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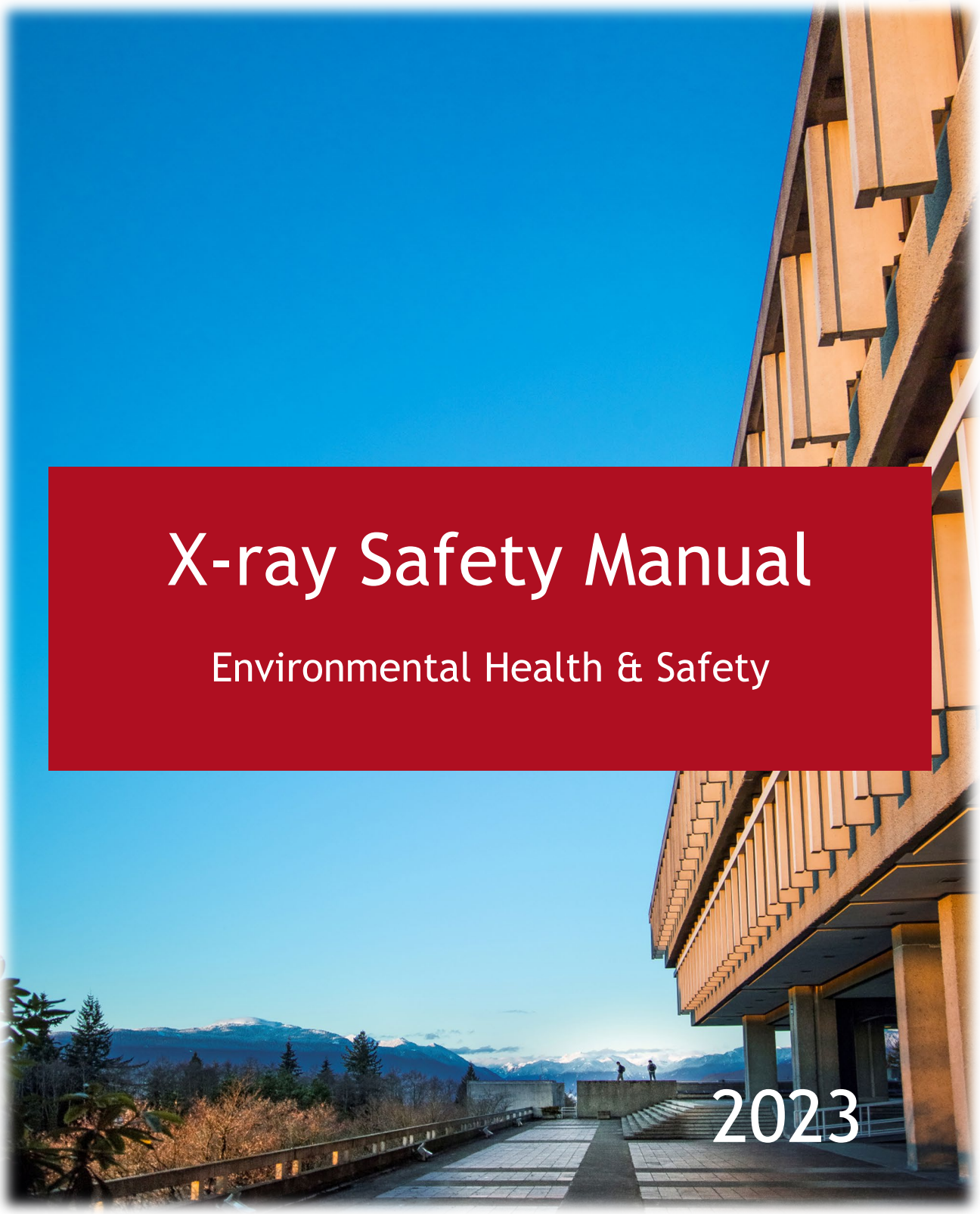

X-ray Safety Manual

Environmental Health & Safety

2023

SFU SAFETY & RISK SERVICES | ENVIRONMENTAL HEALTH & SAFETY

This manual was prepared by the Department of Environmental Health and Safety, Simon Fraser University (SFU).

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Record of Changes

Date	Revised by	Revision
January 14, 2021	Jutta R.-Haunerland	Updates
January 15, 2021	Melanie Gascoine	Updates
September 27, 2021	Alina Tepes	Updated contact Information
March 21, 2022	Jutta Haunerland	Updates
May 4, 2023	Jutta R.-Haunerland	Contact updates

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Contact Information

SFU Emergencies		
IN AN EMERGENCY CALL 911		
Emergency Support/First Aid Line	24 hours/day at any campus	2-4500 or 778-782-4500
Non-Emergency/Safe Walk Line	24 hours/day at any campus	2-7991 or 778-782-7991

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1. Overview

The X-ray Safety manual descrbes the responsibilities and safe work practices of all individuals involved with the use of X-ray Emitting Devices (XEDs). At Simon Fraser University (SFU), Radiation Emitting Devices (REDs), in particular analytical X-ray Emitting Devices are used for teaching and research purposes.

X-rays are a type of ionizing electromagnetic radiation similar to gamma radiation. They are distinguished based on their source: X-rays are emitted by electrons, while gamma rays are emitted by the atomic nucleus. Alternatively the differences can be described based on their wavelength.

Typically X-ray diffraction devices and X-ray spectrometers, have been designed to utilize very intense X-ray beams in order to facilitate elemental analyses of materials.

Cabinet X-ray equipment generating devices, not including the analytical X-ray equipment, have the X-ray tube permanently installed in a cabinet. These devices are primarily designed for the examination of material which is also placed within the cabinet.

In addition to analytical X-ray equipment and cabinet X-ray equipment Dual-Energy Absorptiometry (DXA, previously DEXA) is used for bone mineral density (BMD) studies. Here, two X-ray beams (with different energy levels) are aimed at patients' bodies.

The use of XEDs is regulated by the Federal Government's "Radiation Emitting Devices Regulations" (RED) Act, and Health Canada's Safety Code 32. The Consumer and Clinical Radiation Protection Bureau (CCRPB) is part of the Healthy Environment and Consumer Safety Branch (HECSB) of Health Canada. The CCRPB carries out inspections (compliance verification) and can apply various subsections of the *RED Act* to verify and enforce compliance of radiation emitting devices. In addition, XEDs are federally regulated by the Canadian Nuclear Safety Commission (CNSC), and provincially by WorksafeBC (WCB). *Safety Code 32* provides requirements and guidance to ensure that radiation risks from XEDs remain low or compare to risks from unavoidable natural background radiation. Specific responsibilties for the equipment owner, user and maintenance personnel are described and information about safety procedures, standards, surveillance and monitoring is provided. In addition, Health Canada's Safety Code 25 provices "Guidelines for Limiting Radiofrequency Exposure".

All manufacturers, sellers, importers and distributors of radiation emitting devices must ensure that devices comply with the applicable requirements of the *RED Act* and including , if applicable, other federal legislation and associated regulations.

The regulations vary according to the type of X-ray equipment, therefore in this manual guidance is given for the instrument type. The Radiation Safety Officer (RSO) will classify the equipment at the time of inventorizing to determine the regulatory and safety requirements.

2. Radiation Safety Program at SFU

SFU's Radiation Safety Program is an integral component of Environmental Health & Safety and is described under SFU's policy R.20.04.

One condition of this policy is to keep occupational exposures to both ionizing and non-ionizing radiation in accordance with the **ALARA** (**A**s **L**ow **A**s **R**easonably **A**chievable) principle and within the legislated prescribed dose limits.

SFU's Radiation Safety program, including the use of XEDs, is designed to keep radiation exposures ALARA through: training, implementation of standard operating procedures and protocols to control storage, use and disposal of X-ray generating and emitting equipment.

Radiation Safety at:

https://www.sfu.ca/srs/work-research-safety/research-safety/radiation-safety/compliance-oversight.html

X-ray Safety at:

https://www.sfu.ca/srs/work-research-safety/research-safety/xray-safety/compliance-oversight.html

3. Administration of X-ray Safety

3.1 Purpose

The X-ray Safety Manual is intended to provide guidance and serves as a reference for trained faculty, staff and students. Individuals may use this document as a general guideline, but are advised to also contact the RSO at 778-782-3633 in the EHS Department for questions and/or concerns. Due to the potential hazards associated with X-ray radiation, the use of XEDs require approval from the institutional RSO.

This manual, along with provincial and federal regulations, provides the framework for creating a safer environment for all individuals at Simon Fraser University (SFU) working with XEDs.

3.2 X-Ray Safety Program

The X-ray safety program is an integral component of the Radiation Safety Program of SFU's Department of Environmental Health & Safety (EHS). SFU strives to provide an incident and accident free environment. The University believes that health and safety is a shared responsibility and recognizes that the employer is ultimately responsible for the health and safety of all individuals within the university community.

As one of several research safety programs, the Director of Research and Laboratory Safety oversees this program. The Program Manager of Ionizing Radiation functions as the Radiation Safety Officer.

The Radiation Safety Program is described by policy R20.04 and specifies compliance required by the regulations. This policy is available at http://www.sfu.ca/policies/gazette/research/r20-04.html

The University Radiation Safety Committee (URSC) provides internal auditing of the Radiation Safety Program. Detailed responsibilities of the committee can be found in SFU's Radiation Safety Manual on the SRS EHS website.

The X-ray Safety Program applies to faculty, staff, students and temporary external researchers on campus.

3.3 Responsibilties

Department Chairs/Directors support and direct required practices to ensure compliance with policies and regulations.

Owners/Responsible Users, Supervisors, Principal Investigators (PI), and **faculty and instructors** in general, ensure that all personnel under their supervision (including, but not limited to: graduate students, post-doctoral fellows, research assistants, teaching assistants, visiting scholars, co-op students, staff and undergraduate students) are trained as per regulations and policies.

