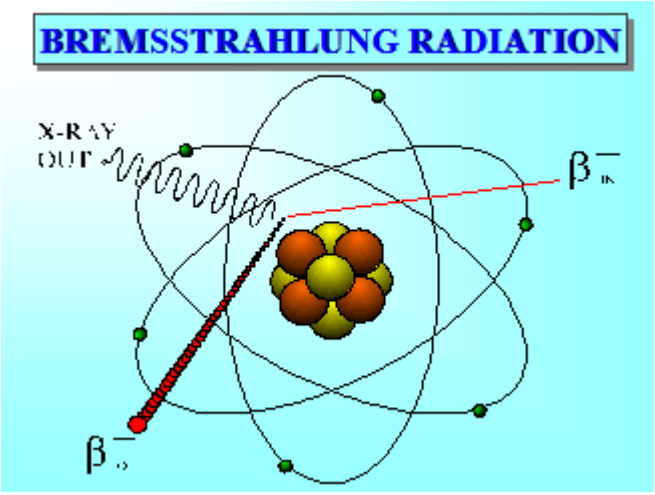
Analytical X-ray Training

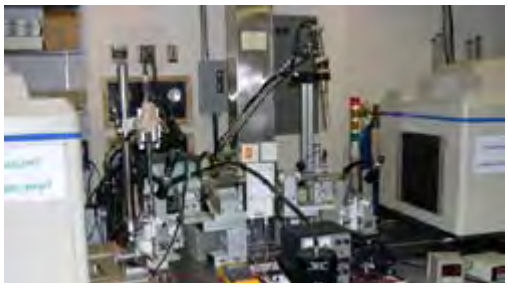
X-rays are photons (electromagnetic radiation) which originate in the energy shells of an atom, as opposed to *gamma rays*, which are produced in the nucleus of an atom. X-rays are produced when accelerated electrons interact with a target, usually a metal absorber, or with a crystalline structure. This method of x-ray production is known as *bremsstrahlung*. The bremsstrahlung produced is proportional to the atomic number (Z) of the target (absorber).



Bremsstrahlung means "braking radiation" in German. Bremsstrahlung occurs when high energy electrons are slowed down in the presence of the field of the atom. The deceleration of the electron causes the release of energy in the form of x-rays.

Many different types of machines produce x-rays, either intentionally or inadvertently. Some devices that can produce x-rays are cabinet x-rays, x-ray diffractometers, electron microscopes, x-ray photoelectron spectrometers, and Van de Graaf accelerators.
X-rays can also be produced by the attenuation of beta particles emitted from radionuclides.

This is an example of properly enclosed and interlocked x-ray diffractometer. The enclosure is made of tin-impregnated polycarbonate. If a panel is opened while the x-ray diffractometer is being used, the interlock will either shut off the x-ray or close the shutter, preventing accidental exposure to personnel.

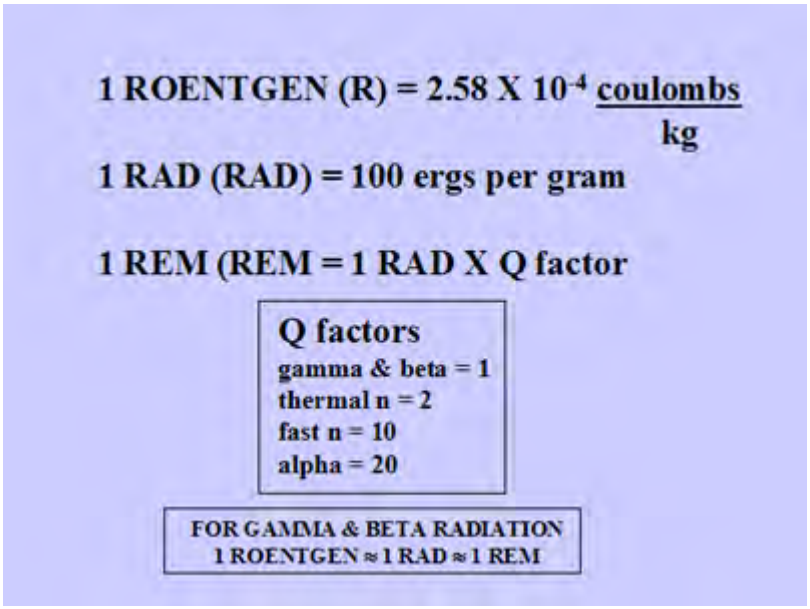


This is an example of an unenclosed (open) x-ray diffractometer.

