TEMPLE UNIVERSITY

RADIATION SAFETY GUIDE

For Diagnostic Imaging

Environmental Health and Safety
Radiation Safety Department
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1. **Radiation**

Radiation is described as a bundle of energy in the form of electromagnetic waves. These bundles of energies are called photons. X-rays and visible light are both a form of electromagnetic radiation. However, X-rays used for imagining have significantly higher energy photons than visible light approximately 10,000 times higher. X-rays photons are energetic enough that they can disrupt the chemical bond and cause ionization. X-rays are one type of ionization radiation. Visible light does not have sufficient energy to cause ionization. Visible light is one example of non-ionizing radiation.

**A. Radiation Quantities**

Exposure is a measure of the ionization produced in air by x or gamma radiation. The conventional unit of exposure is the roentgen (R). The international unit (SI) of exposure is C/Kg. The effect that radiation has on any material is determined by the "dose" of radiation that the material receives. Radiation dose is simply the quantity of radiation energy deposited in a material. Absorbed dose is the amount of energy deposited in any material by ionizing radiation. The unit of absorbed dose, the rad, is a measure of energy absorbed per gram of material. The SI unit of absorbed dose is the gray. The dose equivalent is a measurement of the effectiveness of the absorbed dose. It expresses all radiations on a common scale for calculating the effective absorbed dose. The unit is rem. Rem is a multiplication of the absorbed dose by a quality factor that depends on the type of radiation. The quality factor is 1 for X-ray exposure. The SI unit of dose equivalent is the sievert. The conversions between conventional units and SI units are listed below:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Conventional unit</th>
<th>(SI) unit</th>
<th>Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>roentgen (R)</td>
<td>Coulomb/Kg of air</td>
<td>1 C/kg = 3876 R</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(C/kg)</td>
<td>1 R = 2.58X10^-4 C/kg</td>
</tr>
<tr>
<td>Dose</td>
<td>rad (100 ergs/g)</td>
<td>gray (Gy)</td>
<td>1 Gy = 100 rad</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1cGy = 10^-2 Gy = 1 rad</td>
</tr>
<tr>
<td>Dose equivalent</td>
<td>rem (rad X quality factor(Q))</td>
<td>sievert (Sv) (Gy X Q)</td>
<td>1 Sv = 100 rem</td>
</tr>
</tbody>
</table>

Because low levels of radiation are routinely present in the medical environment smaller units are used. The table below is the lists the smaller units that are commonly used in the medical environment.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>unit</th>
<th>conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>milliroentgen (mR)</td>
<td>0.001 R</td>
</tr>
<tr>
<td>Dose</td>
<td>millirad (mrad)</td>
<td>0.001 rad</td>
</tr>
<tr>
<td>Dose equivalent</td>
<td>millirem (mrem)</td>
<td>0.001 rem</td>
</tr>
</tbody>
</table>

**B. Background Radiation**

Radiation is all around us, occurring naturally in the environment. We are exposed to radiation from radon in the air all the time; uranium, radium and thorium in the earth; cosmic rays from outer space and the sun; radioactive potassium in our food and water; and radioactive material within our own bodies. This is commonly called naturally-occurring background radiation.

An individual in the United States is exposed to the average background radiation of about 300 mrem per year. Background radiation varies depending on the area where you live, the type of housing construction you live in, and what you eat. For instance, Colorado has higher radiation levels because, at its high altitude, there is more exposure to cosmic rays and with its naturally-occurring uranium enriched soil, there is more terrestrial radiation. Brick homes have higher natural radiation levels than homes made of other materials such as wood; domestic water supplies naturally contain radon; and certain foods such as bananas and Brazil nuts naturally contain higher levels of radiation than other foods. In addition, consumer products such as tobacco, fertilizer product and coal have noticeable concentrations of naturally-occurring radionuclides including potassium-40.
C. Biological Effect of Radiation

Biological effects of radiation on living cells may result in three outcomes:

- cells repair themselves, resulting in no damage;
- cells die, much like millions of body cells do every day, being replaced through normal biological processes; or
- cells change their reproductive structure.

The effects of radiation, like those of most chemical substances, can be seen clearly only at doses much higher than are allowed by Federal and State regulations.

Biological effects of radiation may be classified as prompt or delayed. Prompt effects can appear in a matter of minutes to as long as a few weeks after exposure to very high doses of radiation. The higher the dose, the sooner the effects will appear, and the higher the probability of death. For example, in 1986, firefighters battling the fire at the Chernobyl nuclear power plant in the Ukraine died from very large doses approximately 1,100,000 millirad of radiation.

Because radiation affects different people in different ways, it is not possible to indicate what dose is needed to be fatal. However, it is believed that 50% of a population would die within thirty days after receiving a dose over a period of a few minutes to hours of between 250,000 to 450,000 mrem. This would vary depending on the health of the individuals before the exposure and the medical care received after the exposure. These are acute whole body doses, meaning that the whole body is exposed to the radiation in a very short period of time (minutes to hours). Exposure of only parts of the body will likely lead to more localized effects, such as skin burns or tissue damage in the exposed area.