3.3.1 User/Owner Responsibilities

The **responsibilities** of the **Owners/Responsible Users** extend to **contractors, corporations**, onsite personnel or research laboratories personnel. The responsible user is the person listed on the registration certificate and the responsibilities include:

Please refer to example image in **Appendix O**

- Initiate the registration procedures for all XEDs before use and de-registering and decommissioned parts of equipment with the RSO.
- Ensure compliance with X-ray safety policies, procedures and codes
- Establish standard operational procedures (SOPs)
- Provide SOPs near equipment
- Wear assigned radiation dosimeter as directed
- Minimize radiation exposure
- Report incidents or concerns to the RSO
- Enforce the use of required personal protective equipment (PPE)
- Ensure that all users and maintenance personnel have received adequate training
- Ensure that all users are knowledgeable about the X-ray Safety manual's content and understand the safety rules, safe operating and emergency procedures before using and/or servicing x-ray devices
- Maintain training records
- Conduct self-inspection, refer to checklist
- Respond to inspection reports
- Implement a system of verification, supervision and periodic review
- Provide an appropriate and functional survey meter
- Post required safety signage and emergency procedures near XEDs and at entrance to room
- Assume role and/or delegate role of dosimetry contact person who liaises with Radiation Safety
- Provide cost coverage to EHS when dosimetry lost/late fees are incurred

3.3.2 Faculty, Principal Investigator (PI), Supervisor Responsibilities

- Contact the RSO when a new XED is purchased/removed/transferred
- Consult with the RSO regarding required set-up procedure before first time using the XED
- Ensure that all required warning signs at entrance door and near equipment are in place
- Ensure that all users have received required training (EHS X-ray online, instrument specific training)
- Follow standard operational procedures (SOPs) available near equipment
- Control the purchase, use, transfer, and/or disposal of the equipment
- Maintain an operating log and any equipment history or maintenance records
- Ensure that personal dosimeters are used and returned for read-out on time
- Provide an appropriate and functional survey meter
- Maintain training records
- Notify Radiation Safety for any emergency
- Notify Radiation Safety for any changes which are made to the equipment, location or manner of use

Please refer to the following **Appendices**:

Appendix A: SFU XED Emergency Procedures

Appendix B: A Maintaining Records list

Appendix C: External contractors please refer to Checklist for Industrial Radiographers at SFU campus

Appendix K: External contractors please refer to Contractor's Safety Checklist

4. General Safety Rules and Regulations

The regulations detailed in the federal 'Radiation Emitting Devices Regulations' and the *Safety code 32* 'Safety Requirements and Guidance for Analytical X-Ray Equipment' provided guidance for this manual preparation.

As XEDs have the potential to harm human health and safety, they must meet the general requirements of Section 4 and 5 of the RED Act as well legislative requirements are set out in the *Act* and the *Regulations*.

The *RED Regulations* prescribe specific safety standards governing the design, construction and function of various classes of XEDs, including certain medical devices, consumer products or industrial/commercial products.

Training and Orientation for individuals who intend to use, manipulate, or handle XEDs could potentially receive a measurable annual radiation dose above the background level as identified by the CNSC and WorkSafeBC.

4.1 Training and Orientation

Individuals who intend to use, manipulate, or handle XEDs could potentially receive a measurable annual radiation dose above the background level as identified by the CNSC and WorkSafeBC.

All **authorized users/operators** including faculty, staff, students, volunteers, contractors are required to:

- Complete the SFU X-ray orientation online training. To register visit https://www.sfu.ca/srs/work-research-safety/training.html
- Receive instrument/device specific training provided by the manufacturer and demonstrate understanding of the operation of the equipment before starting work.
- Specific to **XRF Analyzers:** Operators/users must be certified level 1 Natural Resources Canada (NRCan) trainees, trainers must be certified level 2 NRCan examination
- Understand all applicable radiation safety rules, codes and emergency procedures laid out in the SFU X-ray Safety Manual
- Be authorized by the Responsible User/Owner

Please refer to **Appendix E** - Training log, for documenting record of training

4.2 Initial Workspace Evaluation and Survey

Radiation Safety staff has to verify that the requirements regarding the regulations and policies, as laid out in the manual, are being met. The requirements include proper personnel training, dosimeters, signs and warning indicators, interlocks and emergency procedures.

Surveys of X-ray devices have to be conducted by the Responsible User/Owner upon initial set up and at least once per year. Radiation Safety should verify the survey after initial set up. Additional surveys may be required after modification and alignment activities, or repair that could significantly affect the X-ray system operational parameters, or when visual inspection finds a defect in the X-ray system. A visual inspection, survey or risk assessment may also be conducted by Radiation Safety at the request of the owner or system operator.

Further guidelines on equipment type are provided in the appendices.

4.3 Engineering Controls

4.3.1 Security

XEDs and/or their operating keys must be either locked within an access controlled room, cabinet or equipment case, or otherwise secured in a way that reasonably prevents the use and removal of the XED by unauthorized personnel.

The outside of each room containing XEDs is required to have appropriate X-ray warning signage posted. The sign must be clearly visible in 2 m distance for any individual approaching the room door.

- Secure instrumentation against unauthorized use by using an **instrument control key** or **room lock**
- **Secure** unused ports to prevent accidental exposure to radiation
- **Warning lights**, 'fail-safe lights', when X-rays are being produced, have to be visible to the operator/user
- Turn the instrument **off** before **changing samples** – verify that the beam is not activated by checking with a survey meter
- When **switching off instrumentation** use the **main switch**, not the safety interlock
- **After re-alignment check radiation scatter with survey meter**

4.3.2 Signage

The outside of each room containing XEDs is required to have appropriate X-ray warning signage posted. The sign must be clearly visible in 2 m distance for any individual approaching the room door.

Figure1: Caution X-ray

4.3.3 Barriers & Interlocks

- Administrative controls, barriers and interlock must be used to ensure that there is no accidental access to the primary beam or high scattering radiation areas
- **Warning lights**, 'fail-safe lights', when x-rays are being produced, have to be visible to the operator/user
- When **switching off instrumentation** use the **main switch**, not the safety interlock

4.4 Administrative controls

- Training in operation and hazards
- Written standard operating procedures
- Administrative controls, barriers and interlock must be used to ensure that there is no accidental access to the primary beam or high scattering radiation areas
- Do not operate with covers, shielding or tube housing removed; or with modified shutters or collimators

- **After re-alignment check radiation scatter with survey meter**
- Regular maintenance program
- Warning signs
- For **Sample Changing,** ensure that the x-ray beam is inactive by using a survey meter. Use the shutter to stop X-rays. Verify that the shutter activation and the shutter indicator is properly indicating shutter status prior to operating the XED. For devices without shutters turn the unit off and check with survey meter before changing samples
- Delineate a **1 m safety zone**, if applicable

Log book:

- Date of use
- Name of operator
- Peak kilovoltage (kvP) used
- start and end time documentation of maintenance

Prior to beginning work, check:

- Interlocks
- Warning lights
- Timers
- Shields
- Survey meter (battery, response)
- Personnel alarms

All **inadequacies** must be resolved prior to beginning work and documented in the log book. Repairs must be done by authorized personnel. At no time should anyone defeat a safety interlock or alter equipment without authorization from the Responsible User/Owner or PI.

4.4.1 Standard Operating Procedures (SOP)

- Initial preparation of laboratory environment for normal operation (key position, status indicator on, interlock activated, etc.)
- Sample preparation
- Special procedures (safety checks, maintenance tests, etc.)
- Operation procedures (power settings, working mode, other parameters setup)
- Shutdown procedures

Example SOP:

- Obtain interlock key
- Inform unauthorized users and leave room , if applicable
- Note date, operator, beam voltage and current in operation log
- Turn on device, allow for warm-up time
- Verify that 'X-ray-ON 'light is illuminated and beam shutter closed

- Set up test components as needed
- Secure test chamber and all beam ports
- Insert the interlock key into the interlock switch and unlock the X-ray
- Turn the X-ray unit on (open beam shutter)
- Adjust camera settings
- Verify that the X-ray beam is off/beam shutter closed prior to changing samples
- Turn off
- Entry of complete exposure time in operating log
- In case of emergency, shut off X-ray and remove interlock key (if possible)

Please refer to: **Appendix N**: XED SOP template

Please find the 'X-ray Safety – General Safeguards' checklist in **Appendix D**

4.4.1.1 Safe Working Practices

Equipment specific SOPs have to be provided by the Responsible User/Owner to all X-ray equipment operators. **No deviation from written operating procedures**. No person shall bypass a safety device or interlock system. All inadequacies should be taken care of immediately.

If a device is no in use, a sign with following text: "**XED not in use**" should be placed on the X-ray tube housing.

Any repair or modification of the X-ray device should not be undertaken without determining that the tube is turned off and will remain off until safe conditions have been restored.

Radiation surveying is well advised whenever a new sample is placed into the beam, leakage and scatter can cause significant unwanted radiation exposures.

Always, ensure proper enclosure of the entire beam path, by use of the shutters, collimators and securing of unused ports. Be aware of beam status ON/OFF-mode and never cross the X-ray beam path with any body parts e.g. hands. Do not overlook that additional sources of X-rays from support equipment such as high voltage supplies contribute to the X-ray hazard. Consider using lead lined glass when manipulating the device to reduce exposure to scatter radiation.

4.4.1.2 Beam alignment activities

Any beam alignment procedures should be performed by the device manufacturer, if possible or by trained maintenance personnel. In the event that beam alignment is necessary, it is recommended to follow these steps:

- Wear a finger/extremity dosimeter
- If available, use electronic alignment
- Use remote/ long handles on the fluorescent screens
- Only trained and qualified user should perform an alignment
- Use the lowest power settings for beam alignment procedures
- If safety locks must be by-passed seek approval from Responsible User/Owner and post sign indicating the safety switch status. Reinstate the safety switch as soon as possible.

4.5 Personal Protective Equipment and Shielding (PPE)

Use appropriate **Personal Protective Equipment** (PPE) for any hazardous materials or parts that are used in conjunction with X-rays. Protective equipment (e.g. aprons and shields) are required to be checked annually for defects such as holes, cracks and tears to assure reliability and integrity. If additional shielding is required for the attenuation of X-rays, Radiation Safety will provide recommendations on the appropriate shielding material and thickness.

Shielding for X-rays may be lead lined glass for visibility or lead. The X-ray tube housing also provides some shielding of the X-rays. Additionally, the system may have engineering controls in the form of interlocks and shutters which will close automatically if the shielding mechanisms ae defeated.

4.6 Personal Exposure Monitoring

Personal whole body and/or extremity **dosimeter** are required for all authorized operators/users working with the instrumentation Personal dosimeters (PD) are intended to monitor occupational doses.

