RADIATION WORK WITH PROTECTIVE LEAD APRONS

Preface

This policy covers several aspects involving the use of lead aprons as a protection against radiation from x-ray fluoroscopes.

Section I basically informs personnel **that at least 0.25 mm of lead equivalent shielding** is necessary to shield all personnel in a fluoroscopic room from patient scattered radiation. Also at least **0.50 mm of lead equivalent shielding** is required for any body part that may enter the direct radiation beam from the fluoroscopic x-ray tube. The latter is likely to occur if the patient is handled when the fluoroscopic x-ray beam is energized. Gonadal shielding of at least 0.25 mm lead must also be considered for the patient when it would not interfere with the examination itself.

Section II informs workers that personnel radiation dosimetry, while a requirement for some workers, is not required for all personnel who have to be within the fluoroscopic x-ray room. It is definitely required for personnel who are radiological technologists and anyone who would operate the fluoroscopic equipment. Individuals who work at distances greater than a meter from the patient are not required to wear radiation dosimetry. Personnel are required to take reasonable measures that reduce their radiation exposure. These include such measures as 1) minimizing the time they spend in areas proximal to the patient, 2) moving away from the primary beam and patient scattered radiation whenever possible and 3) making use of lead shields available for their use. Dosimeters to measure the dose of the fingers, wrists, ankles and feet are not required. If fluoroscopists must place their hands in the direct beam when palpating patients, they must wear lead gloves. The protection provided by the gloves will adequately protect their hands from exposure.

Section III describes basic techniques for relieving tension that develops in the spines of workers during long x-ray fluoroscopic procedures. It addresses issues regarding pre-existing back problems and describes the steps workers should take when experiencing lower-back problems during their general fluoroscopic work.

Section IV describes some of the types of lead aprons available and even special aprons designed to help relieve tension on the worker's back or otherwise accommodate workers suffering from lower-back problems.

Section V describes considerations involving purchase, replacement and repair of lead aprons

Section VI describes some of the requirements for the disposal of lead aprons

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I.	Radiation Protection Required in the Working Environment

Jefferson County's Radiological Safety Division is the Agency with the authority for controlling the use of X-rays in Jefferson County. UAB has developed and implemented a radiation protection program sufficient to ensure compliance with the Jefferson County regulations. UAB Administration has also adopted an ALARA philosophy with regard to the use of ionizing radiation. This philosophy, in its simplest form, means that we should strive to use procedures and engineering controls based on sound radiation protection principles to achieve occupational doses that are as low as are reasonably achievable.

The minimum requirements for the protection of workers and patients are addressed in Section E.3(b) of the Jefferson County Regulations Governing the Use of X-Rays. This section is entitled Administrative Controls. Pertinent requirements addressed in this section are as follows:

(a) Except for the patient, only the staff and the ancillary personnel required for the medical procedure or training shall be in the room during the radiation exposure,

(b) All individuals in the room at the time of the exposure shall be positioned such that no part of the body, including the extremities, not protected by 0.5 mm of lead equivalent will be struck by the useful beam unless protected by **0.5 mm of lead equivalent**.

(c) Staff and ancillary personnel shall be protected from the direct scatter radiation by protective aprons or whole body protective barriers **of not less than 0.25 mm of lead equivalent**.

(d) Provision must be given for the use of gonadal shielding for certain patients **of not less than 0.25 mm of lead equivalent** protection. Except for those cases where this requirement would interfere with the diagnostic procedure, this is for patients who have not passed the reproductive age at the time of any radiographic exposure in which their gonads are in the direct useful beam,

(e) Patients must be given lead gloves if they must hold x-ray film. **Human holders are allowed and must be provided with adequate protection as well 0.5 mm lead**.