Delayed effects of radiation are effects that appear many years (usually between 5-20 years) after exposure. The period before cancer appears is known as the latent period. Genetic effects and the development of cancer are the primary health concerns. The cancers that may develop as a result of radiation exposure are indistinguishable from those that develop spontaneously or as a result of exposure to other carcinogens. Radiation exposure may be only the initiating step that may or may not eventually lead to cancer. Genetic effects may appear in the exposed person's direct offspring, or may appear several generations later, depending on whether the altered genes are dominant or recessive.

Although radiation is known to cause cancers at high doses and high dose rates, currently there are no data to unequivocally establish the occurrence of cancer following exposure to low doses and dose rates below about 20,000 mrem. Studies of a population exposed to chronic low-levels of radiation above normal background have shown no biological effects. This population includes occupationally exposed radiation workers and people living in areas having high levels of background radiation above 1,000 mrem per year.

D. X-ray Beam

When X-rays irradiate a patient, the patient will absorb a major portion of the photons in the useful beam, some will be scattered and the remainder will be transmitted through the patient. The transmitted X-ray carries the diagnostic information that forms the image. Images are formed because of the differential absorption of the useful beam by different tissues or organs. The maximum energy of photons in the X-ray beam for a typical X-ray tube is the operating peak Kilovoltage (KVp) at which the exposure was made. However, many of photons are in a very low energy range. The penetrating power of X-rays increases with photons energy. As the energy increases the penetrating power of X-rays increases. The low energy X-rays cannot penetrate through the patient. However, they will be absorbed by skin without contribution to the information reaching the image receptor. Filters are used in X-ray tubes to absorb the low energy photons. In general, the greater the amount of filtration, the greater the average energy of the X-ray beam and smaller the organ doses for exposure needed to make the image. However, too much filtration decreases the ability to distinguish between similar materials.
2. **RADIATION PROTECTION**

Minimizing radiation exposure to patients, members of the public and persons whose work involves exposure requires trained and experienced workers using good safety practices and equipment with proper safety features, in appropriately shielded facilities.

**A. Protection of individuals**

No individuals shall be exposed to the useful beam for training, demonstration or nonhealing arts purposes. A licensed practitioner of the healing art must authorize exposure. Exposure of an individual for the purpose of research must be approved by the Institutional Review Board (IRB) and Radiation Safety Committee (RSC). Approval must be obtained before initiation of any research study.

**B. Protection of patient**

Medical decisions related to need for the examination and treatment should be left to the patient and the professional judgment of the physician. Sensitive body organs such as the gonads and the lens of the eye should be shielded with at least 0.5 mm and 0.2 mm lead equivalent respectively if these organs are in the primary beam, provided such shielding does not eliminate useful diagnostic information or proper treatment. The equipment should operate and be maintained in proper working condition.

**C. Protection of persons other than the patient**

- Minimize the external radiation exposure by increasing the distance of the individual from the source of radiation, namely the patient and the X-ray machine. The intensity of the radiation field is reduced by a factor of four when the distance from the radiation source is doubled.

- Reduce the time spent near the source of radiation. The longer exposure time, the higher is the dose.

- Use a protective barrier such as leaded panel, leaded apron or walls. For X-ray equipment used in diagnostic procedures, a lead apron is a very effective attenuator to decrease the exposure.

- Only the individuals who need to be present in the X-ray procedure room during the exposure should be in the room. Leaded aprons, leaded gloves and/or portable shields must be used to protect these individuals.

- Sometimes parents of young children often desire to be present in the room. The radiologist or authorized personnel should discourage the parents from being present. If the presence of parents is necessary, they should stand as far as possible from the source of radiation. They should wear protective garments such as lead aprons.

- No person should routinely hold patients or film during diagnostic examinations. When a patient must be held in position for radiography, a mechanical supporting or restraining device should be used. Pregnant women or persons under the age of 18 years should not be permitted to hold patients. If someone must hold a patient, that person must be protected with appropriate shielding devices such as protective aprons and gloves. Positioning should be arranged so that no part of the holder's torso, even if covered by protective clothing, will be struck by the useful beam and so that the holder's body is as far as possible from the useful beam.

**D. Protection of fetus**

Special consideration must be given to the protection of the embryo or fetus of women known to be, or potentially, pregnant. A patient of childbearing age should be questioned to ascertain the likelihood of
pregnancy. If the patient is found to be pregnant or likely to be pregnant, the physician or radiologist should be consulted to decide whether this radiation dose to the patient is justified. The decision to proceed with procedure for a pregnant patient must be made by the patient and the physician.

E. **Occupational dose limit**
The annual dose limit for occupational radiation workers is 5,000 mrem for whole body, 15,000 mrem for the lens of the eye and 50,000 mrem for organs (e.g. breast, lung), skin and extremities.

F. **Dose to an embryo/fetus**
The National Council on Radiation Protection and Measurements (NCRP) has recommended limits for radiation exposure to an embryo/fetus. The Nuclear Regulatory Commission (NRC) and the Department of Environmental Protection of the State of Pennsylvania (PA) have set limits for radiation exposure to the embryo/fetus of a declared pregnant woman. The NRC and PA require that the dose to an embryo/fetus during the entire pregnancy, from occupational exposure of a declared pregnant woman, must not exceed 500 mrem. Efforts must be made to assure that this dose is distributed uniformly over the entire period of pregnancy.

