Ionising Radiation

January 2018

Working Safely with Radiation Generators

Occupational Health and Safety Service
HSD017R (rev 4)

UNIVERSITY OF CAMBRIDGE

Contents

APPENDICES – please refer to Safety Office website to select individual appendices

1. Introduction

This document has been prepared by the Safety Office, and sets out arrangements for control of work with radiation generators in the University of Cambridge. It also provides practical guidance on control measures and safe working with radiation generators and is aimed primarily at individual research workers and their supervisors.

This document supplements the more general arrangements for managing work with ionising radiations, including the roles of Heads of Departments and nominated Radiation Protection Supervisors which are described in the separate document *Management of Work with Ionising Radiation.* Any person requiring further advice on work with generators should consult their research supervisor and Radiation Protection Supervisor (if appointed) in the first instance. The University's Radiation Protection Advisers at the Safety Office must be consulted over certain matters (see appendix 1) but can be consulted on any matters relating to radiation protection.

This document does not cover the use of unsealed radioactive sources, sealed radioactive sources or equipment containing sealed sources. Guidance on work with sealed sources is covered by the University policy and guidance document *Working Safely with Sealed Radioactive Sources,* and guidance on unsealed radioactive sources is given in the University document *Working Safely with Unsealed Radioactive Sources*.

All work with radiation generators must comply with the requirements of Ionising Radiations Regulations 2017 (IRR17) which are enforced by the Health and Safety Executive and other regulations may also apply.

This document will be subject to review at intervals not exceeding three years.

2. Roles and Responsibilities

The Head of Department is responsible for implementing effective safety management. The Departmental Safety Officer (DSO) advises on and coordinates safety in the department, and assists in ensuring compliance on all safety matters including radiation safety (unless this task is delegated to another member of staff in writing).

A Radiation Protection Supervisor may be appointed for some work with Ionising radiation, but if an RPS has not been appointed for the work with X-ray generators, refer to your Departmental Safety Officer for information on local arrangements.

Research supervisors and local managers have responsibilities in ensuring risk assessments are written, safe working procedures are followed locally and any necessary training is provided.

Radiation Protection Advisers are employed to advise the University and can be contacted at the Safety Office. A Radiation Protection Adviser must be consulted over certain aspects of work with ionising radiation under IRR17. Refer to appendix 1 for matters that require consultation with an RPA.

The Radiation Protection Supervisor

The Radiation Protection Supervisor is a statutory appointee who assists the employer in complying with the Regulations and specifically ensures that the local rules are complied with. The RPS reports to the Head of Department on ionising radiations safety issues. The general role of the RPS is described in more detail in *Management of Work with Ionising Radiation* and normally includes the following.

1. Keeping in good contact with research groups within their areas of responsibility
2. Where appropriate, checking risk assessments for new work involving ionising radiations
3. Ensuring that radiation generators are assessed against requirements of the generic authorisations published by the HSE (preferably check this prior to purchase)
4. Ensuring that appropriate critical examinations are carried out and documented
5. Where appropriate, offer practical advice and assistance to users of ionising radiations
6. Supervising the system for testing of radiation monitoring instruments
7. Ensure that departmental safety procedures (department's safety policy/manual) and local rules are prepared and maintained and that their implementation is supervised.
8. Provide assistance in dealing with emergencies
9. Responding when notified of specific incidents involving radiation generators, and where appropriate, supervising tests of engineering controls, safety features etc.

The Research Supervisor

The research supervisor or "line manager" will:

1. Generally, ensure that the written requirements set out in this document and in the department's safety procedures (and local rules where relevant) are complied with
2. Cooperate with other persons in the department including the Radiation Protection Supervisors so as to ensure that the department's safety requirements are met

3. Ensure that new work has been subjected to a written risk assessment that has been agreed by themselves and the Radiation Protection Supervisor (if an RPS is appointed), and ensure that measures to restrict radiation doses, including training, are put into place
4. Ensure that the agreed practical precautions are followed by those workers for whom they are responsible
5. Ensure that appropriate personal protective clothing and other equipment is provided and is suitable for the work, is maintained in a good condition and is being worn
6. Ensure that the agreed programme of monitoring, safety checks and record-keeping is undertaken within their area of responsibility.

The user of ionising radiations

The individual research worker (the user) will:

1. Ensure that they have registered their work with their department
2. Take all reasonable steps to protect themselves and others who could be affected by their work
3. Never misuse radiation generators or equipment provided to restrict exposure
4. Cooperate with others involved in safety including their research supervisor and the RPSs
5. BEFORE commencing any new work involving radiation generators inform their research supervisor (or line manager) and always inform the RPS (where appointed)
6. If required by the department, prepare a written risk assessment for the work, which should be approved by their research supervisor (or line manager) and the RPS (where appointed)
7. Ensure that they are aware of the underlying hazards associated with this type of work, as described in this document, local rules, and in training, etc
8. Observe the safety precautions identified in this document and in the department's local rules, and any special precautions identified in the risk assessment, experimental protocol or warning signs
9. Ensure that they wear the appropriate protective clothing and other equipment including personal dosimetry, as specified in the department's local rules and risk assessment
10. Notify their research supervisor and the RPS in the event of faults or damage to equipment, or untoward exposures or other specified incidents (refer to local rules for further information on contingency plans appropriate to the work).