5. X-ray Exposure

5.1 Acute Radiation Exposures related to X-ray systems

With properly functioning instrumentation and adequate safety precautions, there is only a small risk of significant radiation exposure. In order to understand the importance of safety interlocks and following proper procedures, it is crucial to know the signs of an acute localized exposure. The effects can be caused by coming into contact for only a fraction of a second. The most common effect from large radiation exposure is reddening of the skin (erythema), similar to a sunburn but more complex. Cell division could be damaged and hair growth might be stopped. If the radiation exposure is high, skin scarring, which may lead to chronic radiation dermatitis or skin cancer can occur.

5.2. Unintended X-ray radiation exposure

Contact Radiation Safety immediately if an unintended or inappropriate x-ray radiation exposure occurs which results in a greater dose. An incident report needs to be filed at https://www.sfu.ca/srs/contact/report/report-incident.html

Unintended radiation exposure might occur:

- From operating an XED without a shield or insufficient shielding
- From occupying an area nearby an active XED
- From prolonged, low rate radiation exposure

Besides the description of incident, name, date and location, the incident report should include the type of XED.

5.3. Dosimetry

Regulators set low-risk annual exposure limits and in addition, SFU's R20.04 policy states that the **ALARA** (**A**s **L**ow **As R**easonably **A**chievable) principle has to be applied.

At SFU the external monitoring is accomplished by using Optically Stimulated Luminescent (OSLs) dosimeters, leased from Health Canada— National Dosimetry Services. For the monitoring of radiation exposure to the extremities (e.g. fingers) Thermoluminescent Dosimeters (TLDs) are used. The dosimeters are worn for a 3-4 month period prior to the processing of exposure results by Health Canada. Therefore, the wearing periods can add to a delay to the exposure evaluation process. If immediate exposure results are required for work undertaken in high radiation fields pencil dosimeters are made available on loan by Radiation Safety.

EHS's goal is to keep the radiation exposures below the given limits and to investigate and implement corrective actions for overexposure. If the exposure exceeds the set limits, Radiation Safety staff investigates and implements corrective measures.

The **annual occupational dose limits** are provided in **Appendix G.**

Pregnant workers must inform the Radiation Safety Officer in writing (see 'Radiation Safety Manual' for details, pregnancy declaration). The effective dose to a pregnant nuclear energy worker (NEW) must not exceed 4 mSv for the balance of the pregnancy. The dose to a female worker who is breast-feeding must be such that the dose to the breast-fed infant does not exceed the whole body dose to a member of the general public which is 1

mSv/year. In addition to the CNSC regulations, the provincial WorkSafeBC regulations stipulate that when requested by a pregnant worker the employer must make counselling available with the respect to the hazards associated with exposure to ionizing radiation.

All **XED operators** are required to wear **personal dosimeters**. Information of what kind of personal dosimeter is required (XED specific) can be found in **Appendix G.**

After completion of SFU's x-ray online training, the authorized user can apply for a personal dosimeter. Radiation Safety staff will then assign a temporary personal dosimeter. **The assigned dosimeters may not be transferred to another individual**. The dosimeters must be worn when working with or nearby XED equipment. The dosimeters should be stored in a location where no accidental exposure from inappropriate storage can occur. The dosimeters should not be taken off campus.

If PDs are required for **off campus** work please consult with Radiation Safety to discuss adequate application and storage of PDs, possible need for reference dosimeters in the event of air-travel and adequate shielding for field work (e.g. lead aprons). Film guard bags which provide shielding to dosimeter radiation exposure due to airport security scanning can be provided on loan in the Hot Lab B7249.

Depending on the XED system design, monitoring the extremity doses as well as the whole body doses may be required.

More general dosimetry information can be found on the SFU **Dosimetry information** sheet in **Appendix G**

Dosimetry Exposure results are reviewed by Radiation Safety. If a current dose is reported on the received **Exposure Report**, issued by National Dosimetry Services, then the Radiation Safety staff will be in touch to investigate the exposure and implement corrective measures.

6. Reporting

- **Notify** Radiation Safety immediately for any abnormal radiation exposure
- **Notify** Radiation Safety for any change of location, purchase or removal of equipment

Appendix B: A Maintaining Records list

7. Inspections

7.1 Surveys

Surveys have to be conducted by the Responsible User, in conjunction with Radiation staff upon initial set up and at minimum once per year. Additional surveys may be required after modification, alignment activities, repair and/or visual inspection, which reveal deficiencies and/or defects. The Responsible User or the XED operator/user can request a risk assessment to be conducted by Radiation staff. The survey is conducted by following the XED safety inspection checklist form (**Appendix F**). X-ray surveying should be conducted by the operator/user. Surveys include an XED inspection and the **record maintenance of logs**.

Log the date, user, beam voltage and current, and total exposure time per use

7.2 Internal inspections

Compliance with internal and external regulations is confirmed through **inspections** and audits carried out by Radiation Safety. Responsible Users are required to conduct internal x-ray safety inspections and submit the results annually to the RSO.

Please refer to **Appendix F** for the **inspection checklists** of Engineering & Exposure controls.

If items of **non-compliance** are observed, confirmation should be obtained that the deficient items are **corrected immediately** at the time of inspection, or for more complicated items through re-inspection.

8. Acquiring and Decommissioning of XEDs

For any purchase or receipt of XEDs the RSO has to be notified and specific device information (e.g. manufacturer, model, serial number, type of device) has to be provided. Radiation Safety guides through the set-up procedures and facility requirements amongst others.

Radiation Safety requires the following information for any change in XED use (e.g**. termination, transferal**):

- Owner/Responsible User name, room, telephone number
- XED manufacturer
- XED model
- XED serial number
- XED disposal (specify: with or without power cord)
    - XED disposal by an authorized service provider
    - XED disposed at through Radiation Safety
    - XED was transferred to (name, address, telephone)
    - XED was disposed at municipal transfer station (name of waste site)

Please refer to **Appendix M** for the XED Termination Form.

After submitting the termination form to Radiation Safety, an '**equipment decommissioning form** ' can be downloaded from the X-ray safety website, filled in and an 'order pick-up request' can be placed to Facilities Services for disposal service.

9. Record Keeping

All information including: training logs, maintenance logs, survey records, acquiring, transferal and decommissioning records have to be maintained by the Responsible User/Owner.

10. Emergency Procedures

X-ray accidents:

- Bring XED to safe shut-down condition (if possible) while minimizing any system or configuration changes
- Immediatley call 911 for help
- Notify coworkers and ask for assistance
- If skin burns are present seek Urgent Care medical attention
- Contact the Responsible User/Owner, Principal Investigator, Supervisor

Appendix A: SFU XED Emergency Procedures

11. Analytical X-ray Equipment

Analytical X-ray equipment is an electrically powered device with a primary purpose to produce x-rays. These analytical XEDs may analyze materials, structures or are medical devices which are used in new and novel applications, and not intended or approved for use in medical purpose on humans or animal exposure.

The predominant X-ray producing equipment used in research is analytical X-ray instrumentation. Intense beams of low energy X-rays are generated and exposure to the beam can cause severe injury. Newer instrumentation is manufactured with enclosures, interlocks and shielding to minimize the risk of accidental exposures. The hazard is not limited to the primary beam but can also exist of leakage or scatter radiation. **Radiation surveying** is strongly advised whenever a new sample is placed into the beam, the experimental set up modified or the equipment is replaced. The high intensity of the primary beam, leakage and scatter can cause significant unwanted radiation exposure. **Proper enclosure of the entire beam path, use of shutters and collimators and securing unused ports, has to be installed.** Additional sources of X-rays from support equipment (e.g. high voltage supplies) should not be overlooked.

In analytical equipment, high voltage is applied between the cathode and the anode and high energy electrons collide with a metal target in a vaccuum tube. The cathode emits electrons thermo-ionically which accelerate to the anode. The collision generates heat, which is dissipated by the cooling system, and X-ray radiation exits through a gasket made of e.g. a beryllium window to face a target. A variety of metals are used as target material, such as iron, gold, chromium, cobalt, molybdenum, copper and tungsten. The interaction at the anode produces characteristic and broad spectrum X-rays. **X-ray generation is terminated when turning off the high voltage**.

11.1 X-ray Diffraction (XRD) equipment

X-ray diffraction (XRD) or X-ray crystallography (XRC) is a technique used for determining the crystal and molecular structure of material. The crystalline structure causes an X-ray beam to diffract at specific angles. The analysis of the intensities and the angles of the diffracted beams allow the prediction of a three-dimensional image of the electron density within the crystal.

The X-ray diffraction method is based on the principle that X-rays can undergo elastic collision with atoms. The scattered X-rays have the same wavelength as the incoming X-ray, and the energy of the X-ray photon is maintained while the direction has changed. Different compounds produce different X-ray diffraction patterns. Upon analysis, the structure and identity of the material will be passing X-rays through a gasket manufactured of material (e.g. beryllium), which is transparent to X-rays; make it possible to obtain specific diffraction patterns. Please note that Beryllium is a well suited gasket material as it is the lightest air stable metal, it's strong to generate a vacuum seal, but is extremely toxic.

X-ray diffraction analyses make use of mono-energetic X-rays and rotate the crystal to satisfy the diffraction condition. The crystal is stationary, selects the wavelength and the direction of the diffracted beam. X-rays of other energies such as Bremsstrahlung interfere in the analysis process. Bremsstrahlung can be concentrated by the use of filters that selectively attenuate this radiation.

The sample chamber and beam line are enclosed by metal covers, which prevent radiation leakage. The equipment design protects the operator from receiving a dose from radiation scattered off the sample and other components

in the beam line. Shielding is incorporated specifically to maintain leakage, and keep secondary/primary radiation exposure below the 0.5 µSv allowable rate.

Other design features that protect the operator from radiation exposure are transparent, lead lined acrylic enclosures around the diffraction equipment. Sliding doors are part of the enclosure and are interlocked with the X-ray tube power supply to prevent accidental access to high radiation areas. If the sliding doors are opened while the X-ray tube is energized or the shutter is open, a magnetic switch on the door is activated which automatically turns off the X-ray tube.

However, during beam alignment, the operator needs access to the inside of the enclosure and the interlock system can be defeated with a key switch on the control panel. The removable key to operate the switch provides security and control over the interlock system.