A pregnant employee is highly encouraged to voluntarily inform her employer, in writing, of her pregnancy and the estimated date of conception. Further, such an employee is encouraged to visit the Radiation Safety Department and receive information regarding concerns she may have about radiation exposure during pregnancy. Such an employee may discuss her concerns with the Health Physicist. Upon submission of a completed “Declaration of Pregnancy” form (available at the Radiation Safety Department, 3307 N. Broad Street, # B 49), the Radiation Safety Department will:

- Provide information concerning risk and precautions;
- Evaluate the working environment with respect to radiation exposure;
- Make recommendations for reducing radiation exposure;
- Monitor monthly radiation exposure with respect to the NRC and PA limits.

G. **Registration of Radiation Workers**
The Department of Environmental Protection of the State of Pennsylvania regulations require that those who work with X-ray producing machines are provided training, and are monitored for potential radiation exposure. In order to assure that the requirements of these regulations are met, a Radiation Worker Registry is maintained by the Radiation Safety Department (RSD). This registry includes, but is not limited to, those who are addressed by the Radiation Dosimetry Program. Appendix A is a copy of the Radiation Worker Registration form.

H. **Badging and Dosimetry**
The Radiation Safety Department uses personnel monitoring to identify inadequate or improper radiation safety practices and potentially serious radiation exposure situations. These consist of Film Badge and/or TLD to monitor exposure to the whole body, and a Ring Dosimeter to monitor extremity exposure. Radiation exposure (individual radiation exposure as well as collective dose equivalent) must be kept as low as reasonably achievable. This so called “ALARA” principle has been introduced into the regulations of the U.S. Nuclear Regulatory Commission and the Pennsylvania Department of Environmental Protection, and has been adopted by our institution. The RSD will issue dosimeters when evaluation of equipment or workload reveal that the radiation dose to personnel could potentially be larger ALARA limits.

Exposure of a personnel monitoring device to deceptively indicate a dose delivered to an individual is
prohibited and is a violation of Pennsylvania Department of Environmental Protection regulation. (PA 221.11.j)

I. Dosimeter Placement
Interpretation of the measured dose depends on the placement of the dosimeter. All personnel must wear their dosimeters correctly. The following list indicates where the dosimeters are to be worn:

- The individuals with a single whole body badge must wear the badge above any protective clothing at collar level.
- Individuals with a dual badge must wear the badge that is identified as a waist level badge under the lead apron and the collar badge above the lead apron at collar level.
- Ring Dosimeter: ring dosimeters are to be worn on the hand that receives the maximum exposure.

Dosimeters are sensitive to extreme heat. Store dosimeters in an area away from any radiation source not with your lead apron.

Dosimeters must be returned to RSD promptly at the end of the interval specified by the RSO. Individuals who are late in returning their dosimeters will be fined and repeated non-compliance will be referred to the RADIATION SAFETY COMMITTEE (RSC) for further disciplinary action.

J. Exposure Reports and ALARA:
Radiation exposure (individual radiation exposure as well as collective dose equivalent) must be kept as low as reasonably achievable. This so called “ALARA” principle has been introduced into regulations of the U.S. Nuclear Regulatory Commission and the Pennsylvania Department of Environmental Protection, and has been adopted by Temple University. This policy provides specific guidance and data on Temple University’s approach to the implementation of the ALARA principle.

Exposure Reports: The Radiation Safety Department reviews exposures on a regular basis. Subsequently, high or unusual exposures are reported to the Radiation Safety Committee. Written investigations by the RSD are performed when an individual's total effective radiation dose equivalent in one year exceeds trigger levels listed below:

<table>
<thead>
<tr>
<th>ALARA</th>
<th>Notification</th>
<th>Level I</th>
<th>Level II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mrem/m</td>
<td>mrem/y</td>
<td>mrem/Q</td>
</tr>
<tr>
<td>Whole body</td>
<td>40</td>
<td>480</td>
<td>120</td>
</tr>
<tr>
<td>Lens of Eye</td>
<td>125</td>
<td>1500</td>
<td>375</td>
</tr>
<tr>
<td>Extremities, Skin, any organ/tissue</td>
<td>400</td>
<td>4800</td>
<td>1200</td>
</tr>
<tr>
<td>*X-ray users, single badge and badge worn at collar level outside of leaded protective clothing.</td>
<td>125</td>
<td>1500</td>
<td>375</td>
</tr>
<tr>
<td>**Exposure from x-ray source for Interventional Radiologists and Cardiologists. Badge worn at collar level outside of leaded protective clothing.</td>
<td>450</td>
<td>5600</td>
<td>1400</td>
</tr>
<tr>
<td>x-ray users extremities Interventional Radiologists and Cardiologists.</td>
<td>1000</td>
<td>12000</td>
<td>3000</td>
</tr>
</tbody>
</table>

*Critical organs are protected by leaded garments the formula to calculate the Total Effective Dose Equivalent TEDE= 0.3 badge wore outside lead apron, NCRP 122

**Critical organs are protected by leaded garments the formula to calculate the Total Effective Dose Equivalent
(TEDE) is: NCRP report 168, the Effective dose equivalent (EDE) for the fluoroscopy guided interventionists be calculated with the formula EDE= collar badge reading / 5.6

K. **Training**
Individuals who operate a X-ray machine must have training and demonstrate competence in

- Use and operation of the X-rays equipment including:
  - Identification and function of each control,
  - Use of technique charts.