3. Definition of radiation generator

For the purposes of this document, a radiation generator is defined as electrical equipment capable of emitting ionising radiation and containing components operating at a potential difference of more than 5 kV. This includes X ray equipment and accelerators, and also equipment where radiation is produced adventitiously (not inherent to the process, but as a by-product of the process). Examples of practices using radiation generators within the University include:

- Electron-microscopy
- Accelerators (including cyclotrons) in Medicine/Physics/Engineering/Materials Science research
- X ray for analytical and investigative purposes e.g. X ray Crystallography
- X ray irradiation of material
- Diagnostic X ray use in veterinary radiography (including CT)
- Use of Accelerators in veterinary treatment

Accelerators

An Accelerator is defined as an apparatus or installation in which particles are accelerated, and which emits ionising radiations with energy higher than 1 MeV

Note that “accelerators” include a wide range of laboratory and medical equipment, some of which are controlled by the requirements of IRR17 and others not. Consult the Safety Office/RPO/RPA if in any doubt.

Further information about X-ray equipment and accelerators typically used in the University can be found in section 12 of this document.

4. Control of work

This section sets out the arrangements for control of work which the University departments must follow. Departments should additionally consult the Radiation Protection Adviser as necessary. These arrangements must be in place *prior* to starting work.

- Prior risk assessment

  (local rules may also be required – see section 6)

  Departmental responsibility

- Prior registration/authorisation of work

  Departmental responsibility

- Critical examinations of equipment

  Installer's responsibility

  (Departmental responsibility to check this is done – note that the department may be the installer if this is carried out by Departmental staff)

- Authorisation for work

  and ensuring that appropriate training is provided

  Departmental responsibility

Please refer to the Safety Office website or contact us directly for the latest copies of the relevant forms and publications, updates and further information.

http://www.admin.cam.ac.uk/cam-only/offices/safety/radiation/ir/

4.1 Prior risk assessment

Before any new work with radiation generators is undertaken the department must ensure that a written risk assessment is in place and that the control measures required by the risk assessment are implemented.

Adequate assessment of the risks of work with radiation generators, and recording of the significant findings of such an assessment, are fundamental to safe working and are requirements of both the Ionising Radiations Regulations 2017 and the Management of Health and Safety at Work Regulations 2017.

Once the risk assessment is complete a copy should be held by the user in the same file as the experimental protocol or other local rules documents. Anyone directly involved in the work covered by the assessment must be familiar with its findings.

As a result of the risk assessment, any specific working procedures relevant to an individual piece of work must be set out in clear and concise **local rules** and/or safe working procedures within departments. These documents should be readily accessible to users. Departmental arrangements should refer to this manual.

Risk assessments must be recorded, and for all new work the suggested format in appendix 2 should be used.

Risk assessments for significant new work in the department must also be passed to the Safety Office for comment by University's Radiation Protection Adviser (unless the RPA advises that this is not necessary).

Responsibility for preparing the risk assessment rests with the University. In practice, the person responsible for the work (the research supervisor or line manager) will normally carry out the risk assessment. Users should not begin new work until a risk assessment has been agreed by the research supervisor and the RPS (if an RPS has been appointed). This does not mean that a separate risk assessment needs to be prepared for every single piece of experimental work. For example, a series of experiments could be undertaken under the same risk assessment (with variations if necessary). Departments must use their own judgement in this matter and users must also follow any departmental policy.

RPSs who are familiar with the work and/or the University Radiation Protection Officer/RPA can provide advice and assistance on preparing risk assessments for work with radiation generators.

4.2 Registration/ authorisation of work

Prior registration/authorisation via the Safety Office is required for specific practices using X ray machines and accelerators (IRR17). This covers details of the equipment, the design of the work area including access arrangements, protective clothing, and, testing and maintenance schedules.

The Safety Office requires that an equipment registration form is completed (appendix 4) for X-ray machines or accelerators as applicable. Please consult with

the RPA prior to establishing a new practice (and acquisition of new equipment relating to the practice).

4.3 Critical examinations

Installer's Duty

If there are radiation protection implications from installing, erecting, moving or modifying a radiation generator, a critical examination must be carried out.

A Radiation Protection Adviser must be consulted regarding the nature, extent and results of the critical examination.

The critical examination is to ensure that safety features and warning devices operate correctly and there is sufficient protection for persons from exposure to ionising radiation. The installer also has a responsibility to ensure sufficient user operating and maintenance instructions are provided. A record must be kept by the Department, and a certificate should be supplied by the installer. A copy of the critical examination certificate should be sent to the University RPA.

The employer who erects or installs the equipment is responsible for carrying out the critical examination. This would also apply in situations where moving or modifying the equipment may have safety implications. When constructing and commissioning equipment built "in house", the responsible employer is the University. When purchasing equipment installed by an external company, the installer is responsible.

Please check with the manufacturer or supplier prior to purchasing new equipment that a critical examination will be carried out on installation before use, and contact the Safety Office if there are any problems. If two or more employers are involved in the installation, it should be established prior to installation which employer is responsible for carrying out checks.