Provide procedure/SOP when interlock is defeated. The procedure must be documented, refer to general safeguards

Safety Code 32, Safety Requirements and Guidance for Analytical X-ray Equipment must be adhered to.

Owner/Supervisor responsibility:

- Responsible to ensure all safety standards are met
- Equipment is installed according to *Safety Code 32*
- SOPs and emergency info available near unit
- Regular maintenance checklist/log
- Survey meter access
- Reporting of overexposure and accidents to EHS and WorkSafeBC within 5 days
- Ensure injured/overexposed personnel receive medical attention
- Ensure users are trained in hazards and operation of equipment
- Follow SOPs
- Wear Personal Dosimeters (PDs) as required
- Survey when equipment is installed, maintained, modified, damaged, and overexposure accident occurred

User responsibility:

- Survey when installed , maintenance work and modifications conducted, damage or over exposure occurred
- Tube housing, beam port and shutter check, confirm that radiation field is < 0.5 mR/hr (5 µSv/hr) from any external surface
- Conduct pre-operational checks
- Stop, Turn off if any unsafe conditions arise and notify supervisor immediately

Maintenance:

- During maintenance, maintenance personnel must install a flashing red light or intermittent sound so that passersby are alerted that safety mechanisms may be temporarily non-functional

- Post notification at the light that safety device is temporarily altered
- Survey to assure that radiation levels are < 0.5 mR/hr during maintenance
- Ensure that safety device(s) and shielding are re-established
- Examine all shields, beam ports and shutters

11.2 Cabinet X-ray Equipment (Closed X-ray Systems)

A **cabinet X-ray system** is an x-ray system installed in an enclosure. The devices are used in research to determine heterogeneities in the structure of a sample. Employed Imaging techniques generate X-ray radiographs. Samples are placed between the X-ray source and a 2D detector to capture an image. Any heterogeneity in the sample will appear as light or dark spots depending on the absorption characteristics. The box-like design includes a shielded interior cabinet, which houses the X-ray tube, the beam collimator and the detector. The doors provide shielded access. The shielded control panels include a key switch that enables the X-ray tube and an ON/OFF switch for X-ray generation. In addition, the devices are equipped with 'power on/off' warning lights and safety interlocks on the door and exterior panels.

In order to penetrate dense samples intense high energy X-rays are required, therefore, thicker lead shields are required to avoid leakage radiation. The instruments must be designed to meet minimum standards of radiation leakage (~4.39 µGy/h at 5 cm). The equipment has to be maintained properly in order not to pose a radiation hazard to the operator. While a sample is radiographed, access to the interior of the cabinet must be avoided, as this would pose a greater radiation exposure hazard. The electrical interlock prevents the X-ray generation while the cabinet door is open.

An **electron microscope** system also consists of an enclosed structure with the X-ray tube and irradiated material inside, and provides shielding.

Each microscope should display the label '**Danger Radiation**' and '**Caution—X-ray'**, as this equipment produces radiation when energized near any switch that energizes the tube. A sign with the words 'caution – X-ray' should be placed near the tube head to clearly indicate to anyone operating, aligning, or adjusting the unit or handling a sample.

Note: **Sputterers** or lithographs also fall under the category of cabinet X-ray systems.

The protective cabinet limits the leakage of radiation, measured at a distance of 5 cm from the external surface, and therefore a dose in excess of 0.25 µSv/hr is unlikely.

X-ray equipment that temporarily has shielding incorporated is not considered a cabinet X-ray system.

For cabinet X-ray-equipment, each requirement of the applicable *RED Regulation* (Schedule II, Part XV) must be met. It is good practice that industry carry out relevant compliance evaluations of their products and retain all supportive documentation.

11.3 Dual-Energy X-ray (DEXA) absorptiometry scanners

Dual-energy x-ray absorptiometry (DEXA) or clinical x-ray systems are a widely used thoroughly studied and most validated method for assessing bone mineral density. The same principle as in the X-ray tube is used and X-rays are generated from acceleration of electrons. Two beams are required as the human body is not homogenous.

Two energies of X-rays are created by continuous switching of high & low voltage or by use of filters. The Low energy X-ray beam is absorbed by soft tissue while the high energy X-ray beam is absorbed by the bone tissue. Bone absorption depends on the thickness of the bone and mineral content. The computer software allows for subtraction of and calculates the calcium content.

DEXA scanners make use of rather small doses of ionizing radiation to produce images of, for example, a patient's lower lumbar spine or hips to diagnose osteoporosis or osteoporotic fractures. No radiation remains in the patient's body after an X-ray examination. Special care is taken during the X-ray examination to use the lowest radiation dose possible while producing the best images for evaluation.

The X-ray system has very controlled X-ray beam and dose control measures in place in order to minimize stray (scatter) radiation. In addition to other regulations, Health Canada *Safety Code 20A* applies.

11.4 X-ray Fluorescence (XRF) Spectrometers

X-ray fluorescence (XRF) spectrometers are used to determine the elemental analysis of material. X-ray fluorescence emits characteristic 'secondary' (or fluorescent) X-rays from a material that have been excited by being bombarded with high energy X-rays or gamma rays. When materials are exposed to short wavelength X-rays, elements are able to produce a characteristic fluorescence spectrum. When excited by X-rays, ionization of the component atom occurs. X-rays or gamma rays can be energetic enough to expel tightly held electrons in the inner orbitals of atoms. The electronic structure of the atom is made unstable by such removal of electrons. Therefore, the electrons fill the hole by transitioning from a higher orbital to a lower orbital. The released energy, the fluorescence, takes place when this energy leaves the sample in the form of photons.

Each element produces a unique and characteristic spectrum of fluorescence and this characteristic property is used to identify the element. A radiation detector converts the photons emitted from the sample into electrical pulses. A digital analyzer then determines the energy spectrum of the radiation emitted from the sample.

While XRD equipment requires low and specific energy X-rays, XRF spectrometers utilize poly-energetic X-rays and allow a simple design to eliminate X-rays of certain energies, which are not needed. The disadvantage is that any scatter or leakage radiation consists of higher and more penetrating energy. Only lead shielding is effective to prevent any accidental exposure to radiation. XRF spectrometers use an open port with a collimated primary beam, filter and internal detector to pick up generated X-rays. They are equipped with lead shielding and a closed design to reduce the hazard from the high energy X-rays. The closed design eliminates the need to gain access to the X-ray beam, which makes the instrumentation safer than XRD equipment, where the access to the beam is possible. The devices also have a failsafe switch which shuts the unit off when the finger is removed from the ON/OFF switch.

Nonetheless, a special hazard exists for the hand-held XRF devices as they house an open port from the collimated, high intensity primary beam. The use of other administrative controls are essential to minimize the possible dose received by the operator.

XRF administrative controls:

- Carry proof of ID and certification
- Perform functional checks
- Survey that radiation field is <0.5 mR/hr (5 µSv/hr) at 5 cm
- Survey meter must be calibrated annually at several photon energies
- Keep non-essential staff at **1 m distance**
- Operators who are training must be NRCan level 2 certified
- Users/students must be trained and supervised
- If no direct supervision is provided , students/users must be NRCan level 1 certified
- Wear extremity personal dosimeter (PD)
- Note that the exposure at the open port are typically 5mSv/min
- Poor practice over many samples could generate fields over **300 mSv/hr** which is well over the max. permissible Occupational Level of **50 mSv/yr for the General Public** and **500 mSv/yr for Nuclear Energy Worker (NEW)**
- Note that due to the energy of the X-rays the bone receives a much higher does than the skin
- While the XRF has various interlocks and sensors to prevent irradiation of the skin, **do not change samples while the device is on**

Safe XRF Working Practices:

- Do not point the 'gun' at individuals
- Take note of beam direction, not always in straight line
- Remember X-rays can penetrate desks, counter tops etc.
- Watch your feet, check floor plans of neighboring spaces, labs

Please refer to the following **Appendices** for diffraction/fluorescence units:

Appendix H: X-ray Safety – Pre-operational Safety checks for XRF Device

Appendix I: XRF Owner Guide

Appendix J: XRF User Guide

Appendix K: XRF Safety Checklist (external contractors)

12. Regulations/Resources

- Health Canada – *Safety Requirements and Guidance for Analytical X-ray Equipment* – Safety Code 32, 1994, http://www.hc-sc.gc.ca/ewh-semt/pubs/radiation/94ehd-dhm186/index-eng.php
- Radiation Emitting Devices Act (RED Act), http://laws-lois.justice.gc.ca/eng/acts/R-1/index.html
- Radiation Emitting Devices Regulations, http://laws-lois.justice.gc.ca/eng/acts/R-1/index.html
- WorkSafeBC , Noise, Vibration, Radiation and Temperature, June 2013
- Canadian Nuclear Safety Commission (CNSC), *Radiation Protection Regulations*, 1997
- Health Canada – DEXA , Safety Code 20A
- Simon Fraser University - *Radiation Safety Manual*, 2019
- Health Canada Guidance Document, *Cabinet X-Ray Equipment, 2013*

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13. Appendices

SFU SAFETY & RISK SERVICES | ENVIRONMENTAL HEALTH & SAFETY

Appendix A

XED emergency procedures

In the **event of an emergency**, please:

1. **Turn off the X-ray Emitting Device**, immediately!
2. Exit the room
3. Call 911 or Campus Security
   Burnaby Emergency line: 778-782-4500
   Surrey Emergency Line: 778-782-7511
   Vancouver Emergency Line: 778-782-5252
   Non-emergency Campus Security Information: 778-782-3100
4. Contact Radiation Safety staff
5. Contact designated lab personnel
6. Fill out an incident report, at www.sfu.ca/srs/report

Events requiring immediate assistance may consist of, but are not limited to:

- Accidental exposure to the X-ray beam
- Flood
- Fire
- Earthquake

Still Unsure?

When in doubt, call the Campus Security Emergency Line!

