

INTRODUCTION

The Rigaku RA-Micro7 is an open-beam configuration x-ray diffraction unit, located in room C2635 of the TBRC. The machine is located behind an interlocked glass door and barrier, designed to protect the operator from exposure to radiation. This self-study guide provides radiation safety information, and is a supplement to the operational training conducted by the Authorized User.

Operators of the x-ray diffraction unit must follow all of these basic procedures:

- Only persons who have been trained and demonstrated proficiency (including passing a written exam), may operate the x-ray diffraction unit.
- Operators are required to attend annual radiation safety refresher training.
- Only authorized persons may service or perform alignment of the x-ray diffraction unit.
- Follow all Standard and Emergency Operating Procedures.
- Observe all cautions and warnings, and
- Report any operational problems promptly to the Authorized User and/or the Office of Radiation Safety (ORS).
- Comply with State of Wisconsin radiation protection regulations.

RADIATION

The term **radiation** is very broad, and includes such things as radio waves, microwaves, visible light, ultra-violet, gamma rays and x-rays. For the purposes of this guide, *radiation* will be used exclusively to refer to *ionizing radiation*. Ionizing radiation is radiation with sufficient energy to remove electrons from atoms when it passes through a material. Such atoms (or molecules), after the removal of one or more electrons, have a net positive charge, and are called ions. The free electron and the atom are called an ion pair. Ions are more chemically reactive than neutral atoms or molecules, and in some circumstances, the presence of ions in living tissues can disrupt normal biological processes. Just as excessive exposure to other forms of radiation can do harm, excessive exposure to ionizing radiation may result in adverse health effects.

All life forms have always been subjected to natural radiation. The exposure from natural radiation is a result of cosmic radiation from the sun and outer space; naturally occurring radioactive materials in the earth, in the materials of the structures we inhabit and the food and water we consume. There are radioactive

gases in the air we breathe and our bodies contain some radioactive atoms. The levels of this natural or "background" radiation vary greatly from location to location. In addition to natural radiation, individuals are also exposed to technologically developed forms of radiation. X-rays and gamma rays used in medical imaging and therapy are examples of this type of radiation. Within a decade after x-rays came into use in the 1890's it became apparent this type of radiation could either be beneficial or harmful, depending on its use and control, and that protective measures were necessary.

REGULATION OF RADIATION

An x-ray diffraction unit is a radiation-producing machine, and as such is regulated by the State of Wisconsin, Department of Health Services, Radiation Protection Section (hereafter referred to as the State of Wisconsin). Radiation protection regulations are found in the Wisconsin Administrative Code, DHS 157.¹ A copy of the regulations is available to all operators, in print at ORS, or in electronic form at the State of Wisconsin website, http://docs.legis.wisconsin.gov/code/admin_code/dhs/110/157/I/01.²

The State of Wisconsin directed certain rights and responsibilities to persons in areas where radioactive material or sources of radiation are in use or storage. Refer to Form PPH 45027 "Notice to Employees"² in this Study Guide to see what your general rights and responsibilities are. The responsibility for managing sources of radiation has been delegated to the institution's Radiation Safety Committee. The day to day operations involved in the license are overseen by ORS. The Authorized User and each individual operator of the x-ray diffraction unit is responsible for maintaining compliance with the regulations and the terms of usage stipulated by the Radiation Safety Committee.

DOSE LIMITS

The State of Wisconsin in DHS 157.22¹ limits occupational radiation dose (from all sources of radiation at the institution) to individuals as follows:

<u>Type</u>	<u>Annual Limit</u>
Whole Body	5 rem
Extremities	50 rem
Internal Organs	50 rem
Skin	50 rem
Lens of the Eye	15 rem
Minors	10% of any limit above

DOSIMETERS

Anyone who is likely to exceed 10% of any of the limits above must be monitored for exposure to radiation. Even though during normal operation of the x-ray machine it is unlikely that operators will receive exposure above the limits, the State requires all operators of open-beam x-ray diffraction units to wear extremity monitors when operating the equipment.

AUTHORIZED USERS

Authorization to use x-ray diffraction equipment is granted by the Radiation Safety Committee (RSC). Investigators authorized by the RSC are responsible for:

- Maintaining the equipment in safe working condition,
- Verifying that only trained and competent staff are allowed to operate the equipment,
- Ensuring that all State regulations and RSC requirements are followed, and
- Reporting any incidents to ORS.