- Radiation protection including:
  - Radiation dose,
  - Proper use and placement of personnel dosimetry,
  - ALARA program,
  - Understanding units of radiation,
  - Personnel protection,
  - Proper use of gonad shield and (if used) patient protective devices,
  - Adequate filtration of X-ray tubes and restriction of X-ray tube radiation to image receptor,
  - Proper use of grid,
  - Collimation.

- Film processing including:
  - Film speed as related to patient exposure,
  - Film processor parameter,
  - Quality assurance (QA) program,
  - Identification of film artifacts and able to take corrective actions if necessary.

- Procedure including:
  - Knowledge of anatomy and physiology,
  - Knowledge of positioning and radiographic demonstration of the request studies.

- In emergency response procedures in terminating the exposure related to their use of equipment.

And annual continuing education that includes radiation protection.

L. **Shielding for patient**
Shield patient’s gonads with at least 0.5 mm of lead equivalent during diagnostic procedures in which gonads are in the useful beam, except for cases in which this would interfere with the intended diagnostic procedure. For diagnostic procedures in which eyes are in the useful beam, shield eyes with at least 0.2 mm of lead equivalent, except for cases in which this would interfere with the intended diagnostic procedure.

M. **Shielding for Personnel**
Personnel who remain in the room during diagnostic X-ray examinations must be protected by proper shielding. Leaded aprons must be worn if their presence are required in the X-ray procedure room during X-ray exposure. Scatter radiation will be attenuated by a factor of 20 with the use of 0.5 mm lead equivalent aprons. A thyroid shield must be worn during fluoroscopy or for procedures that expose the thyroid to high levels of scattered radiation. Ledged glasses can greatly reduce the exposure of eye lenses to scattered radiation in fluoroscopy, especially for physicians who are involved with invasive procedures. Bucky slot cover or pull down shielding significantly reduce scatter radiation to the operator from the X-ray tube and the patient. Except are the physicians who perform invasive diagnostic procedures, others who must have his or her hand near the primary beam (as in cases in which no other means is available to immobilize a patient) should wear leaded gloves to reduce exposure to extremities. Invasive diagnostic physicians must take special care to reduce the amount of time that their hands are in the primary beam.
N. **Structural Shielding**

X-ray procedure rooms have been designed with sufficient shielding in the walls to provide protection to anyone outside of the room or at the control areas. Do not tamper with the integrity of the shielded walls. If any personnel notices structural changes, such as holes drilled into walls (hanging picture) they should notify the Radiation Safety Department or the individual responsible for radiation protection of the facility as soon as possible.

O. **Posting**

- The X-ray machine must be labeled to caution individuals that radiation is produced when the machine is being operated.

- The Commonwealth of Pennsylvania Department of Environmental Protection “Notice to Employees” form must be posted in conspicuous locations in all clinical areas in which X-ray equipment is used. Appendix B is a copy of this notification.

- Any area where radiation levels exceed 5 mrem/hr at 30 centimeters from the radiation source shall be posted with a “CAUTION, RADIATION AREA” sign.

P. **Notification:**

Report all conspicuous problems with X-ray equipment or with shielded rooms, as well as any other safety problems observed by personnel to the Radiation Safety Department at 707-2520 immediately. All X-ray producing equipment must be registered with the Pennsylvania Department of Environmental Protection. The RSD will register all the units on an annual basis. RSD must be notified if:

- you are going to acquire new X-ray equipment. The RSD must confirm the integrity and adequacy of the facility shielding. In addition all new X-ray equipment must be surveyed prior to clinical use. It is responsibility of clinical department to arrange for this initial survey.

- you are planning to dispose of X-ray equipment. X-ray equipment has hazardous materials such as lead that cannot be disposed of in a landfill. Environmental Health & Safety Department will ensure safe disposal of X-ray equipment.

- you are planning to move X-ray equipment to a new location. The RSD must evaluate the new location for proper shielding and radiation exposure to the general public.

- you are transferring X-ray equipment to another institution. The RSD must notify the Pennsylvania Department of Environmental Protection.

### 3. PROPER OPERATING PROCEDURES

The dose to the patient must be kept to a minimum consistent with clinical objectives. However, too low a dose may compromise the examination and diagnosis. The examination must be performed using the technique that is posted. The technique is developed by physicians, technical staff and the individual responsible for radiation protection of patients and proper operation of X-ray equipment.

A. **Mammography units**

- The X-ray tube housing assembly with the attached beam limiting device must be constructed in such a way that radiation leakage at 1 meter is less than 100 mrad in any one hour when the tube is operated at its leakage technique factor.
- The image receptor support must not transmit more than 0.1 mrad per exposure at 5 cm beyond the support with no breast present, for maximum Kilovoltage (KVp), current and time (mAs) used.

- The X-ray tube must have a visible exterior mark to indicate the focal spot location.

- The unit must have a protective barrier for the operator to stand behind to make an exposure and to observe the patient during the exposure.