As the open x-ray beam of such an instrument can be extremely hazardous, it is far preferable to enclose the entire x-ray apparatus.

This is an example of an x-ray fluorescence machine. It is also interlocked to prevent access while the x-ray beam is on.

This cabinet x-ray is interlocked and used to image items placed in it.



Roentgen (R)
The roentgen (R) is a unit of radiation exposure in air. It is defined as the amount of x-ray or gamma radiation that will generate 2.58E-4 coulombs per kilogram of air at standard temperature and pressure.

Rad
RAD stands for Radiation Absorbed Dose. The rad is the amount of radiation that will deposit 100 ergs per gram of material.

The Systeme Internationale (SI) unit of absorbed dose is the **gray (Gy)**, which has the units of Joules per kilogram. *A gray is equal to 100 rad*.

Rem
REM stands for Roentgen Equivalent Man. The REM is a unit of absorbed dose and is equal to the rad multiplied by a *weighting factor* which varies according to the type of radiation. The weighting factor for x-rays is equal to 1. Therefore, **for x-rays, one rad is equal to one rem**.

The Systeme Internationale (SI) unit used in place of the rem is the sievert (Sv). *A sievert is equal to 100 rem*.

The **annual occupational dose limits for adults** are:
• 5000 millirem to the whole body (total effective dose equivalent)
• 50,000 millirem to an individual organ or tissue other than the eye (deep dose equivalent and committed dose equivalent for the organ or tissue)
• 15,000 rem to the eye
• 50,000 millirem to the skin or any extremity (shallow dose equivalent)
The **annual occupational dose limits for minors** are 10% of the annual occupational dose limits for adults.
The **limit on dose to an embryo/fetus** is 500 millirem during the gestation period.

The specific hazards of analytical x-ray equipment can include:
• Exposure to an intense, localized primary x-ray beam
• Exposure to diffracted and/or scattered portions of the primary x-ray beam (includes x-ray leakage)

THE BIOLOGICAL EFFECTS OF IONIZING RADIATION

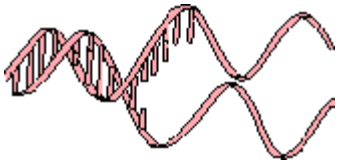
• Cellular effects of Exposure to Ionizing Radiation
The first impact of radiation is on individual cells. Radiation can damage the cells by causing or creating:

• Ionizations of atoms within the cell free radical formation within the cell
• Hydrogen peroxide poisoning of cell
• Breakage of DNA strands (both single-strand and double-strand breaks)

Ionizing radiation will cause ionizations within the cell due to the primary and secondary effects of the radiation. Ionization of water can lead to the formation of H+ and OH free radicals within the cell that will attack proteins within the cell and that can recombine to form hydrogen peroxide (H2O2) that poisons the cell. Finally, the free radicals or the direct radiation can interact with the DNA strands in the nucleus of the cell to cause damage to the information stored there. Under normal circumstances this damage can be repaired properly but, on occasion, it is either improperly repaired or not repaired at all, leading to errors when the cell reproduces itself.

If this damage occurs slowly then it can be repaired as it happens. In the case of a large acute dose the damage may be extensive enough and in a short enough time frame to be irreversible, resulting in the death of the cell.

Genetic effects:
• damage to ova in ovaries
• damage to sperm forming cells
• damage to ova or sperm
• mutations of genetic material in ova or sperm



The genetic effects of radiation are well documented in humans and in animals. Under a high enough radiation dose mutations can occur as the radiation causes changes in the DNA, usually in the ova, as the sperm are relatively short lived. Studies done on the survivors of Hiroshima and Nagasaki and their children, as well as on mice, indicate that the increased mutation rate due to most radiation doses is statistically insignificant. Most mutations that occur, whether due to the normal mutation rate or radiation induced, are either stillborn or are spontaneously aborted (miscarried).
• Effects on the Organism
Gross effects:
• increased cancer risk of about 2 cancers per 10,000 person REM of exposure
• increased cancer death rate of about 1 fatality per 10,000 person REM of exposure
• cataracts from cumulative exposures of several hundred REM over years
• life expectancy changes: ~2 1/2 days per REM (low) ~10 days per REM (high dose)
radiation burns (skin erythema) from acute doses of a few hundred REM

The USEPA conversion factor for converting millirem of exposure to excess lifetime fatal cancer risk are 3.9 * 10-7/mREM for beta gamma radiation and 3.2 * 10-6/mREM for alpha radiation. This comes out to about 4 fatal cancers per 10,000 person REM for exposure to beta gamma radiation.