Appendix B

X-ray safety: maintaining records

The XED responsible user has to maintain the following records indefinitely:

- Registration Certificates/Stickers
- Compliance verification reports/documents
- Internal audits and inspection reports;
- Maintenance and service records
- Training records
- Accident and investigation reports
- List of authorized X-ray users

Appendix C

Checklist for Industrial Radiographers(IR)/X-ray at SFU campus

Contractor to Complete

Please complete the following requirements, by the latest 3 days prior to starting work:

- ☐ Submit a written control and implementation plan to prevent ingress during testing.
- ☐ Submit a copy of the contractor's written site-specific emergency procedures.
- ☐ Submit name and contact information of the company's Radiation Safety Officer.
- ☐ Submit the current Leakage Radiation Test for the device(IR) (valid for 12 months).
- ☐ SFU's Project Manager was informed on safety issues regarding the use of IR/X-rays on site.

Please email this completed form and all above required documents to the SFU contact.

Note: Complying with Safety Code 34: *Radiation Protection and Safety for Industrial X-ray Equipment*, industrial radiographers setting up for a temporary work site are responsible for:

- Set-up a controlled area
- Post written warnings and safety instructions to prevent unauthorized entry
- Set-up physical barriers to prevent entry into areas where the equivalent dose rate >0.1 mSv/ hour as a result of ionizing radiation production
- Appropriate signals (visible from at least 10 meters) and audible warnings (loudspeakers, horns) that alert unauthorized personnel of radiography in the designated controlled area
- At least two individuals, authorized by the contractor's RSO, are responsible to monitor or patrol the boundary of the established controlled area and ensure there is no entry from unauthorized individuals. One of the individuals should be a certified industrial radiographer and the other should be a safety officer or designate who has read and understood the safety procedures relevant to radiography. The RSO can also function as the other authorized individual.

Note: Requirements and documentations are to be completed by the company's Industrial Radiographer.

I certify that the above requirements and documentations are completed and provided by:

Name: _____ Date: _____

Organization: _____ Signature: _____

Appendix C

Checklist for Industrial Radiographers(IR)/X-ray at SFU campus

SFU Staff to Complete

I certify that the above requirements and documentations are completed by the qualified contractor and reviewed by:

Note: The SFU Project Manager only signs-off when all requirements and documentations are met, including the qualified contractor providing the briefing on safety issues related to the use of industrial radiography on-site.

SFU Project Manager

Name: _____ Date: _____

Organization: _____ Signature:_____

SFU Radiation Safety Officer

Name: _____ Date: _____

Signature: _____

Appendix D

General safeguards

In order to achieve an acceptable level of protection, X-ray facilities must include the following safeguards:

- Allocate a room, or portion thereof, in order to isolate the X-ray emitting device. The entrance to the room must display an approved sign indicating the presence of X-ray Emitting Device's (XEDs).
- Access to the room housing the XED should be restricted to **authorized** X-ray workers and lab personnel whenever the X-ray equipment is in use (**Note**: For hand-held XRF devices, maintain a 1m "safe-zone").
- Establish in low traffic area.
- For operations not requiring constant user supervision or surveillance, the analytical equipment must be adequately secured to prevent access by unauthorized individuals.
- Personnel **must not expose** any part of the body **to 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.
- The maximum permissible dose limits must not be exceeded by any maintenance personnel and in general the radiation exposure should be kept **As Low As Reasonably Achievable**(ALARA).
- All protective apparel and safeguards, including the radiation survey meter(s), must be tested regularly to ensure proper working and functional conditions. Proper documentation of conducted tests should be maintained.

Appendix E

XED training log

XED Responsible User: _____

XED Registration Number: _____

Authorized Worker Name/ Job Title: _____

Date	Trainer	Procedure/Protocol/Equipment
	Online	**SFU X-ray Safety Orientation**

Note: The 1st entry must always be an acknowledgement of the completion of the SFU X-ray Online Orientation

Appendix F

XED safety inspection checklist

Please Note:

1. Responsible Users must use this form when conducting Annual Internal Inspections
2. Completed X-ray safety (self) inspection checklists should be submitted to the RSO
3. The device owners must keep a record of all safety inspectionsindefinitely

X-ray Safety Inspection Report

Date of Inspection: Device _____

Owner: _____

Room Number: _____

XED Make/Model: _____

Inspection History: _____

XED Registration Number: _____

Inspector (owner/user) _____

Appendix F

XED safety inspection checklist

Administrative Information

Date of Inspection		**Laboratory Location**	
Principal Investigator		**Department**	
Lab Representative		**Contact Phone Number**	
Contact Email		**Inspector (owner/user/other)**	

Equipment Information

X-ray Emitting Device (XED)		**Manufacture Date**	
Manufacturer		**Type**	
Maximum kV		**Maximum mA**	
Model Number		**Serial Number**	
Tube Manufacturer		**Tube Model Number**	
Tube Serial Number		**Applicable Safety Code**	

Appendix F

XED safety inspection checklist

Equipment and Radiation Survey

Survey Instrument			
Meter used		**Meter calibration date**	
Background (mR/hr)			
Leakage Radiation – Surrounding Housing (At maximum permissible kVp)			
kVp setting		**mA setting**	
Interlock		**Operational status (On/Off)**	
Distance from focal point		**Meter reading**	
Survey Instrument – Operational Check			
Manufacturer		**Model Number**	
Serial Number		**Last Calibration**	
Operational Check		**Battery Check**	
Machine Information – Operational/Adequacy Check			
kVp Meter		**mA Meter**	
Timer Indicator		**Breaker Box**	
Shutter(s)		**Unused ports secured**	

Comments:

Appendix F

XED safety inspection checklist

Engineering & Exposure Controls

	Issue	Yes	No	N/A
1	Interlocks operable			
2	Interlocks adequate			
3	Shielding			

Signage and Postings

	Issue	Yes	No	N/A
1	Warning lights operable			
2	Warning lights adequate			
3	X-rays Warning Sign(s) posted at all entrances			
4	Warning labels (wherever applicable)			
5	Emergency contact information			

Documentation

	Issue	Yes	No	N/A
1	Machine Checks - records			
2	Standard Operating Procedures – available and up-to-date			
3	Emergency Response Procedures - available and up-to-date			
4	Personnel Training Records – General - SFU Radiation Safety Office			
5	Personnel Training Records - Lab Specific			
6	Machine maintenance records - available and up-to-date			
7	Machine usage logs - available and up-to-date			
8	Incidents/Investigations Reports			

Comments:

Name: _____ Date: _____

Signature: _____

Dosimetry for X-ray users

Areas and Equipment - Personal Dosimetry (PD) Requirements

Electron Microscopes/Microprobes	**No PD required**
Cabinet X-Ray	**No PD required**
DEXA - Dual Energy X-Ray Scanner	**Body Personal Dosimeter**
Radiographic Diagnostic X-Ray	**Body Personal Dosimeter**
XRD - X-Ray Diffraction	**Body Personal Dosimeter**
XPS - X-Ray Photoelectron Spectroscopy	**No PD required**
Stationary XRF - X-Ray Fluorescence	**Body Personal Dosimeter**
Portable/Handheld XRF - X-Ray Fluorescence	**Body Personal Dosimeter and/or Extremity Dosimeter**

Operating an XED off-site:

Shielding, such as a protective (lead) apron, is required when an X-ray user operates the X-ray tube outside the physical barrier.

When a protective apron is worn, a personal dosimeter must be worn underneath. A second personal dosimeter located at the neck level may be worn. If extremities are likely to be exposed to higher doses, additional monitors should be worn on the extremities.[1]

Administration of SFU Personal Dosimetry Program (PDP)

- SFU Radiation Dosimeter Application Form must be completed by X-ray User
- The Radiation Safety Technician (RST) is responsible for the Dosimetry Program.
- Radiation Safety Officer (RSO) for X-ray and Non-Ionizing Radiation is responsible for the oversight and review of the Personal Dosimetry Program involving X-rays, including Incident Investigations and Emergency Response.

X-ray user - General Responsibilities

- Take all reasonable precautions to ensure own personal safety and the safety of fellow workers.

[1] Health Canada, Radiation Protection In Veterinary Medicine - Recommended Safety Procedures For Installation And Use Of Veterinary X-ray Equipment - Safety Code 28. Health Canada, 1991. Section 7.1.

Appendix G

Dosimetry for X-ray users

- Use personal protective equipment and other safety devices provided by the employer.
- Report incidents and exposures to the Equipment Supervisor and RSO.

Special Considerations

- Pregnancy

  A worker can be authorized to use multiple sources of radiation or hold multiple work statuses. For example, she can be both a Nuclear Energy Worker (NEW) for nuclear substance and an X-ray User. Only a single quantity of effective dose can be assigned to an individual at a given point in time, even if the effective dose were accumulated from multiple sources or at various times in the past. Therefore, these guidelines regarding pregnancy (Radiation Dosimetry for SFU X-ray Users) consider both Canadian Nuclear Safety Commission (CNSC) regulations and WorkSafeBC - Occupational Health and Safety (OHS) Regulation. CNSC regulations, in general, concern only nuclear substance use,

  However, WorkSafeBC – OHS Regulation often sites CNSC publications. The worker should also observe policies and guidelines set out by SFU on the use of ionizing radiation/nuclear substance. (SFU Radiation Safety Manual)

  - The Canadian Nuclear Safety Commission (Nuclear Energy Workers - NEW) and WorkSafeBC set special Exposure Limits for Pregnant Workers
  - For the General Public (including X-ray Users who are not declared as NEW), there is no differentiation of Dose Limit between that of pregnant and non-pregnant persons.
  - Every Nuclear Energy Worker who becomes aware that she is pregnant shall immediately inform the RSO in writing.
  - When a worker declares her pregnancy to the RSO, her effective dose of ionizing radiation, for the remainder of the pregnancy, from external and internal sources, must be limited by the employer to the lesser of 4 mSv, or the dose limit specified for pregnant workers under the Nuclear Safety and Control Act (Canada).

- Assurance of Safe X-ray Operation
  - Through Exposure Reports and X-ray Usage Logs, if a record of Safe Operation of over one year were established (with no recorded Exposure or Dose; while the operation of X-ray equipment was frequent and regular), the X-ray User would no longer be required to be monitored through the Personal Dosimetry Program.

- Optional Monitoring
  - Monitoring (Personal and/or Area) can be requested through the Radiation Safety staff.
  - The Radiation Safety staff have the authority to exercise discretion when implementing a Dosimetry Program.

Incident and Emergency Response

- If an incident that has the potential of causing over-exposure (near-miss incident) of a person

Dosimetry for X-ray users

occurred, the Radiation Safety Officer (RSO) must be notified.