- The X-ray tube potential (KVp), filtration and source to skin distance (SSD) should be as large as practical, consistent with objective of study. These parameters are set by the individual responsible for radiation protection at the time of acceptance testing and are confirmed during the annual radiation survey of the equipment.

- The technique chart must be posted at the control panel.

- X-ray films and the intensifying screens should be compatible and for special use in mammography

- Collimation must be used to limit the X-ray beam to the smallest area practicable and consistent with the objectives of the radiological examination.

- Compression must be used in all mammographic procedures.

- The X-ray tube assembly must have adequate and proper filtration.

- The system should have beam limiting devices and the deviation between the X-ray field and the light field must be less than 2% of SID along either length or width. The X-ray field should not extend beyond the chest wall edge of the image receptor by more than 2% of SID. The Chest wall edge of the compression paddle should not extend beyond image receptor by more than 1% of SID.

- The X-ray system in combination with the mammography screen-film combination must at a minimum resolve a 11 line pairs per millimeter image in direction which is perpendicular to anode- cathode (A-C) axis and 13 line pairs per millimeter in direction which is parallel to A-C at typical clinical setting.

- Measured average KVp must be within ±5% of the indicated or selected KVp.

- The radiation exposure at given KVp and mAs must be constant. The coefficient of variation must be less than 0.1.

- The Automatic Exposure Control (AEC) System must be capable of compensating adequately for variation in clinical used KVp and breast thickness. Density control setting must operate in such a manner that increase in density setting means increase in mAs and optical density.

- The system must be capable of producing a minimum exposure of 513 mR/sec at 28 KVp in its standard mammography mode at any SID and be able to maintain the exposure for 3 sec.

- The average glandular dose for the average breast must be below 300 mrad.

**B. Dental units**

- The X-ray tube housing assembly with the attached beam limiting device must be constructed in such a way that radiation leakage at 1 meter is less than 100 mrad in any one hour when the tube is operated at its leakage technique factor.
The X-ray tube must have a visible exterior mark to indicate the focal spot location.

For X-ray systems with two or more tubes that are controlled by one exposure switch the selected tube must be clearly indicated on the X-ray control panel and at or near the tube housing assembly prior to initiation of an exposure.

The unit must have a protective barrier for the operator to stand behind it to make the exposure and to observe the patient during the exposure.

The X-ray tube housing assembly supports must remain stable during an exposure, unless tube housing movements are a designed function of the X-ray system

There must be a visual indication at the control panel whenever X-rays are produced. An audible signal must indicate the termination of exposure.

The X-ray tube potential (KVP), filtration and source to skin distance (SSD) should be as large as practical, consistent with objective of study. These parameters are set by the individual responsible for radiation protection at the time of the acceptance testing and are evaluated during the annual radiation survey of the equipment.

Collimation must be used to limit the X-ray beam to the smallest area practicable and consistent with the objectives of the radiological examination.

The radiation exposure of a X-ray tube at given potential KVP must be linear with mAs for units with selectable mA. The exposure per mAs at given KVP should be constant within 10% and be constant within 20% of all combinations of current and time settings commonly used.

The X-ray tube assembly must provide at least 1.5 mm aluminum equivalent filtration, if it operates between the 50-70 KVP. For a unit that operates above 70KVP it should provide a minimum of 2.5 mm aluminum equivalent filtration.

The system should have beam limiting devices and the deviation between the X-ray field and the light field must be less than 2% of SID along either length or width. The X-ray field should not extend beyond chest wall edge of the image receptor by more than 2% of SID and the Chest wall edge of compression paddle should not extend beyond image receptor by more than 1% of SID.

Measured average KVP must be within ± 10 % of the indicated or selected KVP.

For intra-oral dental units, the minimum source to skin distance (SSD) cannot be less than 18 cm for units that operate above 50 KVP and less than 10 cm for units that operate below 50KVP.

For intra-oral dental units, the maximum diameter of the X-ray field at minimum SSD cannot be larger than 7 cm for units that operate above 50 KVP and not larger than 6cm for units that operate below 50 KVP.

The technique chart must be posted near protective area.

C. Radiographic Units

The X-ray tube housing assembly with the attached beam limiting device must be constructed in such a way that radiation leakage at 1 meter is less than 100 mrad in any one hour when the tube is operated at its leakage technique factor.
The X-ray tube must have a visible exterior mark to indicate the focal spot location.

For X-ray systems with two or more tubes that are controlled by one exposure switch the selected tube must be clearly indicated on the X-ray control panel and at or near the tube housing assembly prior to initiation of an exposure.

The unit must have a protective barrier for the operator to stand behind it to make the exposure and to observe the patient during the exposure.

The X-ray tube housing assembly supports must remain stable during an exposure, unless tube housing movements are a designed function of the X-ray system.

There must be a visual indication at the control panel whenever X-rays are produced. In addition, a signal audible to the operator shall indicate that exposure has terminated.

The X-ray tube potential (KVp), filtration and source to skin distance (SSD) should be as large as practical, consistent with objective of study. These parameters are set by the individual responsible for radiation protection at the time of the acceptance testing and are evaluated during the annual radiation survey of the equipment.

Collimation must be used to limit the X-ray beam to the smallest area practicable and consistent with the objectives of the radiological examination.