A copy of the certificate should be available to users of the generator. A suggested critical examination checklist is shown in appendix 5, but this should be adapted if necessary. Further details on critical examination can be found in IRR17 regulation 32(2). Departments should take particular care to ensure that the critical examination process is followed for all relevant equipment.

4.4 Authorisation to work

All users of radiation generators must be authorised to work by prior permission from their Department, subject to training.

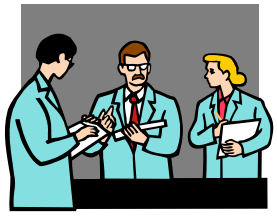
Users are registered to work by the local person responsible for the area, and a registration form (appendix 7) must be completed for each user, countersigned by their research supervisor and the RPS (if an RPS is appointed). The RPS will normally be the contact for new users, and the RPS may also be the person most appropriate to provide instruction in use and safe working practices involving the equipment.

For work where the risks are higher (e.g. work with an unshielded beam and interlocks overridden) a limited time period “Permit to Work” system (signed by the senior RPS) should be used – again the decision, for a particular equipment or situation, to require a special permit system is a matter for RPA/RPS discussion. A decision whether to proceed with a special procedure must be made based on careful risk assessment and consultation with the RPS.

4.5 Training

All users will be required to attend suitable instruction and training for use of ionising radiations within the University.

Training must be appropriate to the work and the needs of the individual, and should be determined as part of the risk assessment process.



Training must include

- the risks to health from exposure to ionising radiation;
- any necessary precautions;
- the importance of complying with relevant requirements of the regulations (the general requirements summarised in this document and, where appropriate, additional specific requirements in “local rules” or written systems of work/procedures/instruction for specific work).

Appropriate practical in-lab training under supervision must be provided by the department and documented by the department. Example induction checklists are available (on the Safety Office website, under Ionising Radiation/Forms) which departments can adapt as necessary. Before users are permitted to work unsupervised, they should be required by the RPS or person responsible for the equipment to demonstrate their knowledge by means of verbal or written tests/exercises as well as practical demonstrations.

The Safety Office provides regular training courses which are appropriate for most applications (but must always be supplemented by practical training provided by departments) – further information is available on the Safety Office website under training. Please contact us for further advice on suitable training for specific areas of work.

5. Designation of areas

The decision on appropriate designation of the area should be based on risk assessment and in consultation with the RPA. For radiation generators, the designation depends upon the accessible dose rates and the need for special procedures to restrict exposure, taking into account foreseeable accidents. In most cases, the physical control measures should be designed to sufficiently restrict exposure. However, if special procedures and instructions need to be followed *in*

addition to the physical control measures, the area should be designated as a "*controlled area"* and the procedures/instructions must be set out in a "System of Work" which can be incorporated into a local rules document. A "temporary controlled area" can be designated if appropriate.

This would apply to walk in-enclosures, and also to enclosures where only the hands can enter, for example, during alignment or other maintenance of X ray diffraction optics.

Supervised areas are designated on the basis of keeping an area under review, or on the basis of lower dose rates. Supervised areas are not normally appropriate for work with radiation generators.

6. Local Rules and the RPS

Local rules must be in place for all controlled areas (and some supervised areas). Where areas are neither controlled or supervised it may still be appropriate to have some written rules but these are not strictly "local rules" under IRR17.

Where local rules are in place, an RPS must be appointed and the role of the RPS is set out in section 2 of this document and in *Management of Work with Ionising Radiation.*

Local rules must include

- the name of the RPS
- the designation of the area and location/description of the designated area
- a summary of the working instructions and any special procedures necessary for restricting exposure (if controlled area)
- the contingency plans for any foreseeable accidents/incidents that might arise
- the University's formal dose investigation level as specified in section 4.2 of *Management of Work with Ionising Radiation*. For X-ray applications this is 2mSv whole body (effective) dose and 50mSv extremity dose, for non-classified workers.

For more information on local rules, refer to section 2.8 of *Management of Work with Ionising Radiation*.

7. Classified persons

Some radiation workers may be formally "classified" on the basis of possible significant exposures under the requirements of IRR17. However, this is not normally necessary for work with radiation generators in the University and the vast majority of radiation work is carried out by non-classified radiation workers. The RPA will advise on the process of registration as a classified worker if this is necessary.

8. Hazards and Risks Associated With Radiation Generating Machines

8.1 *Biological effects of external exposure to ionising radiation*

Work with radiation generators can lead to *external* exposure of persons to radiation. The harm caused by exposure to ionising radiations may be manifest as early effects such as skin burns and late effects such as cancer and the risk of late effects is assumed to be proportional to the dose received. It is assumed that there is no threshold for the latter and so the emphasis is on avoiding unnecessary exposure in the first place and keeping any unavoidable exposure as low as reasonably practicable.

Although dose limits are in place, it would never be acceptable at the University to involve any person in work that approached these limits, however, such a situation could occur in the event of an accident. With the types of work undertaken at the University significant doses are very unlikely, except perhaps in a few situations; for example:

1. Doses to the fingers and hands from exposure to the primary radiation beam
2. Unauthorised access or entry into areas while radiation beams are present, for instance in therapeutic veterinary situations.