The minimum requirement is 0.25 mm of lead equivalent shielding

In the cardiac catheterization laboratory, patients are not required to hold film or place any part of their body in the beam other than the area of clinical interest. Also the gonads of the patient are not in the direct beam. So no protective shielding for the patient is required. In addition, workers, including nurses are not required to hold patients such that any part of their body would be exposed to the direct and useful x-ray beam; therefore, **0.5 mm of lead equivalent shielding is unnecessary** for them. In fact, the only radiation to which they are exposed is the radiation that is scattered from the patient. So, **the minimum requirement is at least 0.25 mm of lead equivalent shielding to protect the major portion of their body**.

It is recognized that it is difficult to provide radiation protection for the head of the body without utilizing a lead equivalent protective, facemask. The lens of the eyes is more resistant and has a higher threshold to the somatic effects of radiation than the whole body. So the annual limit is three times higher than the limit for whole body radiation. Therefore, it is not a requirement for a worker to wear protective shielding for the eyes.

The voltage applied to the x-ray tubes of cardiac catheterization equipment is, for the most part, in the range from 80 kVp to 90 kVp. While the safety factor for 0.25 mm lead is somewhere in the range of **15 to 20**, the marginal protection in the use of an additional 0.25 mm lead, giving a total of 0.50 mm lead, is a factor of only three.

II.   The Use of Personnel Radiation Dosimeters to Monitor Exposures

It should be pointed out that while lead aprons provide protection of the body from radiation, radiation monitors do not. Wearing a lead apron does not necessitate having to wear a dosimeter. Radiation dosimeters are used to evaluate the doses that individuals receive during their radiation work. Sometimes these evaluations show that the dosimeters are required and sometimes they show that they are not. Once it has been established that radiation dosimeters are unnecessary for a particular type of radiation work conducted a distance from the fluoroscope, then they are not required. These decisions may be based either on a history of prior dosimetry information or on exposure measurements and/or calculations. Such evaluations may find that radiation dosimetry is required only for certain individuals working within a radiation room, and these are the individuals that are closer than one meter from the point where the primary beam is scattered from the patient. While the Jefferson County regulations require either lead shielding or lead aprons to be worn within a room where fluoroscopic work is conducted, this does not necessarily mean that either a whole body dosimeter or an extremity dosimeter is required as well. The threshold dose requirement for having to wear radiation dosimeters is usually 10% of the annual limit to the portion of the body exposed. Individuals who operate fluoroscopic equipment or portable x-ray equipment are required to wear radiation dosimeters to monitor whole body radiation. Most diagnostic fluoroscopic times are not very lengthy and involve the use of normal or low-level controls. When high-level cine controls are utilized, these are generally less than 5 or 6 seconds. During these exposures, personnel should move back as far as they can reasonably due so and/or seek the shelter of a lead shield. If they cannot do this, then the personnel monitor would be required. Also during therapeutic procedures involving substantial fluoroscopic time, then personnel monitors are required.

When personnel radiation dosimeters are required, then they must be worn at the collar level and outside the lead apron. If the dosimeter is not worn at the vertical midline of the collar, it should be worn on the side of the body closest to the radiation source (usually the patient). The dosimeter should not be clipped to shirtsleeves. For a pregnant worker, an additional badge is required to be worn beneath the lead apron over the pelvic area.

III.   Using Good Body Mechanics During Fluoroscopic Procedures

Wearing a protective apron would undoubtedly compound any back problems a fluoroscopist may have, particularly if preventive measures are not taken. For workers who have preexisting back conditions, they should see their supervisors for reasonable accommodations in terms of alleviating their back problems. It should be noted that due to the nature of the work, it might not be possible to do this.   Good body mechanics and the all-around posture used by fluoroscopists during x-ray fluoroscopy are all important in preserving their back health and preventing back injury. Several areas merit special attention. If the patient table is too low, the fluoroscopist has to lean forward toward the patient to do the procedure. This adds more stress on the worker's spine. The patient table should be raised to minimize this problem. Sometimes equipment constraints require the patient carriage to be higher (i.e., bi-plane use of two x-ray units) and no further correction is needed. With the table at the proper height and using good body mechanics, only very slight leaning would occur. Any leaning that is necessary should take place at short intervals. The majority of the time, the fluoroscopist should be able to stand erect. The image

