unknown directions. Therefore, an instrument with a low directional dependence should be used.
6. Extreme care should be exercised if a large detector is used for measuring narrow beams of radiation because of differences in areal response of the detectors.⁽¹⁰⁾ A practical approach would be to determine the distance from the source where the field is wide enough to encompass the detection volume, measure the exposure rate there, and then use the inverse square law to estimate the exposure rate at the source (it should be higher). The result so obtained would be satisfactory for making relative comparisons that would alert or warn of the existence of a radiation hazard; that is, the instrument is used in a qualitative sense. Alternatively, a detector that is small enough to make field variations over its own dimensions negligible, may be used to quantify the radiation exposure, provided that the appropriate calibration factor corresponding to the radiation energy of the measurement is applied.
7. Geiger Mueller (GM) survey meters may be sensitive to daylight, uv radiation, radiofrequency fields, and may undergo paralysis of response (read zero) at high exposure or count rates. Therefore, when a reading is obtained it should be ascertained that it is not affected by these factors. GM meters used in surveys should be turned on before entry into the zone to be checked, in case the radiation field is so high that it causes the detector to undergo paralysis and indicate zero reading (i.e., a false indication of a radiation field). GM meters used for x rays and gamma radiation <100 keV are highly energy dependent and unless a calibration is available for the energy spectrum present, their use should be restricted to only the detection of radiation. An end-window GM detector, because of its small size and increased x-ray sensitivity compared to an ion chamber, is very useful in detecting high radiation areas close to, or on, the equipment; a pancake type GM probe has the advantage of allowing the user

to keep the hands out of the beam while placing the probe head into an x-ray beam. In addition, GM detectors should not be used for the measurement of short high intensity pulsed radiation because the level during pulsation may be sufficiently high to cause the instrument to respond in its non-linear range, thereby causing readings that are too low.

8. The instrument(s) must be in good working condition, and constancy performance and functional tests should be conducted periodically.

Appendix III Provincial and Territorial Agencies Responsible for Radiation Safety

Alberta

Alberta Radiation Health Service
Occupational Health & Safety
4th Floor, Donsdale Place
10709 Jasper Avenue
Edmonton, Alberta
T5J 3N3
Tel: (403) 427-2691
FAX: (403) 427-5698

British Columbia

Worker's Compensation Board of British Columbia
P.O. Box 5350 Stn Terminal
Vancouver, British Columbia
V6B 5L5
Tel: (604) 231-8374 (toll free within B.C. 1-888-621-7233)
FAX: (604) 279-7410

Newfoundland

Medical and Hygiene Services
Employment and Labour Relations
Fall River Plaza
P.O. Box 8700
St. John's, Newfoundland
A1B 4J6
Tel: (709) 729-2644
FAX: (709) 729-2142

Northwest Territories

Occupational Health and Safety Division
Safety and Public Services
Government of the Northwest Territories
P.O. Box 1320
Yellowknife, N.W.T.
X1A 2L9
Tel: (403) 920-8616
FAX: (403) 873-7706

Prince Edward Island

Division of Environmental Health
Department of Health and Social Services
P.O. Box 2000
Charlottetown, P.E.I.
C1A 7N8
Tel: (902) 368-4970
FAX: (709) 368-4969

Quebec

Service de Radioprotection
Ministère de l'Environnement
Gouvernement du Québec
6072 est, rue Sherbrooke
Montréal, Québec
H1T 3X9
Tel: (514) 873-1978
FAX: (514) 873-8953

Manitoba

Radiation Protection Service
Department of Medical Physics
Manitoba Cancer Foundation
100 Olivia Street
Winnipeg, Manitoba
R3E 0V9
Tel: (204) 787-2211
FAX: (204) 775-1684

Nova Scotia

Department of Health and Fitness
P.O. Box 488, Station "M"
Halifax, Nova Scotia
B3J 2R8
Tel: (902) 424-4077
FAX: (902) 424-0558

Saskatchewan

Radiation Safety Unit
Department of Human Resources,
Labour and Employment
Saskatchewan Place
1870 Albert Street
Regina, Saskatchewan
S4P 3V7
Tel: (306) 787-4486
FAX: (306) 787-2208

New Brunswick

Radiation Protection Services
Department of Health and Community Services
2nd Floor, Carleton Place
King Street
P.O. Box 5100
Fredericton, New Brunswick
E3B 5G8
Tel: (506) 453-2360
FAX: (506) 453-2726

Ontario

Radiation Protection Service
Ontario Ministry of Labour
81 Resources Road
Weston, Ontario
M9P 3T1
Tel: (416) 235-5922
FAX: (416) 235-5926

Yukon

Consumer, Corporate and Labour Affairs Branch
Department of Justice
P.O. Box 2703
Whitehorse, Yukon
Y1A 2C6
Tel: (403) 667-5450
FAX: (403) 667-3609