The radiation dose rate depends on the exposure factors (kVp, mA), local shielding provided and distance from the source of radiation. It is in principle possible to predict doses from external radiation if the dose rate and time of exposure is estimated. Precise quantification of the dose and the risk is not always simple given that dose rates are typically highly localised and the exposure of the body is non-uniform. However, estimates of the worst case dose rates give a useful indication of the severity of harm (see table 1 below). Note that in an accident situation an assessment of the exposure is required under the regulations.

Table 1. External dose effects

Tissue	**Acute Dose (Gy) of X ray or gamma radiation**	**Effect**	**Latency**
Skin	2 Gy 6 Gy	Reddening Desquamation & Hair Loss	One day Ten days
Lens of Eye	0.5 Gy 5 Gy	Detectable lesions Cataract	Years Months
Ovary	2.5 Gy	Reduced Fertility	Days
Testis	0.15 Gy	Temporary sterility	Months
Bone Marrow	0.5 Gy	Reduced white cells	Days

8.2 *Associated hazards*

Exposure to radiation is unlikely to be the only hazard associated with the work. Associated hazards include chemical, biological, electrical and other physical hazards. Research supervisors and others responsible for work areas and equipment must ensure that the risks from all associated hazards are assessed, and refer to separate risk assessments if necessary. Consult your Departmental Safety Officer and refer to the Safety Office website for more information on risk management and specific safety topics.

8.3 *Who is at risk?*

This will include the users and any co-workers but may also include others such as maintenance contractors, or workers in adjacent areas who may inadvertently be exposed to radiation. Particular consideration must be made of anyone who may be at particular risk, or for whom lower dose limits apply.

8.4 *Pregnancy and working with radiation generators*

Female employees are reminded that any work with ionising radiations presents a possible risk to the foetus. Although for most applications, the risk to both the mother and foetus will be very low, it is important that individuals notify the "employer" (preferably the Department – the supervisor or line manager) in these situations so that the radiation risk assessment can be reviewed and a further risk assessment can be undertaken. Each case should be discussed with the Safety Office and the appropriate Radiation Protection Adviser. Notification can also be given, in confidence, via the University's Occupational Health Service, who will seek advice from the Safety Office/Radiation Protection Advisers. Any recommendations on changes to work patterns are likely to be determined by the need to consider the risk of accidents since with normal procedures routine exposures should be negligible.

Further guidance on this and other general safety issues appears in the University's Maternity Policy. Also refer to section 4.3 of *Management of Work with Ionising Radiation*. A guidance leaflet is also available from the Health and Safety Executive website www.hse.gov.uk/pubns/indg334.pdf (appendix 9).

9. Practical control measures and precautions

This section sets out typical control measures and relevant information regarding requirements for maintenance and periodic checks. These standards of protection must be followed where possible, and the RPA must be consulted regarding any equipment which does not comply with these standards of control measures. Records of maintenance and checks on safety features should be kept in the form of a log book or similar.

The practical control measures and precautions needed should be identified by prior risk assessment and the RPA must be consulted regarding significant new work.

Good design and engineering controls are essential to safe working with radiation generators. Purpose built equipment is normally designed and engineered so that it is safe for normal use. Equipment which is built in-house by a department, or used contrary to its intended use, or significantly modified will need to be carefully risk assessed and engineering and design controls applied as far as possible. The RPA must be consulted.

Administrative controls may complement design and engineering controls, but are only effective as long as they are followed and remain workable.

The use of personal protective equipment (PPE) is not normally relevant to work with X ray generators in the University, with the exception of veterinary medicine diagnostic X ray work, and PPE used for associated hazards (for example, for handling cryogens).

9.1 *Engineering and administrative controls (including shielding materials)*

The requirements for safety systems such as interlocks, shielding maintenance and warning signals will normally be identified when the prior authorisation/equipment registration forms for X ray generators and accelerators are completed.

Enclosures

Enclosures may either be ‘local’ that is specific to an accessory or particular port of the tube, or “total” enclosing all of a number of accessories and the rest of the generator. A local enclosure may be more difficult to design, whilst a total enclosure is simpler and more effective – it must be large enough to permit easy and safe access, for instance when beam alignments are carried out by authorised persons.

Local Shielding

In addition to enclosures, other shielding can be used to reduce radiation dose rates:

Beam Stops – the main beam must always be terminated so that it cannot, in the absence of an accessory at an open port, strike the enclosure and probably pass into the workplace. A beam stop may be made from lead, brass, steel, or lead glass, be positioned in line with the primary beam and be large enough to encompass the whole area of the beam. An accessory, such as a camera or other functional system

component, may act as a beam stop.

Port Blanking Plates – tube shields may have a number of ports, therefore ports that are not in use must be blanked off by means of a plate manufactured from materials as used for beam stops. It must not be possible for the plate to be removed by a casual action, although interlocking is not required. The best way of achieving this is to ensure that the only way for the plate to be removed is by the use of tools, to unfasten bolts or screws.

Viewing Windows – certain equipments require viewing windows in order for operators to observe the process within the equipment. These windows must be manufactured from "leaded Perspex" of sufficient composition to achieve attenuation of the beam.