RADIATION PROTECTION

The major factors in reducing radiation exposure are TIME, DISTANCE and SHIELDING. The following is a brief explanation of each:

TIME

As **T I M E** decreases

E X P O S U R E decreases

Radiation exposure is measured as a radiation dose per unit of time. The most common used unit is mR/hr. Radiation dose is directly proportional to time. This means the less time you spend in a radiation field the less radiation you will receive.

EXAMPLE: If you spend 10 minutes in a radiation field of 60 mR/hr, you receive a dose of 10 mrem.

DISTANCE

As **D I S T A N C E** increases

E X P O S U R E decreases

Radiation exposure is inversely proportional to the square of the distance from the source. This means as you increase your distance from a source of radiation, your radiation exposure decreases very rapidly. By doubling your distance from a source of radiation, you will receive one-quarter the radiation exposure. It is important to note, however, if you move to half the distance, you receive four times the radiation.

EXAMPLE: If you are working 2 feet from a radiation source that is emitting 16 mR/hr, at that distance, and you move 1(one) foot closer, you will be

working in a radiation field of 64 mR/hr.

SHIELDING

As **SHIELDING** increases
EXPOSURE decreases

Radiation can be stopped or attenuated by a barrier or shield. The amount of radiation penetrating the barrier depends on the density and thickness of the barrier material and the energy of the radiation.

ALARA

The main principle of the Radiation Safety Program is to maintain radiation exposures **As Low As Reasonably Achievable** (ALARA). Simply put, this means to take appropriate actions to reduce exposure for the procedure being performed.

X-RAY BEAM CHARACTERISTICS

X-rays are generated in the diffraction unit by accelerating electrons from a filament cathode to a target anode inside the x-ray tube. The accelerating force is created by a voltage difference applied between the cathode and the anode. The kinetic energy of the electrons is proportional to the accelerating voltage, in the case of x-ray diffraction units a maximum of 40 kilovolts peak potential (kVp). When the electrons arrive at the anode, they are stopped suddenly in the dense material. The kinetic energy of the electrons is dissipated in the form of *bremstrahlung*, or braking radiation in the form of x-rays. The x-rays are emitted at a broad range of energies, up to a maximum equivalent to the accelerating voltage, 40 kilo electron-volts (keV).³ As a practical matter, most of the x-rays are emitted at some lower energy than the maximum, and a “preferred” energy is the $K\alpha$ -characteristic energy of the copper anode at 7.4 keV.⁴ By comparison, a typical medical x-ray radiograph or fluoroscopic image uses x-rays generated by 100 to 125 kVp electrons. The average energy of a medical x-ray beam is about 50 keV.⁵ Consequently, x-rays used in diffraction are less deeply penetrating, and pose more of a skin dose hazard than medical x-rays.

The intensity of the x-ray beam is proportional to the number of electrons striking the anode, called the beam current, measured in milliamps (mA). The maximum beam current is 20 mA,³ or 1.25×10^{17} electrons per second. Only a fraction of the energy from the electron beam is converted to useful x-rays, however the intensity of the direct beam can be as high as 4×10^5 R/minute, and the scattered beam can be as high as 1.3 R/minute.⁶ While not all of this energy can contribute to skin dose, it only takes a fraction of a second exposure to the direct beam to reach the threshold for radiation burns of the skin.

BIOLOGICAL EFFECTS OF RADIATION

The biological effects of exposure to high doses (hundreds of rems) of radiation are well known and documented. The consequences of exposure to low doses (less than the dose limits) of radiation are less clear, and are most frequently expressed as risk factors. The following information is provided for both types of radiation exposure.

HIGH-DOSE EXPOSURE

Due to the intensity and penetrating ability of x-rays from a diffraction unit, as well as the physical size of the beam and its accessibility within the apparatus, the most immediate radiation protection concern is exposure of the skin of the hands and fingers of operators. The following table⁷ lists threshold doses and effects that may be expected within a few days or weeks from an exposure:

Threshold Dose	Description of Effect
200 rad	Early transient erythema – reddening of the skin. At doses of 600 rad, the peak may occur at 10 to 14 days from the time of exposure.
300 rad	Temporary epilation – loss of hair to the exposed area.
700 rad	Permanent epilation.
1,400 rad	Dry desquamation – flaking of the skin.
1,800 rad	Moist desquamation.
2,400 rad	Secondary ulceration.

In addition to the effects listed above, dermal atrophy, telangiectasis (lesions formed by capillary damage) and delayed necrosis can occur a year after doses above 1,000-1,200 rads.