screen should also be close and large enough to the fluoroscopic to be clearly visible. This would not only help prevent any back injury, it would also reduce eyestrain. Lastly, it is important for someone other than the fluoroscopist to make observations concerning the body mechanics being utilized. If all of these approaches have been taken and the fluoroscopist continues to have back problems, then he/she should be evaluated by an occupational medicine physician as to what further measures should be taken. The evaluation might demonstrate that a back brace may be necessary or even that a protective apron with special support structures might help. A back brace, if prescribed, could also be a reminder to a fluoroscopist to be more careful in the posture maintained during a procedure.

IV.   Specially Designed Lead Aprons

Using two-piece protective clothing (vest and skirt) removes half the weight from the spine. The transfer of this weight gives no more compression to the girdle joints of the body. Less weight to the spine, particularly in the front of the body reduces the lordosic curvature and stress on the spine. If the weight is more balanced between the front and the back of the spine, the lordosic curvature and stress on the spine will be reduced.

Adding an additional 0.25 mm of lead equivalent protection above the minimum requirement to the vest will double the weight and stress on the spine, while providing only a marginal increase in radiation protection. Any additional weight that would impair an individual's overall efficiency may lead to no advantage to the individual's overall health.

Lead has been found to be the best shield for the protection against diagnostic x-rays. It has the highest atomic number of any element that is nonradioactive*. Given the fact that one is limited to this maximum atomic number (82) in choosing from the various elements, the density thickness of a lead apron then becomes the most important parameter in providing protection from diagnostic x-rays; however, there are a few elements that are less dense that offer similar protection and this is due to their K-Edge absorption characteristics at energies less than 40 KeV. Among these are barium and iodine. Combinations of these few elements with nonradioactive lead isotopes may provide the same equivalent protection as lead by itself and reduce the overall weight of the protective apron. This weight reduction might be as much as 20 percent.

Special plastic struts in protective aprons may also reduce the stress directly atop the shoulders of workers. This feature works best when the aprons are tightly belted around the waist.

When considering the use of any special aprons, consideration should be given as to the time that is needed for a particular procedure. A single piece apron may be more appropriate for a short procedure. While there are some advantages to using two-piece protective aprons, there are some problems associated with their use. It does taken a little longer to put them on and there is more difficulty in keeping a set together for the same user. One could keep the one-piece aprons for quick work and the two-piece ones for longer studies. Sufficient overlap (at least several inches of overlap) between the vest and the skirt is necessary to protect the portions of the body between the vest and the skirt. This will often depend on the size of the worker and should be considered when ordering these aprons. A worker has more freedom of movement (i.e., rotation along the body's longitudinal axis and bending over at the waist or from side to side) when wearing a two-piece apron. Additional support from the weight of an apron may be provided by the design of the apron itself, including a back brace if necessary.

V.   Criteria for Purchase, Replacement, Repair

The type, size and thickness of lead apron used in occupational radiation environments will often depend on the following:

      a.   The Regulatory Requirements,
      b.   The proximity of the individual to the source of radiation,
      c.   The radiation workload (proportional to level of radiation and time in radiation field),
      d.   The motions and activities of the individual within the radiation room, and
      e.   The physical characteristics and health of the individual.

When the majority of the time a worker faces the radiation source, then the protection provided by the front of the apron is the most important issue. If, however, a worker moves about the room often turning the body so that their back faces the radiation source, then a wrap-around apron is more important for them. When considering aprons for a number of personnel who work within a room where a fluoroscope is used, then a sufficient number should be made available for the various tasks performed within this room.

