AAPM REPORT NO. 25

PROTOCOLS FOR THE RADIATION SAFETY SURVEYS OF DIAGNOSTIC RADIOLOGICAL EQUIPMENT

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A REPORT OF THE DIAGNOSTIC X-RAY IMAGING COMMITTEE TASKGROUP

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Introduction and General Clarifications

Introduction

The task group: "Protocols on The Radiation Safety Survey of Diagnostic Radiological Equipment" was formed by the Diagnostic X-ray Imaging Committee to provide a unified approach to radiation surveys of x-ray imaging equipment conducted by radiologic physicists. Stationary and mobile radiographic, fluoroscopic, dental x-ray, and mammographic equipment are covered. Due to its specialized requirements computed tomography (CT) equipment is not.

The protocols described are intended to verify compliance with the radiation safety regulations outlined in the Code of Federal Regulations and the majority of state agencies. State regulations are not uniform from state to state, and federal regulations are revised periodically. Therefore, it is recommended that the appropriate state and federal radiation control regulations be reviewed prior to conducting surveys. Also, in view of the complexity and cost of x-ray equipment, advice should be solicited and/or the operator's manual referred to when the surveyor is not familiar with a given type of equipment.

The objective of the report is to achieve a unified approach to routine radiation surveys of x-ray imaging equipment and was reflected in the task group's membership, which included:

(a) Representatives from regulatory agencies,
(b) Medical (diagnostic radiologic) physicists, and
(c) Medical health physicists.

The CRCPD (Conference of Radiation Control Program Directors, Inc.) has published radiation survey protocols for use by state-employed inspectors which may be useful in certain situations.

General Clarifications

"Good Radiological Practices" set forth by the Joint Commission on Accreditation of Hospitals (JCAH) require that patients and personnel are protected from radiation, electrical, and mechanical hazards associated with x-ray equipment and that quality images are produced. The radiation survey protocols described in this report address only the radiation hazards question.

To assist hospitals in their quality assurance efforts, most diagnostic radiologic physicists also:

1. Check the x-ray generator calibration (kV, mAs linearity, phototimer, etc.),

2. Determine typical patient exposure levels for standard radiographic exams and fluoroscopy,
3. Assess fluoroscopic contrast and spatial resolution,
4. Evaluate radiographic image quality, and
5. Review processor quality control procedures.

These quality assurance efforts are beyond the scope of this report.

The performance levels cited from Reference 1 do not apply to non-certified components. In the absence of specific state regulations for these components, certified component performance levels should be considered "ideal" goals for this type of equipment, but may not be achievable due to design limitations.

In addition to survey data, records should also be maintained on:

(a) the manufacturer, model number, and serial number of the transformer/generator and control console,
(b) the manufacturer, model type and serial numbers of the x-ray tube housing and insert,
(c) the model type and the serial number of the collimator, and
(d) the manufacturer, model type and serial number of the x-ray image intensifier.

Outlines of these records and survey data are at the end of each "part" of this report.

Unless specifically noted in the text or outline, each parameter should be checked at least annually or after machine repairs or adjustments (e.g., x-ray tube replacement) which could affect performance. Heavily used equipment may require more frequent (semi-annual) checks.

Measurements of parameters such as the half-value layer (HVL), the source-to-image receptor distance (SID), etc. that are common to all four radiological systems are discussed in detail in Part I -- Medical Radiographic Installations. Recommended modifications in the measurement methods for unique types of radiological equipment are listed in the section where the unique type of equipment is discussed.

Part I: Medical Radiographic Installations

I-l. Introduction

Pages 19-21 contain a checklist of the physical parameters to be evaluated and the information pertinent to the radiation protection survey of radiographic instal-lations. The record keeping information identified in the checklist normally has practical value in identifying the radiographic unit under evaluation. If information concerning the certification status of the unit or warning labels affixed to the control panel, etc., is desired, additional space should be provided on the form developed by the radiologic physicist.

I-2. System Information

Items A-D of Part I-2 of the checklist are "record keeping' items to identify the survey of a specific room in an institution and the date the survey is conducted. The generator/control manufacturer, model type or number, and serial number should be recorded. The model type may be needed to verify technical specifications of the unit, such as

(a) Single phase or three phase,
(b) Falling load and/or constant load,
(c) Minimum switching time, etc.