The major safety concern with x-ray diffraction is accidental exposures to the direct beam, which can be severe and result in the loss of fingers, even for very short exposures.

LOW-LEVEL EXPOSURE

The effects of low-dose radiation exposure are less clearly defined. At doses of 15-25 rad to the whole body, temporary changes in blood cell ratios in humans can be observed.⁸ Below this level, biological effects are delayed stochastic and genetic effects that may occur in one individual and not another. For this reason, low-level radiation exposure effects are expressed in terms of risk of occurrence in a population uniformly exposed.

Stochastic effects of radiation exposure are effects characterized by the following:

- Occurrence in both exposed and unexposed populations,
- The probability of a given effect occurring increases with dose,
- The severity of the effect is unrelated to dose, and
- There is no threshold dose below which it can be said with certainty that an effect will not occur.^{5, 8}

Risk can be generally defined as the probability (chance) of an event (injury, illness, etc.) from some activity (exposure). Risk estimates are generally expressed in terms of the excess occurrence of an effect (the number of extra incidences of an effect above the natural occurrence rate) per rem in a group of people exposed uniformly.

The main stochastic effects attributed to low-level exposure to radiation are cancer and genetic effects. The National Council on Radiation Protection and Measurements (NCRP) has published risk estimates for occupationally exposed adults, summarized below:

Effect	Excess occurrence per rem
Fatal cancer	0.0004
Nonfatal cancer	0.00008
Severe genetic effects	0.00008
Total	0.00056

According to the estimates above, there will be 4 excess fatal cancers in a population of 10,000 people who each receive a radiation dose of 1 rem. It is important to recognize that these risk estimates are quite low when compared to the actual number of cancer deaths that occur in the U.S. population. According to the National Cancer Institute, the number of cancer deaths per 10,000 is 2,290.¹⁰

TERMS AND DEFINITIONS

ALARA	"As Low As Reasonably Achievable". ALARA means making a concerted effort to maintain exposures to radiation as far below the limits as practical, consistent with the purpose for which the licensed activity is undertaken, the economics for improvements in relation to benefits to the public health and safety and in relation to utilization of atomic energy in the public interest.
Alpha particle	Charged particle emitted from the nucleus having a mass and charge of two protons and two neutrons
Becquerel (Bq)	The SI unit of radioactivity, one Becquerel equals one nuclear transformation per second. $1\text{Bq}=2.703\text{E}-11\text{Ci}$.
Beta particle	Negatively charged particle emitted from the nucleus with a mass and charge of the electron.
Curie (Ci)	The unit of radioactivity. One curie equals $3.7\text{E}10$ nuclear transformations per second. $1\text{Ci}=3.7\text{E}10\text{Bq}$
Gamma ray	Electromagnetic radiation of short wavelength emitted from the nucleus.
Gray (Gy)	The SI unit of absorbed dose. $1\text{Gy} = 100\text{rad}$.
Neutron	Neutrally charged particle emitted from the nucleus.
Proton	Positively charged particle emitted from the nucleus.
Rad	The unit of absorbed radiation dose equal to 0.01 J/kg in any medium. $1\text{rad} = 0.01\text{ Gy}$.
Radiation	The combined processes of emission, transmission and absorption of radiant energy.
Radioactive	Material which spontaneously emits particles or photon radiation.
Rem	The unit of radiation dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor and any other necessary modifying factors. $1\text{rem} = 0.01\text{ Sv}$.
Roentgen (R)	The unit of radiation exposure. One roentgen equals $2.58\text{E}-4$ coulomb per kilogram of air.
Sievert (Sv)	The SI unit of dose equivalent. $1\text{Sv} = 100\text{rem}$
X-ray	Electromagnetic radiation emitted usually from the cascade of an electron from a higher orbital to a lower one.

COMPARATIVE RADIATION DOSES

Television	<<0.001 rem/yr
Round trip flight between London and New York	0.004 rem
Chest x-ray exposure	0.024 rem ¹¹
Average background radiation in USA	0.360 rem/yr
Lumbar spine x-ray exposure	0.127 rem ¹¹
Maximum Permissible Annual Occupational Exposure - deep-dose	5 rem
Cigarette smoking (to areas of bronchial epithelium at segmental bifurcations-based 30 cigarettes/day)	16 rem/yr
Maximum Permissible Annual Occupational Exposure -skin & extremities	50 rem
Brachytherapy dose to tumor(gyn) (delivered over 1-4 days)	1000-2000 rad
Blood Bank irradiation of blood (to prevent graft vs. host disease)	3000 rad
Radiation Oncology external beam therapy (gyn) (delivered over 5-6 weeks)	5000 rad