Prompt somatic effects to skin after irradiation (Graphic Photo)
Although irradiation of fingers or hands with x-rays at energies of about 5 - 30 keV does not seem to result in significant damage to blood-forming tissue, at high exposures some general somatic effects to the skin can occur. Very high exposures

may necessitate skin grafting or amputation of the affected extremity.

ACQUISITION OF A RADIATION-PRODUCING DEVICE

Prior to obtaining a radiation-producing device the facility Authorized User must:

1. Pre-register with the Radiation Safety Office by providing the following information:

a. Name and address of the person having administrative control and responsibility for the proposed facility.
b. Location where the device(s) is to be stored or used.
c. A designation of the general category of proposed use (analytical, dental, medical, industrial, veterinary, or other).
d. Plans and specifications for the proposed facility and an evaluation by a qualified expert such as required by 902 KAR 100: 160, and

2. Submit an application to use to the Radiation Safety Committee.

REGISTRATION

All machines capable of producing ionizing radiation must be registered with the UK Radiation Safety Office. The following types must be registered:

- Academic x-ray (x-ray diffraction/fluorescence units)
- Dental x-ray units
- Diagnostic x-ray (radiographic, fluoroscopic and other diagnostic or therapeutic units)
- Particle accelerators
- Neutron generators
- Veterinary x-ray
- Any other equipment that may produce ionizing radiation

Registrants using x-ray machines shall provide the Radiation Safety Office with documentation of the type, make, model, location, and maximum radiation output of the device before installation. A copy of the radiation survey performed at the installation and acceptance testing shall be maintained for inspection, including exposure rates in all adjacent rooms. Radiation surveys shall be repeated after major maintenance, modification or relocation of the device.

To register the radiation-producing device or accelerator, provide the Radiation Safety Office with a completed Registered form (Appendix A).

Before installation of an x-ray device, a radiation shielding plan and specifications must be produced and filed with the regulatory agency.

An initial radiation safety survey of the equipment and all adjacent rooms, shall be conducted and a copy maintained. Similar radiation surveys shall be repeated after major maintenance, modification or relocation.

The Radiation Safety Office must be notified prior to any device installation, maintenance, modification or relocation, discontinuation or transfer of a radiation-producing device. Reports of transfer (surplus, sale, gift, etc.) must include the name and address of the transferee.

RADIATION WORKER REGISTRATION AND TRAINING

All radiation workers must complete a **Radiation Worker Registration Form**. This form provides essential information for issuing a radiation monitoring badge, and provides information on training and experience. The Radiation Safety Officer (or his/her designee) will review registration forms and schedule necessary training sessions. The Radiation Safety Office is to be informed of all changes in personnel working with radiation sources. Radiation worker updates should be provided when a worker is added, deleted or transfers to another Authorized User.

Training
All individuals using radiation-producing devices will receive radiation safety training offered by the Radiation Safety Office. Training must be completed before using a radiation-producing device. In addition individuals will be trained on the operation of the particular radiation producing device he/she will be using and actions to take in the event of an emergency.

RADIATION PROTECTION POLICIES AND PROCEDURES

Radiation producing devices do not make anything radioactive and do not produce radiation contamination (certain particle accelerators may be an exception). External radiation exposure is from x-rays only (with the possible exception of clinic or research accelerators). Applying basic radiation control measures can control the external dose.

Radiation Control Measures
Time / Distance / Shielding: The principal objective of radiation protection is to ensure that the dose received by any individual is as low as reasonably achievable (ALARA), while not exceeding the maximum permissible limit. Any one, or a combination, of the following methods may achieve this objective:

Time. Limit the time of exposure. For illustrative purposes, a person entering a relatively high radiation field of 1000 millirem/hr, but for only 30 seconds, would receive a relatively low dose of 8 millirem. The maximum permissible whole body dose is 5000 millirem per calendar year for occupational workers.

Distance. The inverse square law states that radiation intensity from a point source varies inversely as the square of the distance from the source. The formula is:

$I_1/I_2 = (D_2)^2/(D_1)^2$ where I1, I2 = intensities and D1, D2 = distances

By increasing the distance between the source of exposure and an individual, the dose received can be significantly reduced. When an individual doubles his/her distance from a source, the dose will usually be reduced by approximately three-fourths.