The maximum tube potential and the maximum tube current of the generator are useful in setting up a radiographic technique chart for various examinations as well as for radiation protection considerations when required. Depending on the specific needs of the hospital, the assumed "maximum tube potential and current" may be the maximum technique factors employed in the radiographic examination room.

The model numbers of the x-ray tube insert and housing allow the identification of thermal characteristics of the x-ray tube. The serial number of an x-ray tube is important since x-ray tubes are replaced upon failure. The radiation output varies from one x-ray tube to another especially when the comparison is made between an old and new x-ray tube. The nominal focal spot sizes identified by the manufacturer, not the actual measured sizes, should be recorded. Any added filtration in the x-ray beam designed to be selected by the operator should be recorded since it affects the machine's exposure rate.

I-3. Beam on Controls and Indicators

Verify the availability of a positive indicator of x-ray production when the x-ray tube is energized, such as:

(a) mA-Meter,
(b) X-ray "on" light, and/or
(c) Audible signal during or at end of exposure.

Test their function by making x-ray exposures. Any of these three warning systems which are provided should be functioning. The x-ray exposure switch should be a deadman type switch; the exposure must terminate when pressure on the switch is released. This can only be verified on a radiographic tube if a l-2 second exposure time is set to allow the operator time to release the switch prior to termination of the exposure by the timer. (When conducting this test avoid excessive tube loading.) A deadman switch is not used nor required in conjunction with rapid film changers; a separate switch is provided to stop the exposure series. Unsteady pressure on a deadman switch in this application could prematurely terminate the exposure series after the injection of contrast media.

If the exposure switch is attached to a cord, the cord or switch should be fastened to the control console or be short enough to prevent the radiographer from extending any part of his/her body outside the protective barrier. If the exposure switch is a built-in type, the control panel should be installed so that the radiographer is confined behind the protective barrier.

For a mobile/portable x-ray unit, the radiographer must be able to stand at least 6 feet away from the x-ray tube/beam during the actual exposure to minimize any scattered radiation reaching him/her. This normally is accomplished by attaching the exposure switch to the unit with at least a six foot long cord.

I-4. Shielding Devices

Lead or Lead equivalent protective aprons and gloves of at least 0.25 mm Pb (Reference 12) should be readily available for the protection of occupationally exposed personnel or parents of children in the procedure room during exposures. Appropriate gonadal shields should be present without exception for use with children and patients under forty-five. At least one apron and gonadal shields should be kept with each mobile unit. Other appropriate shielding devices should be readily available for use in fluoroscopic and angiographic facilities.

The surveyor should verify the presence and use of shielding devices. The surveyor should check or monitor the checking of protective apparel. The shielding apparel should be examined fluoroscopically. The results should be documented as required by the JCAH. These checks should be completed at least annually.

I-5. The Source-to-Image Receptor Distance

Most general radiographic units have a variable SID (source-to-image receptor distance). Head units often have a fixed 32" (81 cm) or 36" (91 cm) SID. Chest units usually have a fixed SID of 72" (180 cm). On variable SID units, the SID indicator should indicate the distance between the focal spot and the film cassette in the cassette holder in the table or on the wall.

Four basic types of SID indicators are available. The first type is interfaced with the telescopic motion of the x-ray tube hanger assembly; the SID distance is displayed on the tube hanger carriage or on the x-ray tube positioning handle. The second-type of indicator is a linear scale or single marks labeled 40" (100 cm), 72" (180 cm), etc., attached to the telescopic support arm. A magnetic or a mechanical lock/detent is the third type of indicator. A marking on the overhead tube rail and or a detent should be provided for all wall cassette holders.

A tape measure is the fourth type of SID indicator. It should be available to determine the SID whenever the film cassette is placed in locations other than the table or wall cassette holder.

The indicated SID on any and all of the types employed on a unit should be within 2% of the measured SID (Reference #l).

The range of SIDs used should be within the focal distance range of the grid. For example, if a wall cassette holder with a 72" (180 cm) focused grid designed for chest imaging is used for 40" (100 cm) upright abdomens, grid cut off occurs which needlessly increases patient exposure,

I-5-A. Fixed Radiographic Units

To evaluate any of the above SID indicator accuracies, the location of the focal spot must be known. On some x-ray tube housings, the focal spot location is marked with a dot or a line at the factory. Thus the SID indicator accuracy can be determined by direct measurement,

If the focal spot location is not marked, triangulation can be used to locate it. Several simple

devices have been developed to expedite this. Hendee and Rossi, for example, employ a plastic cylinder for measuring SID (Reference #3). Localization of the focal spots on tubes should be performed as part of acceptance testing of newly installed x-ray tubes. A repeat of this measurement usually is not necessary until the x-ray tube is replaced.

i-5-B. Mobile/Portable Unit

For (non-dental) mobile or portable x-ray units the minimum x-ray source-to-skin distance (SSD) shall be no less than 12" (30 cm) (Reference #1). This can be measured directly with a tape measure provided the location of the focal spot is known.