- Information to be reported with an incident includes (but not limited to): time, place and nature of the incident.
- An investigation into the circumstances surrounding any complaint, incident or suspected over-exposure will be carried out.
- Personal Dosimeters (and Area Monitor/Survey Meter readings, if any) will be collected to determine committed dose estimates.

Area Monitoring

- Each X-ray facility must have access to an appropriate Radiation Survey Meter compliant to SFU Radiation Safety Policies and Procedures.

Exposure Limits

CNSC *Radiation Protection Regulation*

Item	Person	Period	Effective Dose (mSv)
1.	Nuclear energy worker, including a pregnant nuclear energy worker	(*a*) One-year dosimetry period	20 (WCB)** 50 (CNSC)
		(*b*) Five-year dosimetry period	100
2.	Pregnant nuclear energy worker	Balance of the pregnancy	4
3.	A person who is not a nuclear energy worker	One calendar year	1

**Note: https://www.worksafebc.com/en/law-policy/occupational-health-safety/searchable- ohs-regulation/ohs-regulation/part-07-noise-vibration-radiation-and- temperature#SectionNumber:7.17

Appendix G

Dosimetry for X-ray users

References

- Ontario Ministry of Labour, *Occupational Health and Safety Act*, R.P.O. 1990, X-ray Safety Regulation 861.
- Canadian Nuclear Safety Commission, *Radiation Protection Regulations*, May 2000.
- Canadian Nuclear Safety Commission, INFO-0827: *Introduction to Dosimetry*, February 2012.
- WorkSafeBC - *Occupational Health and Safety Regulation* - Part 7 Noise, Vibration, Radiation and Temperature. June 2013.
- Health Canada, *Safety Requirements and Guidance for Analytical X-ray Equipment* - Safety Code 32, 94-EHD-186. Health Canada, 1994.
- Health Canada, *Radiation Protection In Veterinary Medicine - Recommended Safety Procedures For Installation And Use Of Veterinary X-ray Equipment* - Safety Code 28. Health Canada, 1991.
- Health Canada, *Radiation Protection in Dentistry - Recommended Safety Procedures for the Use of Dental X-Ray Equipment* - Safety Code 30. Health Canada, 1999.
- University of Minnesota - Radiation Protection Division, *Personnel Monitoring and Dosimetry Policies*, 2001.
- University of Alberta - *Analytical X-Ray Equipment - Radiation Safety Manual*, July 2003.
- Hamilton Health Sciences, *Diagnostic Imaging - Radiation Dosimetry for X-ray Workers and X-ray Students at HHS Policy*, 09 February, 2006.
- University of Toronto, *X-Ray Safety Program*, 02 January, 2013.
- Princeton University, R*adiation Safety Manual for Laboratory Users* - Section 6: Dose Limits and Personal Monitoring, 2013.
- Simon Fraser University - *Radiation Safety Manual*, 2018.

Appendix H

Pre-operational safety checks for XRF device

When are safety checks required?

Safety checks are required after installing accessory components to the X-ray Emitting Devices (XEDs) and after conducting maintenance on the equipment.

Safety Checks Should Ensure:

- The proper functioning of all protective and safety devices.
- The proper assembly and functioning of all radiation shields, beam ports, accessories and fittings.
- That ambient radiation levels are within the permissible regulatory limit (~4.3 µSv/hr at 5 cm from all external surfaces of the equipment) by using an appropriate survey meter.
- That any safety by-pass procedures are of the one-time actuation type and revert to a failsafe situation at start-up time of the X-ray generator.

Appendix I

Handheld XRF owner guide

Instrument

Portable/Handheld X-ray Fluorescence (XRF) Analyzers/Device

Acquisition

Training

- Manufacturer is responsible for providing training
- SFU Radiation Safety Officer (RSO) will attend training provided by manufacturer
- Arrange for re-training within 3 years (to satisfy RSO/Level 2 recertification requirements)
- All XRF users must be trained (see below)
- All training must be formally documented, signed and dated by trainer

Documentation

- Formal training documentation (signed and dated by trainer)
- Manufacturer's written confirmation that product complies with Radiation Emitting Devices (REDs) Act
- Radiation scatter profile of device
- Operational procedures
- Log of safety checks (signed and dated)
- Annual survey meter calibration results
- All documentation will be kept by owner and RSO

Equipment

- Survey meter (calibrated annually)
- Optically Stimulated Luminescence (whole body) OSL
- Finger (extremity) TLD

Actions

- Acquire survey meter
- Acquire Body + Finger TLD through RSO
- Provide operational procedures to RSO
- Provide manufacturer's written confirmation of REDs Act compliance
- Receive training
- Determine radiation scatter profile (with RSO)
- Establish logs and schedules (inspection/review/safety checks)

Appendix I

Handheld XRF owner guide

Operation

Servicing	• Service personnel must provide written evidence to RSO and workplace manager that they are authorized by the manufacturer to service the specific equipment
Security	• Notify RSO of usage and location of XRF instrument • Accident/Incident reporting (RSO/Manufacturer/Health Canada) • Lock and Key
Every use	• Calibrated survey meter at job site • Preliminary safety checks • Maintain 1-meter “safe zone” during operation • Wear Body + Finger TLD’s • Usage log • Safety check log
Monthly	• Signs and labels checks and log
Quarterly	• RSO Review • Provide copies of logs of usage and safety checks to RSO
Annual	• Survey meter calibration
Every 3 years	• Re-certification/Re-training

Training Requirements

Provided by	• Manufacturer/Authorized Agent and • Simon Fraser University - EH&S - X-ray Online Orientation

Reference Sources

- “Operator of Portable X-ray Fluorescence Analyzers – Examination Preparation Booklet”, Natural Resources Canada (NRCan), Version 2, Dr. Richard V. Murphy, September 2006.
- Health Canada – Safety Code 34 - Radiation Protection and Safety for Industrial X-Ray Equipment 2003
- Radiation Emitting Devices (REDs) Act and Regulations
- “User Checklists”, SFU EH&S – X-ray Safety, December 2010.

NOTE:

This is a summary of requirements (modified for SFU). These are not comprehensive lists.

Appendix J

Handheld XRF user checklist

Instrument

Portable/Handheld X-ray Fluorescence (XRF) Analyzers/Device

Reference Sources

- Natural Resources Canada (NRCan), "Operator of Portable X-ray Fluorescence Analyzers – Examination Preparation Booklet" Version 2, Dr. Richard V. Murphy, September 2006.
- Health Canada – Safety Code 34 - Radiation Protection and Safety for Industrial X-Ray Equipment 2003
- Radiation Emitting Devices (RED) Act and Regulations

Requirements for XRF Operators/Users

- Training
- Formal training documentation signed and dated by manufacturer's representative or trainer
- Timely renewal (every 3 years)
- Preliminary safety checks (Health Canada –SC34–2003 Section 2.3 Article 9)
- Quarterly review by RSO
- Signs and labels checks, at least monthly (HC-SC34-2003 Sec 2.3 Article 14)
- Survey Meter (calibrated annually) at job site
- Security and Safe-keeping of XRF instrument
- Maintain 1-meter "safe zone" during operation
- Accident/Incident reporting
- SFU recommendations on personnel monitoring (Body + Finger TLD)
- Service personnel must provide written evidence to RSO and workplace manager that they are authorized by the manufacturer to service the specific equipment (HC-SC34-2003 Sec 2.4.1)

Requirements for XRF Radiation Safety Officer (RSO)

- Annual review of log of safety checks (HC-SC34-2003 Sec 2.2.1 Article 15)
- Keep records of radiation scatter profiles (p. 43 NRCan/XRF Booklet 2006)
- Security and Safe-keeping of XRF instrument (not in use)
- Accident/Incident reporting
- Receive written confirmation from manufacturer/authorized agent that product complies with RED Act

NOTE:
This is a summary of requirements (modified for SFU). These are not comprehensive lists.

Appendix J

Handheld XRF user checklist

Documentation Required

Manufacturer	• Send written confirmation to RSO that product complies with RED Act (HC-SC34-2003 Sec 2.2.1) • Responsible for providing training (HC-SC34-2003 Sec 2.4)
Operator/User	• Formal training documentation (signed by trainer and dated) • Operational procedures • Log of safety checks (signed and dated)
RSO	• Radiation scatter profile of instrument • Owner/Device records • Formal training records of users • Log of safety checks/Usage log • Log of monthly (at least) signs and label checks • Records of quarterly reviews • Records of survey meter annual calibrations + results • Manufacturer's written confirmation of RED Act compliance • Operational procedures • Dosimetry records

Training Requirements

Provided by	• Manufacturer/Authorized Agent and • Simon Fraser University - EH&S - X-ray Online Orientation

Consequences to Non-Compliance

Termination and/or Permanent Suspension of XRF Certification

Appendix K

Portable/hand-held X-ray fluorescence (XRF) analyzers

Contractor's Safety Checklist (with no radioactive element)

Instrument

Portable/Handheld X-ray Fluorescence (XRF) Analyzers/Device (without radioisotope)

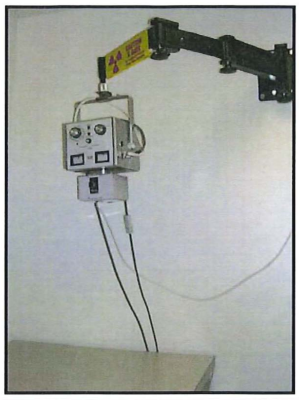
Requirements for XRF Operators/Users

- Formal and current training documentation (see Documentation Requirements below)
- Survey meter (calibrated annually)
- Security and Safe-keeping of XRF instrument (when not in use)
- Maintain 1-meter "safe zone" during operation
- Perform and record Safety Checks
- Perform and record Signs and Labels Checks
- Maintain usage logs
- Accident/Incident reporting
- Operator/User must provide written evidence to Radiation Safety Officer (RSO) and workplace manager, demonstrating that they are authorized and trained

Documentation Requirements

- Proof of current Natural Resources Canada (NRCan) certification: Operator of Portable X-ray Fluorescence Analyzers
- Log of safety checks
- Usage log
- Log of signs and labels checks
- Radiation scatter profiles of the instrument (Portable XRF device)
- Written confirmation from manufacturer/authorized agent that the instrument complies with Canada's Radiation Emitting Devices (REDs) Act
- Standard Operating Procedures (SOP)