Shielding. Absorbing material, or shields, can be incorporated to reduce exposure levels. The specific shielding material and thickness is dependent on the amount and type of radiation involved. Lead shielding is generally used for diagnostic and other low-energy x-rays, while concrete and steel are often used with higher energy sources such as accelerators. The Radiation Safety Office will assist in designing and specifying appropriate shielding.

Exposure. The "**strength**" (killivoltage, milliamphreage, etc.) of the radiation source. By reducing the intensity of the radiation used (lowering the current settings on a radiation producing machine), dose can be reduced.

The fundamental objectives of radiation protection measures are to limit exposure to external radiation to levels that are always within the established dose limits, and as low as reasonably achievable.

Exposure Limits
External radiation levels should be kept to less than 0.1 millirem/hr at 5 centimeters from the source surface or source housing and to levels as low as reasonably achievable.

For x-ray sources, the units of roentgens, rads, and rems may be considered equivalent.

Monitoring Requirements: Radiation protection regulations and UK policy require that appropriate personnel monitoring equipment be provided to individuals who:

• are likely to receive an annual radiation dose in excess of 10 percent of any of the following annual dose limits:
- Total effective dose equivalent of 5 rems
- Sum of the deep dose equivalent and the committed dose equivalent to an individual organ or tissue (other than the lens of the eye) being equal to 50 rems
- Eye dose equivalent of 15 rem
- Shallow dose equivalent of 50 rems to the skin or to an extremity

• are less than 18 years of age and are likely to receive a radiation dose in any calendar quarter in excess of 1 percent of the doses listed in (1) above.

• are radiation workers and have declared a pregnancy or planned pregnancy.

• enter a High Radiation Area (exposure to greater than 100 millirem in any one hour).

• **operate analytical X-ray devices (ring and whole body badges)**.

• meet special criteria as assessed by the Radiation Safety Officer or his/her delegated representative.

Procedures for Monitoring Devices: Authorized Users must file a Radiation Worker Registration Form for each individual who may work with radiation sources. This form provides for the basic information regarding training and experience and personnel monitoring needs. Initial personnel monitoring decisions will be based on this information. Further evaluations, and re-evaluations, will be made through radiation employee registration updates, application reviews, personnel monitoring reports, ALARA investigations, surveys and individual interviews by responsible Radiation Safety staff members.

Badges may be exchanged on a monthly or quarterly basis. Badges must be returned to the Radiation Safety Office by the tenth of the month so that they may be properly processed.

The Radiation Safety Officer may require the use of pocket dosimeters, ring badges, or other monitoring devices when particular procedures are in operation.

The Radiation Safety Office will request prior radiation dose histories from all past employers and will maintain all personnel occupational radiation dose records.

It will be the responsibility of each individual badge recipient to wear and use the badge(s) properly. Authorized Users are responsible for assuring their radiation workers are wearing badges appropriately and that badges are returned on time for processing. Authorized Users/radiation workers may be penalized for late or lost badges.

Use of Personnel Monitoring Devices: The whole body badge (or other device) is to be worn on the body where it will most likely approximate the radiation exposure to the head and torso of the wearer. A badge assigned for whole body monitoring is not to be used to monitor the extremities (hands, forearms, feet, ankles). Separate badges must be assigned for extremity monitoring. Only the individual assigned the badge shall wear it and only at University facilities.

Generally, whole body badges are to be worn between the waist and the neck. When a protective apron is worn, the badge is to be worn at the collar, outside the apron. The Radiation Safety Officer should be consulted for advice in these circumstances.

Extremity monitoring badges (rings) are available in large or small sizes for the right or left hand. Ring badges should be worn whenever working with applicable sources.

Exposure of a personnel monitoring device to deceptively indicate a dose delivered to an individual is prohibited by state regulations.

Personnel Monitoring Reports: Exposure reports are currently monthly and quarterly. Each report includes the name, monitoring period date, dose (millirem) for the immediate past period, current calendar quarter and calendar year.

The personnel monitoring reports are on file in the Radiation Safety Office. They are available for all badged employees to review. The reports are considered medical records and may not be released without written consent.

UK Pregnant Employee - Fetal Dose Policy: The UK fetal dose policy incorporates safety information and radiation dose guidelines for ensuring safe radiation limits for the embryo/fetus of occupationally exposed employees. Pregnant radiation workers should notify the Radiation Safety Office in writing as soon as possible after learning of their pregnancy.

A potentially harmful situation arises when a pregnant worker is exposed to radiation. Exposure of such a worker to ionizing radiation from either external or internal sources would also involve exposure of the embryo or fetus. A number of studies have indicated that the embryo or fetus is more sensitive than an adult, particularly during the first three months after conception, when a woman may not be aware that she is pregnant.