I-6. Radiation Beam Restrictors and Light Localizers

This section describes the evaluation of collimators. These devices restrict the x-ray beam and normally use a light source and mirror arrangement to indicate the direction and extent of the x-ray field. The following parameters need to be evaluated:

(a) Congruence (alignment and size) of x-ray and light localization fields.
(b) Alignment of the central ray and the center of the image receptor.
(c) Agreement of the collimator dial field size indication and the actual x-ray field size.
(d) Agreement of x-ray field size and image receptor size on units equipped with Positive Beam Limiting (PBL) collimators.

I-6-A-c. X-ray/Light Field Congruence, X-ray Field/Image Receptor Centering, and Numerical Indicator Accuracy

The first three collimator parameters listed in Section I-6 (a-c) can be evaluated at the table using two radiographs.

1) Align the x-ray tube assembly to the center of the table or wall cassette holder at an SID that is clinically used. Most units are equipped with a light mounted on the x-ray tube support assembly to indicate when the radiation field is centered.
2) Center a 35 x 43 cm (14 x 17") cassette with film in the cassette holder.

3) Set a standard x-ray field size, 18 x 24 cm (8 x 10"), using the appropriate numerical indicator scale on the collimator.
4) Turn on the collimator light field and place radiopaque markers on the table top to delineate the edges of the light field.
5) Expose the cassette with a technique that results in an optical density range of l-l.4 on the film.
6) Open collimator blades and without moving the markers or cassette make a second exposure using l/5 the mAs used in step 5. This produces an image of the opaque markers.
7) Process the exposed film.
8) Repeat steps 2-7 using a larger x-ray field size, 30 x 35 cm (11 x 14").

The two field size evaluation is necessary since the collimator blades on most units do not move in a linear manner. Any locks routinely used during this test which do not hold properly should be noted in the "Recommendations and Suggestions" at the end of the survey report.

X-ray/Light Field Congruence: I-6(a)

The size of the delineated light field and the size of the x-ray field on the exposed radiographs should agree within 2% of the SID (Reference #l). The shift between the centers of the light field and x-ray field should also be no greater than 2X of the SID (Reference #l). Both x-ray films should be evaluated. This parameter should be measured at least annually or after repairs which involve the removal of the collimator from the x-ray tube housing.

After the x-ray/light field congruence at the table cassette holder has been verified, the light field of the collimator may be used to verify the alignment of the "x-ray field" and center line of any wall mounted cassette holders within the room.

X-ray Field/Image Receptor Alignment: I-6(b)

Draw two sets of diagonals on each radiograph. One set should connect the corners of the x-ray field on each radiograph; this represents the x-ray field center. The other set should be drawn to the corners of the x-ray film; this indicates the center of the Bucky tray. The cross points of each set of diagonals should not be separated by more than 2% of the SID (Reference #1). This parameter should be evaluated at least annually or after any repair which could affect the alignment light

on the x-ray tube assembly.

X-ray Field/Numerical Indicator Size: I-6(c)

Measure the length and width of the x-ray field on each film. These dimensions should agree with the numerical values originally set in step 3 above to within 2% of the SID (Reference #l). Most units have more than one numerical indicator scale. Each of these scales references a specific SID. The units displayed on the scales (metric vs English) should match the units used to size the typically used cassettes. This parameter should be checked-at least annually or after repairs to the collimator blade assembly or dial indicator assembly.

Other Test Methods

Hendee and Rossi (Reference #3) and Gray et al. (Reference #4) have described similar collimator tests. The X-ray Field/Image Receptor Alignment can also be evaluated by closing one pair of the collimator blades to obtain a slit beam and making an exposure. Prior to moving the cassette, a second exposure is made with the opposing pair of collimator blades now open and the original pair closed. This double exposure technique produces a radiographic cross hair which indicates the center of the x-ray field.