The radiation exposure of X-ray tube at given potential KVp must be linear with mAs for unit with selectable mA. The exposure per mAs at given KVp should be constant within 10% and be constant within 20% of all combination of current and time settings commonly used.

X-ray tube assembly must provide a minimum of 2.5 mm aluminum equivalent filtration.

The system should have beam limiting devices and the deviation between X-ray field and light field must be less than 2% of SID along either length or width.

Measured average KVp must be within ±10% of the indicated or selected KVp.

The radiation beam cannot be larger than the linear dimensions of the image receptor (film, digital plate) being used.

The positive beam limitation (PBL) systems must allow further reduction in the X-ray field size.

The variation in the center of the X-ray field with image receptor cannot be larger than 2% of SID.

The variation in size and alignment of X-ray field with image receptor must be less than 2% of SID.

The duration of X-ray beam exposures must be in agreement with the setting of the timer.

When the automatic exposure control (AEC) mode is selected it must be indicated in the control panel. There must a means to terminate exposure if the AEC fails to terminate exposure.

The technique chart must be posted at the control panel.
**D. Fluoroscopic Units**

- The X-ray tube housing, assembly with attached beam limiting device must be constructed in such a way that radiation leakage at 1 meter is less than 100 mrad in any one hour when the tube is operated at its leakage technique factor.

- The X-ray tube must have a visible exterior mark to indicate the focal spot location.

- The X-ray tube assembly must have adequate and proper filtration.

- The fluoroscopic exposure switch must be deadman type switch.

- The image intensifier and X-ray tube must be aligned with the patient prior to the initiation of a fluoroscopy procedure.

- Measured average KVp must be within ± 10% of the indicated or selected KVp.

- The radiation beam cannot be larger than the linear dimensions of the image intensifier.

- There must be interlock in place that X-rays cannot be produced if the image intensifier is not in place to intercept the entire primary radiation.

- During the procedure the KVp and mA must be continuously indicated.

- The variation in size and alignment of the X-ray field with image must be less than 3% of SID in any one direction and the total variation in all direction must be less than 4%.

- The source to skin distance (SSD) must be at least 30 cm. The greater the SSD, the lower is entrance exposure to patient for the same procedure. It also reduces image unsharpness and image magnification.

- The distance from the X-ray tube to the image intensifier (SID) should be minimized. Most fluoroscopy units are equipped with automatic brightness control (ABC); the ABC operations provide for automatic compensation so that patient entrance exposure increases with increase in the SID.

- The image intensifier should be brought as close as possible to patient. This will reduce entrance radiation exposure to the patient, more of the scatter radiation will be intercepted by the image intensifier, and images will be sharper.

- If possible pulsed fluoroscopy should be used instead of continuous fluoroscopy.

- Use of the freeze frame (last image hold) can reduce radiation exposure to the patient and the operator.

- Scatter to unshielded personnel at 1 foot from the patient is approximately 100 times lower than the entrance skin exposure to patient.

- Collimation must be used to limit the X-ray beam to the smallest area practicable and consistent with the objectives of the radiological examination. The total amount of radiation absorbed by the patient is proportional to exposure rate as measured at a point in the center of X-ray beam multiplied by the area of X-ray beam. Also, using the smallest possible X-ray field size can minimize scatter radiation to image intensifier and fluoroscope.

- For spot-film devices the total misalignment of edges of X-ray field with image receptor cannot be larger than 3% of the SID in any direction and the total misalignment in all directions can not be larger than
4% of the SID.

- As KVP increases the dose to the patient’s skin decreases. However, very high KVP reduces the image contrast for soft tissues.

- The dose is affected by the operating mode of the image intensifier. Typically dose increases with use of magnification mode. The patient receives less dose when the 9” mode of image intensifier collimated to 4.5” is used as opposed to the 4.5” mode.

- Scattered radiation has a non-uniform distribution around the patient. The highest intensity of scattered radiation is back-scattered from patient towards the source of radiation (X-ray tube). The scatter radiation is higher where the X-ray beam enters the patient than the area when the X-ray beam is leaves the patient.

- Minimize the use of cine. The dose to both the patient and the fluoroscoper is significantly higher when cine is utilized.

- Minimize fluoroscopic exposure by reducing the ON time of X-ray. Fluoroscopic time, of course, varies with different patients, the type of the examination, and the complexity of the clinical study.

- Operators should use the timing device to indicate a preset time, which will serve as a reminder to keep it as short as possible.

- For a system without high level control, the maximum exposure cannot exceed 10 roentgens per minute.

- The maximum exposure when high level control is activated can not exceed 20 roentgens per minute.

- Personnel must wear a dosimeter and shielding in the X-ray procedure room.

E. Mobile Diagnostic Units
Additional requirement for the mobile equipment:
- If possible, stand at least 2 meters away from the tube head and the patient. Distance is often the best possible protection from radiation.

- It is important that only individuals necessary for the diagnostic examination be in the vicinity. Other individuals who are required to remain in the room should wear protective clothing or should be located behind a protective shield.

- Mobile fluoroscopy units must have image intensification.

- Protective garments must be worn.

- The source to skin distance cannot be less than 30 centimeters.