Optical "photo-beam" systems – for scattered radiation, distance alone may provide sufficient protection. In these cases a photo beam system can be employed, to achieve segregation. Interruption of the beam must prevent X ray emission or terminate it, as the case may be.

Walk-in Enclosures

The entrance door to these enclosures must be interlocked. There must be an AUDIBLE warning signal that X-rays are about to be emitted, and this signal must be audible to persons within the enclosure. If the enclosure door is closed, opening it must terminate the emission of X-rays, and simply re-closing the door must not re-start the emission. In large enclosures, where it is possible that persons may not be able to reach the door before emission occurs, a cut-off button must be provided, to allow the person to prevent or terminate the exposure, without passing through the beam.

Materials used for shielding and enclosures

Shielding is almost always required when using generators. It must be suitable for the radiation.

PVC/Perspex or other polymer which has good shielding properties at low X-ray energies are often used for enclosures. Sheet steel, aluminium, lead/wood laminate, or wood can also be used, but a transparent shield has obvious advantages.

For shielding higher energy X and gamma rays, heavy materials such as lead, steel or concrete are normally used. For single radiation energy, the attenuation follows an exponential law, so that a fixed thickness of shielding material will only reduce the incoming radiation by a fixed amount.

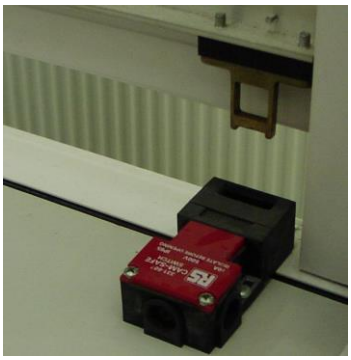
Data on "half value thickness" (the amount of material needed to reduce the exposure to a half of the original value) and "tenth value thickness" (the amount of material needed to reduce the exposure to a tenth of the original value) is a convenient way of calculating the shielding required for a given application:

Table 2 Half and tenth value thickness for lead, for heavily filtered X-rays, broad beam conditions:

Source	Half value thickness for lead in mm	Tenth value thickness for lead in mm
50 kV	0.06	0.2
100 kV	0.3	0.95
150 kV	0.32	1.04
200 kV	0.43	1.42
300 kV	1.3	4.4
400 kV	2.5	8.3

If you require specific advice for particular applications, this should be discussed with the departmental RPS (if an RPS is appointed), and contact the RPA at the University Safety Office.

Interlocks



Interlock devices must be provided to ensure that when an access door is opened, or a whole enclosure removed, the shutters close, or X-ray generation is terminated. The quality of the interlock is vital if it is being relied on for safety. Interlocks should be robust, fail safe (under a single fault) and not easily overridden. Key actuated interlocks are normally preferable to microswitch interlocks (which are not so robust and prone to contact weld).

There is a special requirement that when interlocks are activated, for example by removing or opening shielding during operation of a generator, simply closing the shielding must not re-commence the generation of X-rays – the equipment controls must also have to be reset from the control panel in order to permit the generator to operate again.

Interlock devices must be robust, and, as far as reasonably practicable, tamper proof and not easily defeated. Any switch used as a safety interlock must operate in the positive mode i.e. an act such as opening a door, removing an enclosure or part of an accessory, while X-rays are being generated, should force the switch into the "safe" position so as to cause closure of a shutter or termination of X-ray generation. In other words, this action should not depend on simple switches that rely on springs or other devices to return the switch and the equipment to a safe situation.

There are specific British Standards relating to the design, specification and installation of electrical and mechanical safety interlock systems, and these should

be consulted, when designing interlock systems. Please contact the Safety Office for advice.

Key Access

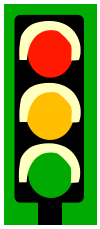
Key access should be used where possible to ensure that only authorised users have access to equipment or equipment rooms. Keys must not be left with the equipment when not in use, but kept securely by a named, trained person. When equipment is in operation under key access, the key must be in a CAPTIVE or RETAINED situation on the equipment whilst the interlock(s) are overridden.

Overriding of interlocks

Key operation, by devices located on control panels or close to the generator, may be used to by-pass interlock systems, but must only be done by properly trained and qualified individuals for operations such as alignments or calibrations. Overriding of interlocks must only be carried out by authorised persons operating under a close system of work or “permit to work”.

Key control systems shall operate when interlocks are overridden and such operation is ONLY permitted for special situations as agreed between user/senior RPS and RPA.

Warning lights/ signals



Audible and/or visible warning systems are a requirement for X-ray generators. A three stage warning system is normally used, for example, “Generator on”, “ready to emit radiation”, “shutter open – X-rays emitted”, or similar wording.

Automatic warning signals must be given when a tube is in the pre-emission state, and separately when X-rays are being emitted. Failure of the warning signal system should result in prevention or termination of X-ray emission. In some older equipment where the signal system is not so interlocked, the sign should be illuminated by at least two bulbs wired in parallel. There should be a monthly check for failed bulbs, and immediate replacement as necessary. The purpose of the audible/visible signs must be detailed in local rules and in the induction training of individuals who will use the equipment.

Safe working procedures

Clear and concise instructions for safe use of equipment should be summarised in rules, local rules, and/or a system of work as appropriate (see section 6) and must be readily available to users.