Federal and state regulations require that special precautions be taken to limit exposure to radiation sources when an occupationally exposed woman could be pregnant.

The current maximum permissible radiation exposure is 500 millirem for the duration of the gestation period, and the monthly exposure should be limited to 50 millirem. Fetal monitoring (double badging) is available at the Radiation Safety Office.

In order to be recognized as pregnant, for the purpose of exposure limits, a person must declare in writing to the University that she is pregnant.

It is recommended that the pregnant person avoid higher radiation exposure procedures such as x-ray fluoroscopy.

ALARA Levels and Notifications: There are two notification levels for the ALARA program, Level I and Level II. Level I notifications involve a radiation worker receiving greater than 10 percent of the maximum allowable dose (prorated for a month's exposure period). The recipient is notified in writing when their exposure meets this level's criteria. The notification requests that the worker review their work procedures in order to reduce exposure, if feasible.

Level II notifications involve a radiation worker receiving greater than 30 percent of the maximum allowable dose (prorated for a month's exposure period). The recipient is notified when their exposure meets this level's criteria. In addition to reviewing procedures as with Level I, Level II requires the worker to respond in writing to the Radiation Safety Office. The response must include the cause of the exposure and a consideration of actions that may be taken to reduce the probability of a recurrence.

	Notification Level I	**Notification Level II**
Part of Body	**(millirem per month)**	
Whole body (head, trunk), gonads, upper arms or	40	125
Lens of the Eye	125	375
Skin of whole body- extremities (hand, elbow, lower arms or legs, foot, knee)	400	1250
Embryo-Fetus	N/A	10

Overexposure: If an exposure exceeds the maximum allowable dose, the employee and supervisor will be notified and the required reports will be filed with the State of Kentucky Cabinet for Health services.

ALARA PROGRAM

The University is committed to minimizing radiation exposure to all persons associated with the University. Therefore, the **As Low As Reasonably Achievable (ALARA)** philosophy is adopted as policy for the University. The Radiation Safety Committee, with the Radiation Safety Officer as its delegated representative, will develop and implement policies and procedures to ensure radiation exposures are ALARA.

The following policies and procedures are utilized to keep radiation exposures ALARA:

• The Radiation Safety Committee will review quarterly and annually radiation worker doses, investigating ALARA notifications to determine whether exposures are being kept to a minimum.

• The Radiation Safety Officer will brief management once per year regarding

occupational exposure levels.

• The Radiation Safety Committee will carefully review applications for radiation producing devices to ensure that the applicant is qualified and that the proposal incorporates the ALARA philosophy.

• The Radiation Safety Committee will adopt investigation levels for occupational radiation exposures. When these levels are exceeded, the Radiation Safety Officer will notify the recipient and review work practices, etc., in order to attempt to lower the exposure if possible.

• The Radiation Safety Officer will provide training classes to radiation workers and ancillary personnel regarding the ALARA philosophy and methods to keep exposures ALARA.

X-ray diffraction and spectrographic devices generate in-beam radiation dose rates of 30 to 7000 rads/sec. Severe tissue damage can be inflicted by very brief exposures to these high dose rates. Surgical treatment or amputation may be required when small body parts, such as fingers, receive greater than 1000 rads.

It is imperative that stringent safety precautions be applied when using these devices. Safety precautions include mechanical and electrical interlocks as well as proper training and instruction. The following safety procedures have been established to help prevent accidents. Adherence to these rules is mandatory.

• A label bearing the words, **"Caution - Radiation - This Equipment Produces Radiation When Energized"** shall be placed near the switch that energizes the tube.
• A sign bearing the words, **"High Intensity X-ray Beam"** shall be in place adjacent to each tube housing.
• Unused ports on radiation source housings shall be secured in the closed position.
• Under no circumstances shall shutter mechanisms or interlocks be defeated or in any way modified, except as approved in writing by the Radiation Safety Office.
• **Be alert to the beam status**. Stay constantly aware of the on/off status of the X-ray beam by repeatedly checking the status indicators.
• **Avoid the beam path**. Stay out of the beam path, even when the beam is OFF.
• **Only experienced, skilled workers should perform beam alignments**. Concentrate fully on the job when doing alignments. Wear the finger and body radiation monitor badges.
• No person shall be permitted to operate academic X-ray machines until they have:
received instructions in relevant radiation hazards and safety
received instructions in the theory and proper use of the machine
demonstrated competence, under supervision, to safely use the machine

Operators must wear extremity (finger) and whole body radiation badges while using the equipment.