- For capacitor discharge units, the radiation from the X-ray tube assembly when the X-ray switch is not in the ON position must be less than 2 mR/h at 5 cm from the diagnostic assembly with the collimation completely open.

- The technique chart must be posted at the unit.

F. Computed Tomography Units
- The X-ray tube housing assembly with the attached beam limiting device must be constructed in such a
way that radiation leakage at 1 meter is less than 100 mrad in any one hour when the tube is operated at its leakage technique factor.

- The operator must be able to terminate exposure during a scan, or series of scans for scanning times longer than 0.5 seconds. The termination of an exposure must only be made possible by the resetting of CT conditions of operation before the initiation of another scan.

- The unit must have a protective barrier for the operator to stand behind to make the exposure and to observe the patient during the exposure. There must be a system to allow for oral communication between operator and patient.

- The technique chart must be posted at the control panel.

- Only individuals whose presence is necessary should be in the CT X-ray room during exposures. All such individuals should be protected with leaded aprons and/or portable shields.

- The CT X-ray control and gantry must provide visual indication when the X-ray is produced. In addition, a signal audible to the operator shall indicate that exposure has terminated.

- The CT conditions of operation must be indicated prior to the initiation of a scan.

- The X-ray tube assembly must provide a minimum of 3.2 mm of aluminum equivalent filtration at 120 KVP.

- The measured average KVP must be within ± 10% of the indicated or selected KVP.

- The total variation in the indication of scan plane and laser indicator can not exceed 5 mm.

- The total variation in indicated and actual slice thickness must not exceed 2 mm.

- The variation in the CT image distance and actual distance measured cannot be greater than 5% for a distance larger than 100 mm.

- The CT X-ray system must be normalized to water.

- For a region of interest not larger than 100 mm$^2$, the mean CT number of water must be 0 ± 10.

- For the same region of interest, the variation in the mean CT number of water must not varied by more than the manufacturer specifications as algorithm, slice thickness or gantry location are varied.

- The noise in the CT number must not exceed manufacturer specifications.

- Performance evaluations for the CT system must include noise, contrast scale, mean CT number and special resolution.

- The result of the most recent performance evaluation and the information related to dates and frequency of this test must be posted on the control panel.

- The date of the latest radiation measurement and the location within the facility where the results of these tests may be obtained must be posted at the control panel.

- The information on the use of CT phantoms must be posted at the control panel.
4. QUALITY ASSURANCE PROGRAM

The quality assurance program will ensure that doses to patients are in accordance with the standards of good practice.

A. Reject-repeat analysis program

The analysis of the rejected radiographs provides information about the different aspects of radiological imaging. Analysis of data will help identify ways to improve efficiency and reduce cost, as well as reduce patient exposure by eliminating repeated exposure.

B. Film processors

Photographic film is a photosensitive materials and it is sensitive to heat, humidity, chemical contamination, mechanical stress and stray radiation.

- Film must be stored at temperature below 75°F.
- Open packages of film must be stored in areas with humidity between 40-60 percent and according to manufacturer guidelines.
- The darkroom must be kept clean and free of dust. Smoking, eating or drinking is not allowed in darkrooms. Ash from smoke produces artifact in cassettes. Darkrooms must be adequately illuminated with safelight. Safelight with appropriate filters must be used so that the produced light will not fog exposed radiographic film.
- Periodic darkroom fog evaluation should be performed.
- Each film processor should be tested daily for temperature, contrast, density, and speed. A graph of the results of daily measurements will show deviation from normal behavior. Corrective actions must be taken if any of these tests fall outside of the established operational range.
- Film crossover should be performed when there is a change in batch or types of film.
- Expired film should not be used.
- Film in darkrooms or in film storage areas should not be exposed to more than 0.2 mrad of stray radiation prior to development.
- Radiographic cassettes should be periodically cleaned.
- Screen-film contact should be periodically checked.

C. Viewboxes

The accuracy of the diagnosis and the efficiency of the interpreting physicians are influenced by the conditions under which the films are viewed. The luminance of the viewboxes as well as the ambient room illumination or the amount of light falling on the view box surface determines these conditions. View boxes provide a relatively high luminance level. The luminance of view box should be checked. For most diagnostic procedures Viewboxes with luminance levels of 1500 candela/m² are needed. Mammographic Viewboxes must have luminance levels of at least 3500 candela/m².

D. Mammography units

Mammography equipment is tested annually by a qualified diagnostic medical physicist as defined by Mammography Quality Standard Acts (MQSA) regulations. The annual test include evaluation of
• Mammographic unit assembly, the proper operation of locks and detents, image receptor holder assembly and compression paddle.

• Collimation system assembly, X-ray field, light field and compression paddle

• Evaluation of focal spot performance

• KVP accuracy and reproducibility

• Radiation beam quality assessment

• Automatic Exposure Control (AEC) System Performance and adequacy of phototimer compensation for change in KVP and breast thickness.

• Adequacy of density control function and uniformity of Screen

• Measurement of breast entrance exposure and calculation of average glandular dose.

• Evaluation of image quality and artifact.