Generally, an exposure of 1 **Roentgen (R)** produces as dose of 1 **rad** (radiation absorbed dose) which is equivalent to 1 **rem** (Roentgen Equivalent in Man)

QUESTIONS AND ANSWERS ABOUT RADIATION SAFETY

1. **What is radiation?**

Radiation, in basic terms, is simply the movement of energy from one place to another by what physicists call an electromagnetic photon or a particle. Anyone who has ever warmed themselves by a fire is familiar with this process if the movement of energy (from the fire) to another (our "backsides") by photons emitted by the fire. This common type of radiation is only one form of electromagnetic radiant energy flow, others are radio, light, ultraviolet, gamma, cosmic, and x-ray. The last three are examples of ionizing radiation, the other examples are non-ionizing.

2. **What is non-ionizing radiation?**

Non-ionizing radiation is a type of radiant energy incapable of creating ions. Radiant energy, both visible and ultraviolet, and microwave radiation are examples of non-ionizing radiation.

3. **What is ionizing radiation?**

Ionizing radiation is the type of radiant energy which is able to disrupt an atom into separate positively and negatively charged parts. Gamma and X are among examples of electromagnetic ionizing radiation. Alpha and beta particles are examples of particulate radiation.

4. **What is electromagnetic radiation?**

Electromagnetic radiation is energy traveling in a wave motion of varying wavelengths. It has no size or mass, but only energy. Since it has no mass, electromagnetic radiation can be very penetrating. Examples of electromagnetic radiation are radio waves, microwaves, gamma rays and x-rays.

5. **What is particulate radiation?**

Radiation emitted in the form of nuclear particles, having dimension and mass. Since it has mass, particles interact more readily and therefore do not penetrate very far. Examples of particulate radiation are alpha and beta particles.

6. **What are the sources of ionizing radiation?**

Ionizing radiation is produced by x-ray generating equipment, such as a unit that takes dental or chest radiographs. Ionizing radiation is also released from radioactive materials.

7. **What is radioactive material?**

It is a material that spontaneously emits radiation generally as x-rays, gamma rays or other particles.

8. **What is radioactive decay?**

Radioactive decay is the decrease in the amount of any radioactive material with the passage of time, due to spontaneous emission of radiation. After the decay event, the atom becomes a nonradioactive atom.

9. **What is radioactive contamination?**

Radioactive contamination is the deposition of radioactive material in any place where it may harm a person or equipment.

10. **What is a half-life ($T_{1/2}$)?**

Physical $T_{1/2}$ - the amount of time it takes for one-half of the radioactive atoms of a radioactive material to disintegrate to another nuclear form. Half-lives vary from millionths of a second to billions of years.

Biological $T_{1/2}$ - the time required for the body to eliminate half of the material taken in by natural biological means.

Effective $T_{1/2}$ - the time required for a radionuclide contained in a biological system, such as human, to reduce its activity by one-half as a combined result of radioactive decay and biological elimination.

11. **What is background radiation?**

Background radiation originates from cosmic sources, terrestrial and technologically enhanced sources, as well as

naturally occurring radioactive materials in our food, building materials and even in our own bodies. The following table is the approximate radiation exposure for some common sources of radiation:

Chest x-ray	20	mrem/exposure
TV set	<0.5	mrem/year
Tobacco products	16,000	mrem/year (to lungs bronchial epithelium)
2 week vacation in mountains	3	mrem
New York to London flight	3	mrem
Natural background		
-Milwaukee	120	mrem/year
-Denver	190	mrem/year

12. How can I tell where radioactive materials are located?

Rooms and laboratories where radioactive materials are stored or used are posted with "Caution Radioactive Materials" or "Caution Radiation Area" signs on the entry doors. The signs are magenta (purple) on a yellow background and have the radiation symbol on them. Bottles and vials containing radioactive materials also have the caution sign and symbol on them.

13. How can I tell if an area is safe for me to work in?

Because humans cannot sense the presence of radiation, the laboratory workers frequently monitor their laboratories for radioactive contamination. The monitoring is performed using equipment specifically designed to detect extremely small quantities of radiation. To ensure the monitoring is being done properly, the Radiation Safety staff routinely audit laboratory records and assist laboratory workers in removal of contamination. Remember, laboratory personnel are not going to jeopardize their own safety and the Radiation Safety staff is present to ensure your well being with respect to radiation safety.