When purchasing lead aprons from a vendor, try to get some assurance that there are no radioactive materials within the lead. There are some isotopes of lead and bismuth that are radioactive and might be present in some of the lead used to make aprons. When aprons are received, they should be checked with solid radiation scintillation counters to make certain that they are not radioactive. Next they should be checked against the order for the proper size and thickness of the apron. This can often be checked by weighing them or checking their shielding capabilities. Then before use, they should be checked to make certain that there are no flaws and loss of integrity in the shielding provided by the apron.

Lead aprons should be checked fluoroscopically at least on an annual basis for their shielding integrity. Whether to reject an apron from flaws that occur depends on the location, areal size and the number of flaws. It is best to keep the number of flaws to a minimum. If a worker finds that they have been working with an apron that has a number of critical flaws, then an investigative evaluation of the possible dose received would have to be performed. A measure to prevent from having to perform such evaluations would be to use rejection criteria when flaws in aprons are discovered.

Possible Rejection Criteria

A common figure deemed reasonable in the nuclear industry to protect individuals from safety defects is $1000 per 100 millirem. The rejection criteria for flawed lead aprons would be product of this cost and area of the apron divided by the cost per unit effective dose averted. In addition, there should be some emphasis regarding the fraction of exposure received by the particular area of apron (side, back or front) where the defects occur, the critical organ being exposed and its depth within the worker's body. Generally the whole body gets a weighting factor of 1.0 from external exposure, but an effective dose determination can be estimated based on the latest ICRP Principles. We have to remember that there are some portions of the whole body that are not covered by the lead apron. These are the head and a portion of the arm from the trunk to the elbows. So this would all have to be placed into perspective.

The evaluation would start out by considering only those portions of the body protected by the particular apron. The formula that might be used would be as follows:

$$ADE = w_t D [(f(A-a) + a]$$

ADE is the cumulative dose summed over the area of the body shielded by the lead apron.

w_t is the body-weighting factor assigned by the latest ICRP Protection Standards

D is the unattenuated dose equivalent.

f is the transmission factor (the radiation that gets through a lead apron of good integrity)

A is the effective cross-sectional area of the lead apron

a is the effective cross-sectional area of the defect(s) in the lead apron

The dose equivalent is the absorbed energy per mass. At a one-centimeter depth, we are interested in the average energy absorbed per square centimeter. Upon dividing the ADE by the frontal area A of the body supposedly protected by the lead apron, we get

$$DE = w_t D [(f(1-a/A) + a/A]$$

The additional dose equivalent that an individual would get if the apron from an area defect were

$$dDE = w_t D (a/A) (1 - f)$$

The incremental dose would occur over the wear period until the apron defect is repaired or a new apron of good integrity is obtained. For reasonable accurate information on the parameters involved, some reasonable estimates may be made for incremental doses from defects of various sizes.

Some fairly reasonable values for the parameters involved are as follows:

1. The life expectancy for a lead apron is assumed to be 10 years,
2. Defects are assumed to appear in 5 years,
3. A fluoroscopist proximal to patient may receive as high as 2000 millirems per year and 10,000 millirems over a five year period,
4. An effective area of body coverage is assumed to be 4000 cm^2.
5. A typical transmission factor for a lead apron is assumed to be one-twentieth (1/20), and
6. The external body weighting factor, w_t, is assumed to be no less than one.

Using the above values in the formula for dDE, we find that the incremental dose is 95 a / A per square centimeter of defect. In other words, the additional dose would be **2.4 millirems for a 1 cm^2 (100 mm^2) defect in an effective 4000 cm^2 area of body coverage, if not corrected over a five-year period**.

Using an ALARA criteria of $10,000 per rem and an average apron cost of $400 (providing body coverage of 4000 cm^2), the rejection criteria would be an incremental dose of 0.04 rem and the size of the defect would be 3.4 cm^2. This uses a weighting factor of 1.00 for the whole body. The defect may be over an area of the body, which has a different weighting factor. If one employs weighting factors less than one, it is seen that the allowable size of the defect would become large by a factor that is the reciprocal of the weighting factor. Rather than allow for larger sized defects, the weighting factors should be used to estimate the dose to the particular tissue of concern.