Warning signs

Appropriate warning signs should be in place depending on the designation of the area. Suggested signs are available on the

Safety Office website (under ionising radiation / forms) which departments can amend as necessary, laminate and display. Any radiation warning notices displayed in the working area should always be followed; these notices are part of local rules.

Consider who might be affected by the work and ensure that they understand the meaning of any warning signs.

9.2 *Checks on engineering control measures including interlocks*

Interlocks, warning signals and associated safety features must be regularly tested AND the results of these tests and any subsequent actions, recorded.

The person responsible for the equipment must ensure that appropriate checks are carried out.

Checks must be carried out at the time of installation or if the equipment is modified or moved such that there are radiation implications ("Critical Examination", see section 4.3).

Routine, regular checks on engineering controls including interlocks must also be carried out. Shielding should be checked to ensure it retains its integrity. Check that it is in good condition and is firmly fixed in place.

The results of any checks, and subsequent recommendations and remedial actions, must be recorded.

9.3 *Personal and Environmental Monitoring*

In undertaking work with ionising radiation, the University must ensure that employees and other persons are not exposed to ionising radiations to an extent that statutory dose limits are exceeded. Significant exposures are unlikely bearing in mind the sort of work undertaken at the University. However ALL doses must be kept as low as reasonably practicable, and personal and environmental monitoring is carried out, in order to demonstrate ALARP.

The risk assessment process should indicate the requirements for monitoring, both personal (film badge or TLD) and environmental, for example monitoring for radiation leakage.

The requirements for general monitoring – both equipment and personal, must be set down in local rules and any systems of work/written arrangements. Environmental monitoring may include the use of some personal dosimetry (see below) used to monitor an area rather than an individual, by positioning in a room in which an enclosed generator is present. This type of area monitoring may have some use, for instance for "re-assurance" purposes, when gaining experience with new or modified equipment, but generally has been found to be of little real value if continued for long periods – direct monitoring using an appropriate hand held radiation monitor is far more effective.

The results of any monitoring should confirm that control measures are appropriate,

therefore monitoring is part of the risk assessment review process.

Personal monitoring

Personal monitoring is carried out using film or TLD badges for whole body monitoring, or thermo-luminescent dosemeter (TLD) rings for extremity monitoring. These will be issued depending on the outcome of risk assessments, and retrospective dose reports are provided, with a minimum reporting level. Any unusual results or exposures will be discussed with the users involved. The Safety Office and RPA will undertake a formal investigation if, in any year, whole body monitoring of an individual indicates an accumulated effective (whole body) dose of 2mSv, or an extremity dose of 50mSv.

Personal monitoring in general should be limited to the use of finger TLD rings for persons carrying out special procedures such as alignments or calibrations. As much of the radiation is in narrow beam state, a whole body film badge worn on the lapel or elsewhere is not appropriate in these situations. Where it is thought that there may be scattered radiation or broad beams then the whole body film badge does have a role, for instance in diagnostic radiography. Consultation by the RPS with the RPA, and a properly carried out RISK ASSESSMENT (section 4.1 and appendix 2 of this document) will indicate the requirements for personal dose monitoring.

If dosimetry is issued, it must be worn for all work with radiation, looked after and returned on a monthly basis according to arrangements set up by the department and the Safety Office. There are legal duties placed on employees to care for and return dosimetry promptly for assessment.

Finger extremity monitors should be worn on the appropriate hand, with the detecting surface towards the source of radiation.

Whole body badges should be worn on the outside of clothing (under a lead apron if one is worn).

Never leave films or extremity monitors within enclosures, and also ensure that badges are removed from protective clothing before sending it to the laundry.

Environmental monitoring

Environmental monitoring is carried out as part of the legal obligation on an employer to ensure that control measures are effective. The regulations (IRR 2017) also specify equipment requirements for annual test and record keeping.

Environmental monitoring applicable to radiation generators include dose rate measurements and leak checks. Please contact us if you wish to purchase a monitor

and we will advise on a suitable monitor (see appendix 6).

Dose rate monitors are relatively expensive, and this type of monitoring can be done during visits from the Safety Office. Dose rate measurements should always be done when new techniques or equipment are introduced into a department, and may inform or verify the risk assessment process. For X-ray generators a leakage check (i.e. checking there is no significant emission of radiation) is required on a regular basis (see section 12 for additional information on monitoring with regard to specific types of equipment).

Annual test of monitors is arranged by the Safety Office. Please check that all departmental monitors are tested each year (a label on the monitor indicates due date of next test), and contact the Safety Office if there are any problems.

9.4 *PPE*

In addition to the checks on engineering controls, regular checks must be made on the condition of any personal protective equipment, for example lead aprons, as they do deteriorate over time.

10. Contingency plans

In the event of any incident, accident, fault or suspected fault of a radiation generator, the contingency plans will depend on the risk assessment, but the electricity supply must be switched off immediately and the RPS informed. If the matter is an incident which has resulted from failure of safety devices, and/or resulted in exposure of persons to ionising radiation, then the RPA must immediately be informed.