Operators shall remain in constant attendance while the X-ray beam is on, or the device shall be secured against access by unauthorized persons.

Any changes in the status or location of a device shall be referred to the Radiation Safety Officer for prior approval.

Periodically monitor for scatter radiation. Sheet lead, lead foil, lead tape or leaded acrylic are all useful for auxiliary shielding.

Be aware of non-radiation hazards. Cryogenic liquids and gases, high voltage and heavy metals are some examples of other lab hazards that require precautions.

Analytical X-ray facilities will be inspected annually by UK Radiation Safety Office. **The following X-ray emergency procedure must be posted at each analytical X-ray device**:

ANALYTICAL X-RAY MACHINES
Radiation Emergency Procedures

IF YOU ARE EXPOSED TO THE DIRECT X-RAY BEAM, OR SUSPECT AN EXPOSURE, IMMEDIATELY FOLLOW THESE STEPS:

1. Shut off the x-ray beam.
2. Remain calm. Call these contacts until (1) medical advice is obtained and (2) the incident is reported.

Medical Advice/Incident Reporting

Emergency Department, UK Medical Center. 323-5901
Radiation Safety Office 323-6777
Radiation Medicine 323-6486
AFTER HOURS CONTACT, UK Police 911
(Ask for Radiation Safety Assistance)

Safety Procedures

X-Ray diffraction and spectrographic devices generate in-beam radiation dose rates of 30 to 7000 rads/sec. Severe tissue damage can be inflicted by very brief exposures to these high dose rates. Surgical treatment or amputation may be required when small body parts, such as fingers, receive greater than 1000 rads.

It is imperative that stringent safety precautions be applied when using these devices. Safety precautions include mechanical and electrical guards as well as proper training and instruction. The following safety procedures have been established to help prevent accidents. Adherence to these rules is mandatory.

1. NO PERSON SHALL BE PERMITTED TO OPERATE ANALYTICAL X-RAY MACHINES UNTIL THEY HAVE:
a. Received instructions in relevant radiation hazards and safety.
b. Received instructions in the theory and proper use of the machine.
c. Demonstrated competence, under supervision, to safely use the machine.
2. RADIATION EXPOSURE TO THE OPERATOR AND OTHERS SHALL BE KEPT AS LOW AS PRACTICABLE. RADIATION SAFETY SURVEYS SHALL BE CONDUCTED AFTER EACH SETUP OR MODIFICATION.
3. OPERATORS SHALL WEAR MONTHLY EXCHANGED FINGER-RING AND BODY RADIATION BADGES WHILE USING THE EQUIPMENT.
4 OPERATORS SHALL REMAIN IN CONSTANT ATTENDANCE WHILE THE X-RAY BEAM IS ON, OR THE DEVICE SHALL BE SECURED AGAINST ACCESS BY UNAUTHORIZED PERSONS.
5. ANY CHANGES IN THE STATUS OR LOCATION OF A DEVICE SHALL BE REFERRED TO THE RADIATION SAFETY OFFICER FOR PRIOR APPROVAL.

APPENDIX A UNIVERSITY OF KENTUCKY

X-ray Registration Form

Instructions: Complete all information and forward two copies to the Radiation Safety Office, 102 Animal Pathology.
New machines must be registered and inspected for safety prior to use.

☐ Existing ☐ New

1. Identify person(s) who will (a) supervise use of the machine and (b) all personnel who will use the machine (attach sheet if necessary).
Name _____
Dept. _____
UK Title _____
Bldg/Rm # _____
Phone# _____

2. Location (Bldg. & Rm. #) of machine
_____

3. Type of use (check all that apply):
☐ Medical: ☐ Diagnostic ☐ Therapeutic
☐ Dental: ☐ Intraoral ☐ Cephalometric ☐ Panoramic
☐ Veterinary
☐ Academic: ☐ Analytical ☐ Cabinet
☐ Other _____

4. Machine Type:
☐ Stationary
☐ Mobile
☐ Portable

5. Manufacturer/Model _____

Serial # _____

6. Maximum Rated kVp _____ mA _____

Note: All X-ray machine operators must wear a personnel monitoring device (badge), which is provided by the Radiation Safety Office. Other requirements may also apply, depending on the type of machine and applications. Please contact the Radiation Safety Office if you need a badge or have any questions.

Responsible Person _____
Printed Name Signature Date

For use by Radiation Safety Office only:
Comments _____
_____
_____