X-ray devices at SFU

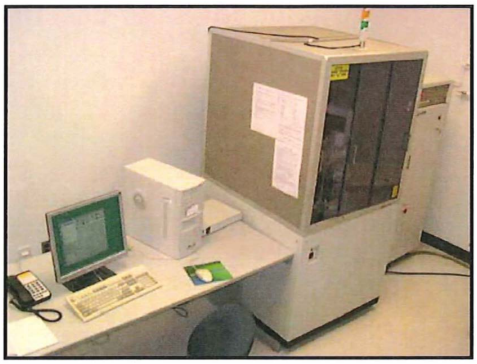


SFU 2010

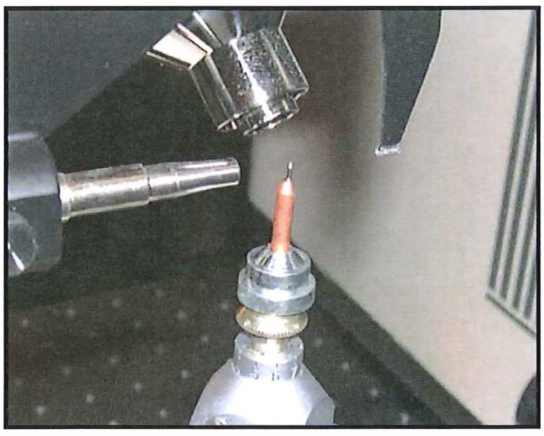
Education Building (Archaeology)
EDB 8609

HG Fischer, Model FP200

TASC II 6072 (4D Labs),



SSB 7158 (MBB),



SFU SAFETY & RISK SERVICES | ENVIRONMENTAL HEALTH & SAFETY

X-ray Emitting Device (XED) Termination Form

Under no circumstances should any X-ray equipment be abandoned, disposed as regular trash. Some X-ray equipment may contain hazardous material such as lead, beryllium and oil contaminated with PCBs in X-ray tube assembly. Please contact RSO for safe disposal.

X-ray equipment is often oil-cooled. Oil may need to be drained prior to disposal. Disable the device and take extra careful measures not to break the X-ray tube. The tube is under vacuum, if broken could splinter and cause injury. Cut the AC source cord or remove all means of activating the X-rays.

XED responsible user: _____

XED registration Number: _____

Authorized worker name/ job title: _____

Room Number: _____

Telephone Number: _____

ED manufacturer: _____

XED model: XED serial number: _____

SFU SAFETY & RISK SERVICES | ENVIRONMENTAL HEALTH & SAFETY

XED Termination Form

Please check off the items below:

- XED referred above has been disposed of by an authorized service provider please attach a of the receipt from the service provider
- XED disposed of at Municipal waste transfer station, specify waste site:

  _____

- XED was transferred to:

Name: _____ Ph: _____

Address: _____

Appendix N

X-ray Standard Operating Procedure Template

System Description & Special Safety Concerns Provide a brief summary of the purpose and application of the X-ray system

X-ray Standard Operating Procedures

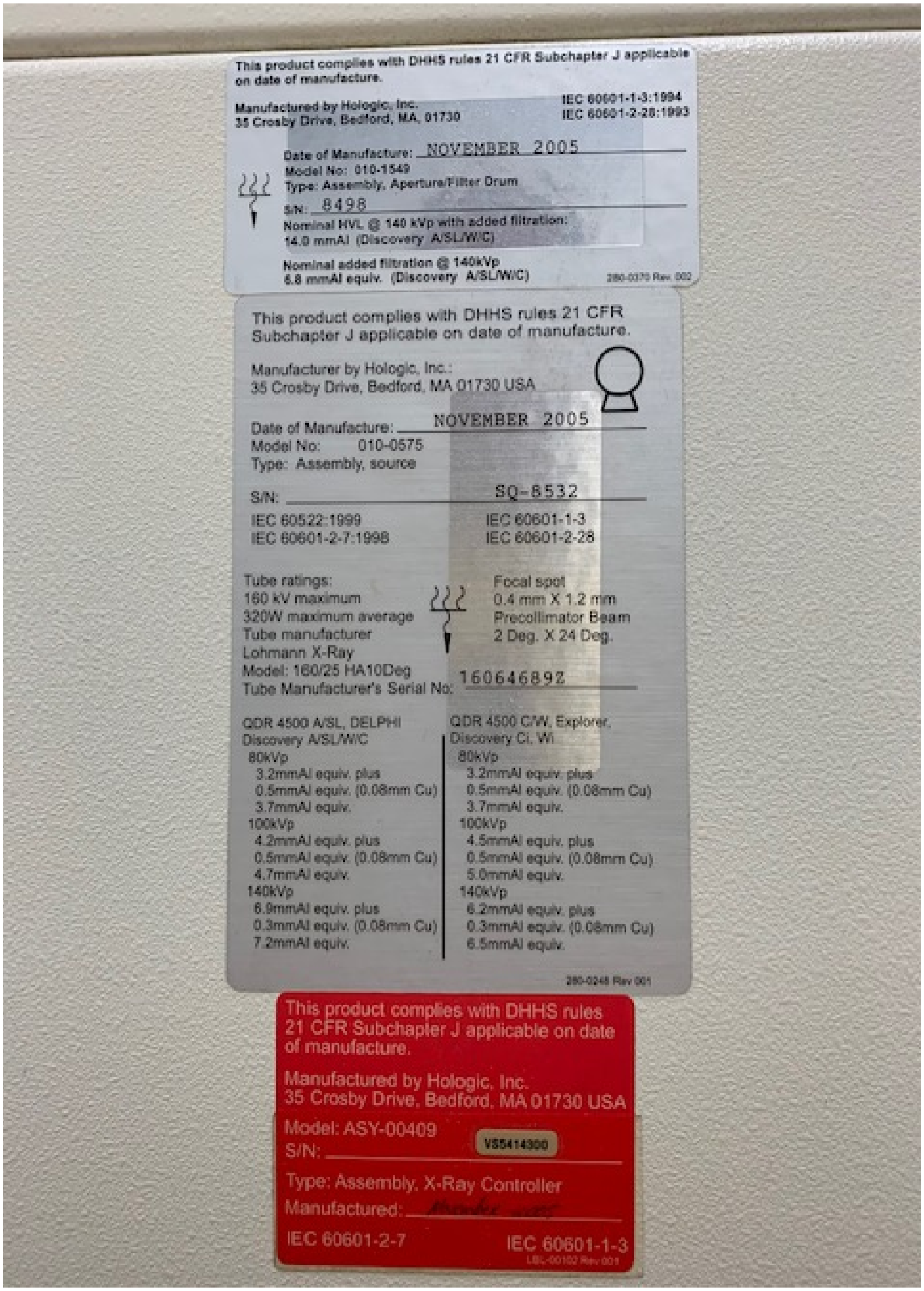
Safety Concerns

Responsible User/ Owner/ Principal Investigator (PI)
Name: Phone #:
Emergency Response Phone Numbers: Campus Security: 778.782.4500 Emergency Call: 911 Radiation Safety Officer: 778.782.3633

Device Identification

Manufacturer:	
Model No:	
Serial No:	
Open or Closed beam:	
Fixed or Mobile:	
Max. Operating:	
Voltage (kV):	
Max. Operating:	
Current (mA):	
Estimated workload (hrs/yr):	

XED Registration Certificate



Appendix P

Dose comparison of exposures from XRD versus other radiation exposures

Procedure	Dose
Unshielded primary beam	2.4 x 10 E 8 mSv/hr
Unshielded diffracted beam	8 x 10 E2 mSv/hr
1 second exposure to skin from primary beam	6x 10 E 4 mSv/hr
Dexa scan dose to patient	0.001 mSv
Natural Background in Vancouver	1.3 mSv/yr

Appendix Q

Definitions for XSM

ALARA – acronym for '**A**s **L**ow **A**s **R**easonably **A**chievable'. Taking every reasonable measure to maintain exposures to ionizing radiation as far below the regulatory dose limits as possible, consistent with the licensed activity

Absorbed Dose – the quantity of radiation absorbed in a unit of mass (SI unit: Gray (Gy) , old unit : rad, equivalence: 1 Gy = 100 rad)

Analytical X-ray Equipment – any instrument utilizing X-rays for examination of structure, or chemical composition of materials. It includes X-ray units used for X-ray diffraction, fluorescence analysis, spectroscopy or electron microscopy

Ancillary Worker – any individual who works in support of the laboratory operations, but does not work with radioactive materials directly

Attenuation – the process by which radiation is reduced in intensity when passing through some material as a result of absorption and scattering processes

Authorization – the approval issued to an individual by Radiation Safety for the use of radioactive material

Authorized User – an individual authorized by Radiation Safety for the use of radioactive material who is primarily responsible for radiation safety in facilities under their control

Background Radiation - radiation from cosmic and terrestrial sources

Beam Axis – a line from the source through the center of an X-ray field

Beam-limiting device – a device which provides means to restrict the dimensions of the X-ray fields (e.g. limiting the beam to focus on the correct anatomy reduces scatter and will reduce patient dose)

Bremsstrahlung – X-rays produced when charged particle (e.g. electrons) lose energy, slow down or deflect in the vicinity of strong electric fields of atomic nuclei

Cabinet X-ray system – an X-ray system with the X-ray tube installed in an enclosure which is intended to contain the material being irradiated, provide radiation attenuation, and exclude personnel from its interior during X-ray production.

An X-ray tube used within a shielded part of a building, or X-ray equipment which may temporarily incorporate shielding is not considered a cabinet X-ray system.

Committed Effective Dose Equivalent – the dose equivalent to organs or tissues of reference that is received from an intake of radioactive material by an individual during the 50 year period following the intake

Collimator- a device which narrows a beam of particles or waves

Appendix Q

Definitions for XSM

Counter – a general term used for a radiation detection instrument: survey meter or liquid scintillation counter (LSC) that detects and measures radiation.