It may not be practicable to *rehearse* the arrangements for contingency plans for generators but the Ionising Radiations Regulations require that "where appropriate" the arrangements in such plans are rehearsed. All users must be fully aware of the plans and must know their role, and who to contact in the event of an incident. The availability of equipment (monitors), personnel and advice to deal with situations should be regularly checked by the (senior) RPS, and a written record made**.**

11. Reporting Incidents

All significant accidents and incidents should be reported to the RPS and the RPA at the Safety Office as soon as possible after the event to ensure appropriate follow up and medical supervision or reassurance to the individual as appropriate. Some incidents also require reporting to the regulators. Departments should submit an accident report via the Departmental Safety Officer. Accidents that are significant and must be reported are:

1. Failure of a radiation generator to terminate the exposure by the usual means.
2. Failure of an interlock or other safety device which causes, or has the potential to cause, an exposure.
3. Any suspected significant exposure or overexposure for any reason

In these situations the RPS will discuss the situation with the University RPA. Any notifications of the regulators will be done through the Safety Office.

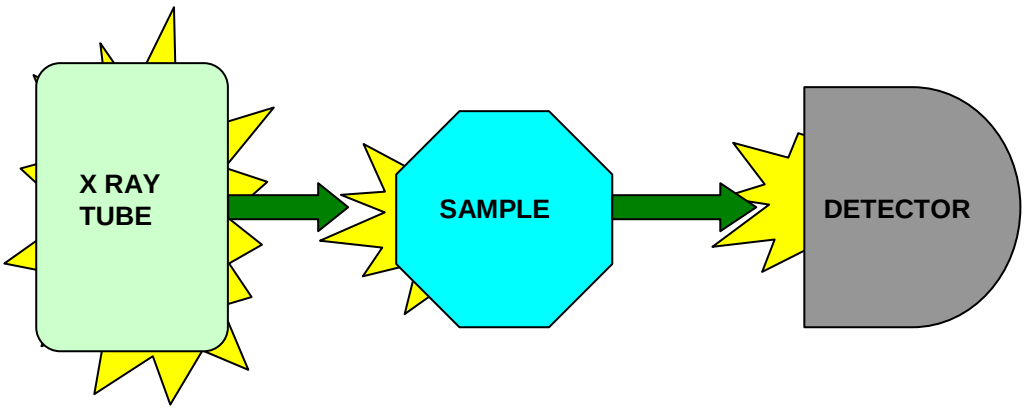
12. Further information and advice on specific radiation generators

Basics of X-ray systems

X-rays are generated by an X-ray tube contained within a tube shield, by a defined route from a “port” in the shield, to the point of use. The beam from the port may pass through a shutter, collimator and filtration systems, and after passing the sample position will be terminated by a beam “stop”. When considering radiation protection issues in respect of X-ray systems, three radiation components need to be considered:

- Tube shield leakage radiation
- Main beam radiation, and
- Scattered radiation from any component of the system or from the sample

Tube shield leakage radiation does not leave the shield through the port, but is transmitted through the shield itself. Scattered radiation consists of X-rays scattered from the main beam when it passes through air, and components of the optical system, or when it impinges on a sample or on the beam stop (as shown in yellow on the illustration below).



X-ray Diffraction equipment

X-ray diffraction machines are designed for routine analytical work, and, in theory, do not present any radiation hazards to the user if simple precautions are observed. However, they make use of beams of extremely high intensity radiation (although energies are generally low), and the beams do not normally exceed one centimetre in diameter. Severe and permanent local damage can occur from only momentary irradiation of the body form such radiation. Exposure rates of the order of 100 Gy/sec can exist at the tube housing port. Erythema would be produced after an exposure to this of only 0.03 second, and in 0.1 sec, severe and permanent injury could occur. Scattered radiation can also be quite high, of the order of a few milliSieverts an hour.

X-ray diffraction machines should be surveyed for excessive radiation levels on a regular schedule and importantly, every time a modification in measurement technique affecting the radiation pattern is introduced.

Careful monitoring of X-ray optics equipment is essential to ensure that emission of X-rays into the adjacent working environment does not occur. A slightly misaligned beam or missing component from an assembly can result in locally high intensity beams and more general scattered radiation.

Suitable monitoring equipment (regularly tested every 12 months) must be available in each room where X-ray optics equipment is used. Always ensure that the batteries are good and that monitor is functioning! Monitor whenever a new or modified assembly is first used, to ensure that X-rays are not being emitted into the working environment. Care and thoroughness are needed as the radiation may often be in the form of very narrow beams.

Always have the monitor on and close by when carrying out special procedures such as alignments and calibrations, when the shielding and interlocks may be overridden.

Local rules should specify the monitoring arrangements, both routine and special, and the records of monitoring that must be made and kept.

The RPS and RPA will determine the frequency of formal monitoring to be specified in local rules, this is the monitoring during normal operation of established equipment and techniques – often a monthly monitoring regime will suffice in many cases.

If excessive radiation levels are found around X-ray analytical equipment, this can easily be reduced because of the low energies of the X-ray photons. Any convenient structural material can be used. Frequently a thin sheet of steel, copper or brass will suffice.

Shutters should be used that cannot remain open unless a collimator is in position. The only equipment failures that have been reported as resulting in radiation injury have involved defective shutters over the tube head ports. Accordingly, even when shutters are provided, they must be inspected and monitored regularly.