In addition the following QC tests are performed by mammography QC technologists:

• Daily check of darkroom cleanliness

• Daily processor QC

• Screen cleaning (weekly)

• Weekly image of mammographic phantom

• Semiannual evaluation of dark room fog

• Semiannual test of film-screen contact

• Semiannual pressure check of compression paddle

• Quarterly analysis of repeat films

• Weekly check of view box and viewing conditions

• Quarterly analysis of fixer retention

The radiation safety characteristics of the machine must meet the FDA, ACR, PA State regulations.

E. Dental X-ray Unit

The dental equipment is tested annually or whenever a repair has been performed that require opening of the X-ray tube head assembly. This test is performed by a qualified expert. The annual test includes the test of the collimation system or field reducing devices, focal spot size, size and accuracy of the X-ray field, field alignment, and SID calibration. The X-ray generator performance is evaluated by testing the accuracy of the tube potential, timer, and the tube current linearity if applicable, and the reproducibility of the X-ray output. The quality of the X-ray beam is evaluated by checking the half value layer. Entrance Skin Exposures (ESE) are measured for typical patient examinations. The exposures are recorded and compared to National Evaluation of X-ray Trend (NEXT) data.

For modality that uses film-screen, the motion unsharpness can be reduced by using a high speed screen-film combination that is consistent with the objective of the examination. Expired film should not be used for any patient study. The radiation safety characteristics of the machine must meet the PA State regulations.

F. Radiographic X-ray units

Radiographic equipment is tested annually or whenever a repair has been performed that required opening of the X-ray tube head assembly. This test is performed by a qualified expert. The annual test includes the test
of the collimation system, focal spot size, accuracy of field size, X-ray field and field alignment, and SID calibration. The X-ray generator performance is evaluated by testing the accuracy of the tube potential, timer, and the tube current linearity, and the reproducibility of the X-ray output. In the absence of the mAs indicator, the phototimer response is evaluated. The quality of the X-ray beam is evaluated by checking the half value layer. ESE are measured for typical patient examinations. The exposures are recorded and compared to National Evaluation of X-ray Trend (NEXT) data.

The motion unsharpness due to long exposure time can be reduced by using a high speed screen-film combination. Fast screen-film combination requires less exposure to make an image and therefore less dose exposure to the patient. However, the speed must be consistent with the objective of the examination. Expired film should not be used for patient studies. The radiation safety characteristics of the machine must meet the PA State regulations.

G. Fluoroscopic X-ray units:
Fluoroscopic equipment is tested annually or whenever a repair has been performed that required opening of the X-ray tube head assembly. This test is performed by a qualified expert. The annual test includes the test of the collimation system, accuracy of field size, field alignment, and SID calibration. The X-ray generator performance is evaluated by testing the accuracy of the tube potential. The quality of the X-ray beam is evaluated by checking the half value layer. Measurement of exposure rate and scatter radiation from the unit under simulated patient conditions is performed. The quality of the image intensifier imaging system is evaluated by testing high- and low- contrast resolution. The effective focal spot size of the system and minimum SSD are measured. The ESE during cine procedures for invasive cardiology and radiology are evaluated. The radiation safety characteristics of the machine must meet the PA State regulations.

H. Computed tomographic X-ray units
CT equipment is tested annually or whenever a major repair has been performed. This test is performed by a qualified expert. The annual test includes the test of the resolution of the imaging system for high and low contrast, scan thickness, distance readout calibration, laser light alignment, noise, contrast scale and Mean CT number of water. Measurement of CTDI or MSDAD to calculate the patient dose with a proper CT chamber and phantom under simulated patient conditions and mR/mAs value must be determined for head and body technique. The X-ray generator performance is evaluated by testing the accuracy of the tube potential. The quality of the X-ray beam is evaluated by checking the half value layer.

In addition the performance evaluation of the CT system using the phantom that was provide by the manufacturer at an interval specified by the manufacturer that does not exceed 3 months must be performed. The performance evaluation includes checking the CT system noise, contrast scale, special resolution (low and high contrast) and Mean CT number of water. The acceptable tolerance for these factors must be listed. A qualified physicist must be contacted if any of these factors exceeded the listed tolerance level and use on patients must be limited to those uses permitted by established written instruction by the qualified physicist.

The radiation safety characteristics of the machine must meet the PA State regulations.

I. Inspection of protective garments
An annual inspection of the shielding garments, such as lead aprons, thyroid shield and lead gloves should be performed. This test must be performed by a trained technologist and if possible by use of fluoroscopy. Garments with holes larger than 3mm or tears larger than 30 mm in location that cover the sensitive organs must not be used.

J. Response to reported problems
All repairs on the units should be made as soon as possible. Repair documentation should be sent to the authorized personnel upon completion of the repairs.
LIST OF REFERENCES

This guide was written using information provided in the following publication:

National Council on radiation Protection and Measurements NCRP report No. 35. “Dental X-ray Protection”


National Council on radiation Protection and Measurements, NCRP report No. 102. “Medical X-ray, Electron Beam and Gamma-ray protection for energies up to 50 MeV (equipment design, performance and use)”

National Council on radiation Protection and Measurements, NCRP report No. 105. “Radiation Protection for Medical and Allied Health Personnel”

American Association of Physicists in Medicine, AAPM report NO. 53. “Radiation Information for Hospital Personnel”

United State Nuclear Regulatory Commission, NRC Technical Issues Papers TIP36, “Biological Effects of Radiation”