The most appropriate and inclusive tissue weighting factors (for the relative radio sensitivity of the tissue) to be used would be the most recent estimates of the International Council on Radiation Protection (ICRP 1991). These take into account the more recent estimates of mortality risks from cancer and the risk of severe hereditary effects (in all generations) for the irradiated tissues and organs, and they also include the risk of nonfatal cancer and the length of life lost if the effect occurs. These tissue-weighting factors are shown below:

Tissue	Weighting Factor	Measured Dose (mrem)	Apportioned Dose (mrem)
Gonads	0.20	1	0.104
Active bone marrow	0.12	1	0.971
Colon	0.12	1	1.172
Lungs	0.12	2	1.194
Stomach	0.12	1	0.023
Bladder	0.05	1	0.011
Breasts	0.05	3	0.258
Esophagus	0.05	2	0.000
Liver	0.05	1	0.223
Thyroid	0.05	70	0.011
Bone surfaces	0.01	1	0.121
Skin	0.01	3	1.000
Remainder[a]	0.05	10	0.000

Total Effective Whole Body Dose=>   5.088

[a] The remainder is composed of the following additional tissues and organs: adrenals, brain, upper large intestine, small intestine, kidneys, muscles, pancreas, spleen, thymus and uterus.

Also shown in the table above are doses measured over the various tissues from fluoroscopy with effective energies of 30 keV, also employing a collar dosimeter measuring 100 millirem worn outside an apron with 0.25 mm lead equivalent thickness. These measurements were an average of experimental readings for monitors placed over the various tissues.

The deep dose to body tissue is the one that is most interested in as its annual limit (5 rems). It is measured at a depth of one centimeter within the tissues of the body for external beams, so some of the deeper organs would receive lesser amounts of radiation.

Note also in the Table above the effective doses apportioned to each of the body tissues considered to be a part of the whole body. The **total effective dose for the body is 5.1 millirem**, when all of the following are considered: the attenuation of the beam to a one centimeter depth, the area size of the tissues facing the beam and the above tissue weighting factors. This is in agreement with the National Council on Radiation Protection and Measurements in their (NCRP

Report Number 122) report entitled "Use of Personal Monitors To estimate Effective Dose Dquivalent and Effective Dose to Workers for External Exposure to Low-LET Radiation."

As just shown, there are some good methodologies available for determining doses to various tissues from readings from personnel radiation dosimeters. This information can be used as a preventive measure to minimize doses from defective aprons. We should keep in mind the ALARA concept – keep these doses as low as reasonably achievable. When defects occur, they should be marked and evaluated as to the extent of the hazard with further use. Workers may be concerned if the defective apron is one that they have been wearing for years. When these occasions arise, they should be instructed as to estimate increases based on their location and size. The Radiation Safety Officer is available for consult in these areas, as well as a number of medical physicists in the Diagnostic Radiology Department.

V.   Disposal of Lead Aprons

When a number of aprons begin to get more and larger defects, then they should be collected and either repaired or disposed of. When they are considered not fit for repair, the lead within the aprons presents a disposal problem. A group of lead aprons can be boxed up and easily manifested for disposal. One merely completes the Chemical Waste Manifest. An example of a completed chemical manifest is attached. The more specific items which have to be completed is as follows:

Item
1	Generator Name	John Doe, Director
2	Generator Number	Not Applicable
7	Person Completing Manifest	Frank Worker
8	Chemical Hazard Code	11 Tx
9	Chemical Compound	10 at 5 lbs each
10	%	Not Applicable
11	Physical Form	Solid
12	"Write" Lbs.	50
13	# of Containers	1
14	Type	Box

The director of the department or division should sign the certification.

∗ ^{209}Bi is nonradioactive and apparently the only stable element of bismuth, and there may be a problem of getting pure bismuth.