14. What should I do if I see or suspect something is wrong in an area where radioactive materials are used or stored?

Secure the area as best as possible and contact your supervisor or the Radiation Safety Office immediately. Describe what you saw or suspect and where.

15. How can I keep my radiation exposure to a minimum?

There are three basic principles of radiation protection. They are time, distance and shielding.

Time - exposure to radiation is at a rate. This means that the longer you are exposed to radiation the higher your total exposure is.

Distance - radiation dose decreases the further away from the source of radiation. Radiation exposure decrease by the inverse square law. This means if you double your distance from a source of radiation, your exposure is one-fourth of what it was at the closer point. Conversely, the closer you get to a source of radiation the higher your exposure is. If, for example, are 3 feet from a source of radiation and you move to 1 foot from the source, your radiation exposure is 9 times higher.

Shielding- radiation can be attenuated or stopped by use of a barrier or shield. The amount radiation penetrating the barrier depends on the density and thickness of the barrier material and the energy of the type radiation. Generally in a hospital environment the most noticeable form of shielding is the lead aprons worn by radiologic technologists. For example, if you think of a sun lamp as being a source of radiation, the principles of time, distance and shielding become easier to understand. The longer you lie under a sun lamp the more tan (burned?) you become. The farther away from the sun lamp you are the less intense the ultraviolet radiations and the lower your exposure. If, while under the sun lamp, you wear sun glasses or clothing, you will notice the outline where your body was shielded.

16. How can I tell if I have been exposed to radiation?

Because our bodies cannot sense the presence of radiation, even that contained in our bodies, you will not "feel" yourself being irradiated. Wearing a monitor, such as a film badge, can inform you of the fact that you have received a radiation exposure after the fact. Common sense is the best way to keep radiation exposure as low as reasonably achievable. Remember and practice the 3 principles of radiation protection, time, distance and shielding.

17. If I am exposed to radioactive materials or radiation, do I become radioactive?

No, you do not. In order for you to become radioactive, a radiation source must become incorporated into your body. This can be done by inhaling a radioactive gas or volatilized particles, ingested by swallowing or absorbed through the skin.

18. What are the possible health effects of radiation exposure?

Health effects from radiation exposure are divided into two types of effects. The first is somatic effects, or effects to your body. Some somatic effects are cataract formation and cancer. The second type of effect is genetic. This affects a descendant, as a result of modification of genetic material, of the exposed individual.

19. What are the risks involved if I become pregnant?

There may be a small risk if you are constantly working in an area where radioactive materials are present. Such persons work in Nuclear Medicine, Cardiac Catheterization Laboratory, or the Angiography section of Radiology. Children are more radiosensitive than adults and fetuses are more radiosensitive than children. Various scientific organizations and committees have conducted studies to evaluate the risks of the unborn when the mother is occupationally exposed. The recommendations of these groups include keeping all the radiation exposure to the fetus as low as reasonably achievable, but definitely below 500 mrem for the nine month gestation period.

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REGULATIONS

DHS 157.87 Radiation Safety Requirements for Analytical X-Ray Systems

(2) RADIATION SAFETY REQUIREMENTS FOR ANALYTICAL X-RAY SYSTEMS. The following safety equipment shall be used with all analytical x-ray systems except as otherwise noted:

(a) *Safety device.* An analytical x-ray system utilizing an open beam configuration shall incorporate a safety device that prevents any portion of an individual's body from entering the primary x-ray beam path or that causes the beam to be shut off upon entry into its path. The person in control at the facility may apply to the department for an exemption from the requirement for a safety device. The application shall include all the following information:

1. A description of the various safety devices that have been evaluated by the person in control.
2. The reason each device evaluated in subd. 1. cannot be used.
3. A description of the alternative safety methods available to minimize the possibility of an accidental exposure, including procedures to assure that operators and others in the area will be informed of the absence of safety devices. The department shall approve the alternate safety devices prior to their installation on the system.

(b) *Warning devices.* Open-beam configurations shall be provided with a readily discernible indication of either of the following:

1. An indication of whether the x-ray tube is on or off, if the primary beam is controlled in this manner.
2. An indication of whether the shutter is open or closed, if the primary beam is controlled in this manner. Warning devices shall be labeled so that their purpose is easily identified.

(c) *Ports.* Unused ports on radiation source housings shall be secured in the closed position in a manner that will prevent casual opening.