Cumulative Dose – the total dose resulting from repeated exposures of radiation to the same tissue, organ or to the whole body over a period of time

Declared Pregnant Worker – a woman who has voluntarily informed her employer, in writing, of her pregnancy and the estimated date of conception

Deep Dose Equivalent – a term that applies to external whole-body exposure, the dose equivalent at a tissue depth at 1 cm

Dose Equivalent – absorbed dose in tissue or organ including quality factor (unit: mrem)

Dose (**Radiation)** – a generic term referring to the amount of radiation received, effective dose

Dose Rate – ionizing radiation dose delivered per unit time (unit: mrem/hour)

Dosimeter – a personal monitoring device used to measure an absorbed dose of ionizing radiation

Effective Dose Equivalent – sum of the dose equivalent to the organ or tissue and the weighting factors applicable to each body organs or tissues that are irradiated

Exposure (Radiation) – measure of the ionization of air due to ionizing radiation from gamma rays and X-rays (SI unit: C/kg, old unit: roentgen, equivalence: 1 C/kg=3876 R)

Exposure Rate – the amount of ionizing radiation in air caused by X-ray or gamma radiation per unit time, unit: Roentgen per hour (R/hr)

External Dose – the portion of the dose equivalent received from radiation sources outside the body

Extremity – arm below the elbow and the leg below the knee

Eye dose equivalent – applies to the external exposure of the lens of the eye and is taken as the dose equivalent at a tissue depth of 0.3 cm

Geiger-Mueller Counter (GM) – a radiation detection instrument that can detect alpha, beta and gamma radiation; response is not energy dependent

Half Value Layer (hvl) – the thickness of any given absorber, shield, that will reduce intensity of radiation to one half of its initial value

High Radiation Area – an area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.1 mrem/hr at 30 cm from the radiation source

Ionization – the process of adding or removing one or more electrons from atoms or molecules. High temperatures, electrical discharges , or radiation can cause ionization

Appendix Q

Definitions for XSM

Ionization Chamber - an instrument that detects and measures ionizing radiation by measuring the electrical current which flows when radiation ionizes gas in a chamber, making the gas an electrical conductor

Ionizing Radiation - any radiation capable of displacing electrons from atoms or molecules, producing ions, e.g. alpha, beta, gamma, X-rays, neutrons, and ultraviolet light. High doses may cause severe skin or tissue damage

Irradiation – exposure to radiation

Kilovolts peak – kV, kilovolts (**p**eak **t**ube **p**otential)

Leakage radiation (non-diagnostic) – all radiation from within the tube housing except the intended, generated beam, (also: stray radiation)

Sodium Iodide (NaI) Detector – a detector which combines a scintillation crystal, which produces light when struck by ionizing radiation, a photomultiplier tube, and associated electronic circuits for counting light emissions produced in the crystal by ionizing radiation

Occupational Dose – the dose received by an individual in a restricted area, in the course of employment

Open beam configuration – an analytical X-ray system in which an individual could accidentally place a body part in the primary beam path during operation

Primary beam – ionizing radiation which passes through the aperture of the source housing by a direct path from the X-ray tube located in the radiation source housing

Protective gear (e.g. lead apron, lead mitts) - gear made of radiation absorbing materials applied to reduce radiation exposure

Protective barrier – a barrier of radiation absorbing material used to reduce radiation exposure

Quality factor – the modifying factor that is used to derive dose equivalent from the absorbed dose, they vary for different radiation types and reflect the degree of biological effect

Radiation – alpha, beta particles, gamma rays, X-rays, neutrons, high speed electrons and protons capable of producing ions (does not include non-ionizing radiation, such as radio waves, microwaves, visible, infrared or ultra-violet light)

Safety device – a device which prevents the entry of any portion of an individual's body into the primary X-ray beam path or which causes the beam to be shut off upon entry into its path

Shielding – reduction of radiation by placing a shield of absorbing material between any radioactive source and a person, work area or radiation sensitive area

Scattered radiation – radiation that has been deviated in direction

Appendix Q

Definitions for XSM

Sievert – SI unit for equivalent and effective dose (Sv)

Shutter – a device attached to the tube housing assembly which can totally intercept the entire cross sectional area of the useful beam and which has a lead equivalency not less that that of the tube housing assembly

Sky shine- X-rays that scatter over and around shielding walls

Stray radiation – sum of leakage and scattered radiation

Survey meter – portable radiation detection instrument especially adapted for inspecting an area to establish the existence and amount of radioactive material or contamination present

Target – part of a radiation head which by design intercepts a beam of accelerated particles with subsequent emission of other radiation

Tube – X-ray tube

X-rays Emitting Device (XED) – an electronically powered analytical device with a primary purpose of controlled production of X-rays to analyze materials and structures

X-rays – penetrating electromagnetic radiation (photon) with a wavelength that is much shorter than that of visible light, they can be produced by excitation of the electrons around certain nuclei (characteristic X-rays) or by the interaction of high speed electrons with the electric fields around nuclei

Appendix R

X-ray Safety Rules for Electron Microscopes

Source of Radiation from an Electron Microscope

X-rays are produced in the electron microscope whenever the primary electron beam or back scattered electrons strike metal parts with sufficient energy to excite continuous and/or characteristic X-radiation. In terms of X-ray hazards, two aspects are important: the composition of the parts which are struck and their efficiency as X-ray sources and the effectiveness/integrity of the shielding provided by the metal casing of the microscope around these.

The higher the voltage and atomic number of the "parts", the greater the efficiency of X-ray production.

The degree of X-ray **"leakage"** also depends on the shielding provided by the metal casing. A poorly designed microscope may have weak points where X-rays can escape, for example, between the gasket sealed junction of two sections of the column.

What are the radiation safety concerns?

The radiation safety concerns are related to the **electrons that are backscattered** from the sample, as well as **X-rays produced** in the process. Most modern electron microscopes are extremely well shielded and do not produce exposure rates greater than background. However, electron microscopes are radiation-generating devices and should be at least inventoried. It is also important that the integrity of the shielding is maintained, that all existing interlocks are functioning, and that workers are aware of radiation safety considerations.

Rules for Safe Use

Applicability

- The rules in this section apply to the following miscellaneous X-ray producing equipment: electron microscopes, electron microphones, luminoscopes, and cold-cathode gas discharge tubes. These requirements are in conformity with Radiation Emitting Devices (RED) Regulations.

Registration

- EHS maintains an inventory of X-ray producing equipment. **Please notify EHS if you install, move or dispose of an electron microscope.**
- EHS includes X-ray emitting devices in the hazardous inventory. When generating a door sign X-ray equipment is required to be registered

Posting

- No area posting is required for electron microscopes.

Appendix R

X-ray Safety Rules for Electron Microscopes

Warnings and Labels

- A label bearing the statement: "**CAUTION: THIS EQUIPMENT PRODUCES RADIATION WHEN ENERGIZED - TO BE OPERATED BY QUALIFIED PERSONNEL ONLY**" should be posted on the electron microscope.

Training

- Individuals who wish to operate electron microscopes are not required to complete documented radiation safety training. However, all individuals should receive hands-on instruction and training (e.g. working with experienced users, reading the manufacturer's operation manual) before independently using the equipment.

Standard Operating Procedures (SOPs)

- Standard Operating procedures (SOPs) shall be written and available to all users near the operator panel.
- Each machine should be key controlled when not in use. Interlocks, if present, must remain operational.

Radiation Limits

- Radiation emitted from electron microscopes shall not exceed a dose equivalent rate (averaged over 10 square centimeters) of **0.5 mrem** (5 µSv)/hr **at 5 cm** from any accessible surface of the equipment.
- All miscellaneous X-ray producing equipment (electron microscopes) shall contain sufficient shielding, and be located and operated so exposure rates in unrestricted areas do not exceed 2 mrem/hr or 100 mrem/yr.

Personnel Monitoring

- Personnel monitoring (personal dosimetry) is **not required** for users of electron microscopes.

Notifications & Emergency Procedures

- The Radiation Safety Office must be notified (email: rad-safety@sfu.ca, ph: 778-782-3633) if any modifications are made to the interlocks or any other safety devices. The microscope user should also keep a copy of **operating and emergency procedures at the operator panel.**
- In the event of an emergency involving the equipment, Campus Security or 911.

Appendix R

X-ray Safety Rules for Electron Microscopes

Inspections & Recordkeeping

- **Safety evaluations** (including **radiation surveys**) should be performed by the Responsible User, in conjunction with the Radiation Safety Officer, initially when equipment is installed and after the equipment has been moved.
- EHS maintains an inventory of X-ray producing equipment and will keep radiation survey information on file. The electron microscope user should keep a logbook of any maintenance done on the equipment.

For further questions or concerns, please contact the **Radiation Safety Officer**

Phone: 778-782-3633

Or

Email: radsafe-info@sfu.ca

EMERGENCY PROCEDURES

IN AN EMERGENCY CALL 911

CAMPUS SECURITY

EMERGENCY/
FIRST AID LINE
778.782.4500

NON-EMERGENCY/
SAFEWALK LINE
778.782-7991

EMERGENCY NOTIFICATIONS

WWW.SFU.CA/SFUALERTS

- In an emergency, visit www.sfu.ca and follow @SFU on Twitter.
- Download the SFU snap app

SEE SOMETHING, SAY SOMETHING

- Report suspicious persons/ objects to Campus Security.

REPORT SAFETY HAZARDS AND INCIDENTS

WWW.SFU.CA/EMERGENCY

SFU SAFETY AND RISK SERVICES

FIRE

- Pull the nearest fire alarm, leave the area and close the door
- Evacuate the building via the nearest exit, do not use elevators
- Proceed to the assembly area
- Do not re-enter until authorized by Fire Department or Campus Security

EARTHQUAKE

- **Drop, cover, hold on** under a heavy desk or table, interior wall, or corner
- Wait 60 seconds after the shaking stops
- Proceed to the designated assembly area

ACTIVE THREAT

- **Run** - Evacuate the area if it is safe to do so
- **Hide** - Lockdown and hide yourself if you cannot evacuate safely
- **Take action** - As a last resort, commit yourself to delay, block or overcome the threat

CARDIAC ARREST

- **Phone 911** and shout for an AED. AED locations: www.sfu.ca/aed
- **Push** hard and fast in the centre of the chest
- **Use an AED** following the automated verbal instructions

SEVERE WEATHER

- Know before you go. Visit www.sfu.ca and follow @SFU on Twitter

SHELTER-IN-PLACE

During hazardous outdoor environments:

- Seek shelter indoors
- Close exterior doors and windows
- Stay indoors until officially advised