X-ray Irradiator Cabinets

These devices are used quite widely within the University, in the biological sciences for irradiating living material, and also in the physical sciences and in some Museums for examining inanimate objects. Examples of types of such equipment are *"Faxitron"* and *"Bigshot"* cabinets.

In normal use these cabinets, which essentially are a metal shielded box, containing an X-ray generator and possibly some sort of imaging system, are very safe. Calculating and measuring doses to the material to be irradiated can be a complex matter, and advice should be sought – the manufacturer or supplier may be able to help, or this can be arranged via the Safety Office (although this type of calibration will need to be financed by the department).

It is important that regular (recorded) checks are made on the safety devices and warning signals associated with the cabinets. These checks should determine that if the cabinet door is opened, the interlock(s) shut off X-ray generation and that the simple act of re-closing the door does not re-start generation – this should only happen after the cabinet's exposure controls are re-set. All other controls and warning lights should be checked. A check should be carried out for X-ray leakage around the cabinet, particularly the door seal areas. A suitable dose-rate monitor is available at the Safety Office, and can be borrowed for this check. If a "mini" contamination monitor (Scintillation type 44A or similar) is used to carry out the check please note that these monitors will respond excessively to extremely low levels of leakage when the probe is close to the cabinet. This does not necessarily mean that there is any problem at all with the equipment but comparing the response of this monitor to the response of a dose rate monitor will be helpful in assessing the results. An annual service for these cabinets should be arranged with the supplier or manufacturer. Unless problems arise, it is not anticipated that RPA/RPO visits to check on cabinet operation and procedures, will take place more than once in any two year period. Cabinets must be clearly identified within a department as the "responsibility "of one of the Departmental RPSs.

Electron Microscopes

Electron microscopes are not exempt from IRR17, but they are exempt from the Prior Authorisation process under IRR 2017 (appendix 4), although any "practice" involving electrical equipment operating at potential differences of more than 5 kV WILL be subject to the other general/specific requirements of the Regulations.

Electron microscopes can produce incidental/adventitious X-rays, generally in a narrow beam from a defective component. If there is any doubt as to the particular status, in terms of the legislation, of bought in or in-house manufactured microscopes, then the RPA must be consulted. A particular area that has caused problems involves the practice of replacing shielded blanking plates, in beam paths, with viewing windows, manufactured from lead impregnated glass. Significant dose rates at the surface of these windows have been recorded. Regular (recorded)

radiation leakage tests of microscope components during high power operation are strongly recommended, and these **must** be carried out for in-house manufactured or after modification of equipment. The “Mini X” monitor (small Geiger tube) is useful for the detection of narrow beams, although it can paralyse at very high dose rates. Consult the RPO/RPA for further advice in respect of monitoring techniques.

Mobile X ray systems

Mobile units are designed to be used in the field in a variety of situations, so shielding may not be practicable. Restricting access to areas of high dose rates is therefore normally achieved by administrative controls such as careful siting of equipment, setting up a controlled area, physical demarcation of the area (the controlled area should be contained within the room if possible or otherwise by use of warning tape), careful supervision of the area and use of clear warning signs. Formal radiation safety training will also be necessary for the operators, as well as appropriate information and instruction (also formal training is necessary for anyone associated with the work). Failure to follow procedures may lead to significant doses. The RPA must be consulted over control measures prior to first use and any significant changes in work and/or environment in which the equipment is used.

Prior authorisation is applicable to work with mobile X-ray units. Critical examination also applies. This should be done by the “installer” before bringing mobile equipment into use (the “installer” may be the University – please consult the RPA). Manufacturers should provide type test information prior to purchase of equipment, and also have a duty to provide information on safe use. Checks on any safety features and warning devices should be made before first use (as part of the critical examination) and routinely to ensure that they operate correctly, where practicable.

For all mobile equipment, dose rates should be monitored using an appropriate dose rate monitor, and personal monitoring may also be necessary for anyone working in a controlled area.

Hand held XRF analysers are increasingly used, and, as these are mobile units designed to be used in the field, the above points apply. The equipment is designed to be safe for the operator if used according to the manufacturer’s instructions; however, dose rates in the primary beam can be in the order of Sieverts per hour therefore access restriction will be necessary. The unit must not be directed at any person. If the unit is misused, significant skin dose may occur, so careful risk assessment is needed. Different manufacturers utilise a range of different design features, for example, some units have an infra-red proximity sensor to prevent operation if the aperture is not in close proximity to the solid surface of the sample, but note that safety features are not necessarily foolproof and interlocks can be overridden. Again, the RPA must be consulted on use of XRF equipment.

Other Accelerators

Electron beam welding devices, thermionic valves and even VDU and television cathode ray tubes are examples of accelerators, as well as the University's linear accelerator used for veterinary treatment purposes, and a cyclotron used for production of radioisotope in medical research. Cathode ray tubes/VDU screens (in normal operating conditions) do not posses significant surface instantaneous dose rates, and are thus exempt from the Regulations. However other equipment operating at above 5 kV fall under most requirements of the regulations, and any accelerator above 1 MeV requires the prior authorisation process to be completed EXCEPT for electron microscopes and some special applications. (RPA advice should be sought for exemptions to this particular regulation).