(d) *Labeling.* All analytical x-ray equipment shall be labeled with a readily discernible sign or signs bearing the radiation symbol and the words:

1. "CAUTION – HIGH INTENSITY X-RAY BEAM," or words having a similar intent, on an x-ray source housing.
2. "CAUTION RADIATION – THIS EQUIPMENT PRODUCES RADIATION WHEN ENERGIZED," or words having a similar intent, near any switch that energizes an x-ray tube if the radiation source is an x-ray tube.

(e) *Shutters.* On open-beam configurations installed after January 1, 1979, each port on the radiation source housing shall be equipped with a shutter that cannot be opened unless a collimator or a coupling has been connected to the port.

(f) *Warning lights.* An easily visible warning light labeled with the words "X-RAY ON," or words having a similar intent, shall be located as follows:

1. Near any switch that energizes an x-ray tube and illuminates only when the tube is energized.
2. In the case of a radioactive source, near any switch that opens a housing shutter and illuminates only when the shutter is open.

(g) *Radiation source housing.* An x-ray tube housing shall be so constructed that with all shutters closed the leakage radiation measured at a distance of 5 centimeters from its surface is not be capable of producing an air kerma in excess of 25 uSv (2.5 mrem) in one hour at any specified tube rating.

(h) *Generator cabinet.* An x-ray generator shall be contained within a protective cabinet which limits leakage radiation measured at a distance of 5 centimeters from its surface to no more than 2.5 uSv (2.5 mrem) in one hour.

(3) AREA REQUIREMENTS.

(a) *Radiation levels.* The local components of an analytical x-ray system shall be located and arranged and shall include sufficient shielding or access control so no radiation levels exist in any area surrounding the local component group that could result in a dose to any individual in excess of the dose limits in s. DHS 157.23 (1). For systems utilizing x-ray tubes, the permissible radiation levels shall be met at any specified tube rating.

(b) *Surveys.* To demonstrate compliance with par. (a), radiation surveys of an analytical x-ray system shall be performed according to all the following criteria:

1. Upon installation of the equipment.
2. Following any change in the initial arrangement, number or type of local components in the system.
3. Following any maintenance requiring the disassembly or removal of a local component in the system.
4. During the performance of maintenance and alignment procedures if the procedures require the presence of a primary x-ray beam when any local component in the system is disassembled or removed.
5. Any time a visual inspection of the local components in the system reveals an abnormal condition.
6. Whenever personnel monitoring devices show an increase of 50% over the previous monitoring period or the readings are approaching the limits of sub. (2) (g) or (h). Radiation survey measurements are not be required if a person in control demonstrates compliance with par. (a) in some other manner.

(c) *Posting.* Each area or room containing analytical x-ray equipment shall have at least one sign conspicuously posted bearing the radiation symbol and the words "CAUTION – X-RAY EQUIPMENT" or words having a similar intent.

(4) OPERATING REQUIREMENTS.

(a) *Procedures.* Operating procedures shall be written and available to all analytical x-ray equipment workers. No individual may operate analytical x-ray equipment in any manner other than that specified in the procedures unless the individual has obtained written approval of the person in control.

(b) *Bypassing.* No individual may intentionally bypass a safety device unless the individual has obtained the approval of the person in control. When a safety device has been bypassed, a readily discernible sign bearing the words "SAFETY DEVICE NOT WORKING" or words having a similar intent shall be placed on the radiation source housing.

(5) PERSONNEL REQUIREMENTS.

(a) *Instruction.* No individual may operate or maintain analytical x-ray equipment unless the individual has received instruction in and demonstrated competence in all the following:

1. Identification of radiation hazards associated with use of the equipment.
2. Significance of the various radiation warning and safety devices incorporated into the equipment or the reasons the devices have not been installed on certain pieces of equipment and the extra precautions required in such cases.
3. Proper operating procedures for the equipment.
4. Symptoms of an acute localized exposure that may cause a radiation burn.
5. Proper procedures for reporting an actual or suspected exposure.

(b) *Personnel monitoring.* Finger or wrist dosimetry devices shall be provided to and used by any of the following individuals:

1. An analytical x-ray equipment worker using a system having an open-beam configuration and not equipped with a safety device.
2. Personnel maintaining analytical x-ray equipment if the maintenance procedures require the presence of a primary x-ray beam when any local component in the analytical x-ray system is disassembled or removed. Reported dose values may not be used for the purpose of determining compliance with s. DHS 157.22 unless the dose values are evaluated by a medical physicist.