The X-ray/Light Field Congruence of the collimator can also be measured without exposing x-ray film if film processing is unavailable. Four fluorescent strips (2 x 10") with appropriate reticule lines drawn in the lengthwise direction can be used. The lines are placed at the edge of the collimator light field. This method is faster than the above method, but may require an observer at table side to view the fluorescent emission during the radiographic exposure. (Appropriate shielding should be used.) A misalignment of l/8" can be detected depending on how the reticule lines are drawn on the fluorescent strips. With care one can also directly measure the distance between the reticule lines to check the numerical field accuracy.

I-6-D. Positive Beam Limitation (PBL) Collimators

Both PBL and manual collimators must be tested according to Section I-6-A-C. In addition, PBL collimators must confine the radiation beam size to the size of the image receptor. The automatic setting of the x-ray field size should also be accurate for any distance between the x-ray tube focal spot and cassette which is within the SID range of the PBL system.

Three different test methods which require no special instrumentation are described below.

Test Method I

1) Place the collimator in automatic mode.
2) Center a small cassette, 18 x 24 cm (8 x 10"), in the cassette tray.
3) Center a larger cassette on the table top.
4) Make an exposure.
5) Process the film. If the x-ray field size exceeds the film size in the cassette tray, use triangulation and the radiograph from the table top to determine the actual x-ray field size at the cassette tray.
6) Repeat steps 2-5 with the cassettes rotated 90 degrees in the cassette tray and on the table top.
7) Repeat steps 2-6 with a larger cassette in the cassette tray.

Test Method II

1) Place the collimator in automatic mode.
2) Center a small cassette 18 x 24 cm (8 x 10") in the cassette tray.
3) Disable the automatic PBL feature.
4) Remove the small cassette and place a larger cassette with film in the cassette tray.
5) Make an exposure and measure the x-ray field size on the film.
6) Repeat steps l-5 with the two cassettes rotated 90 degrees in the cassette tray. Repeat steps 1-6 with a larger cassette'
7) 30 x 35 cm (11 x 14") in cassette tray initially.

Test Method III

Since the Numerical Indicator accuracy was verified in I-6-A-C, these indicators can be used to verify PBL sizing.

1) Place the collimator in automatic mode.
2) Center a small cassette, 18 x 24 cm (8 x 10")) in the cassette tray.
3) Record the dimensions of the x-ray field from the numerical indicators.
4) Repeat steps l-3 with cassette rotated 90 degrees in the cassette tray.
5) Repeat steps l-4 with a larger cassette, 30 x 35 cm (11 x 14") in the cassette tray.

****

Caution: Some PBL collimators do not have a key designed to-disable their automatic sizing as required in step 3 of Method II. If this key is not provided and the automatic collimation feature cannot be readily disabled, method I or III must be used. Method I has the same precision, but less accuracy than Method II. Method III is both less precise and less accurate than Method II.

****

Regardless which method is used, the PBL sizing evaluation should be completed by placing the appropriate size cassettes in each cassette holder (eg. table, wall unit, other, etc.) which is interfaced to the PBL collimator. If any of these cassette holders are used at more than one SID, the PBL sizing for each commonly used SID should be checked.

The above methods cannot evaluate the PBL sizing for a 35 cm x 43 cm cassette without additional effort. Special PBL testing devices have been fabricated to address this and the numerous films which must be made. Lin, Kriz and Storzum (Reference #5) have described one device. Hendee and Rossi (Reference #3) and Gray et. al. (Reference #4) describe test methods similar to Method I.

The measured length or width of the x-ray field in the plane of the image receptor compared to the length or width respectively of the film in the cassette tray must agree to within 3% of the SID used. In addition, the absolute value of the sum of the length and width differences must not exceed 4% of the SID (Reference #l).

If the collimator is designed to allow the operator to override the PBL function, a key must be provided for this function. When the PBL function is overridden, the collimator must not allow removal of the key (Reference #1).

PBL collimators allow the operator to manually reduce the x-ray field size with respect to the image receptor in the cassette holder without using the override key, When this is done, the collimator should revert to the normal PBL mode when the cassette or SID is changed (Reference #l). Both functions should be checked.

Most units are designed to bypass the PBL function when the central x-ray is not perpendicular to the image receptor. As above, the collimator should revert to the normal PBL mode when the central ray is realigned perpendicular to the image receptor. This function should also be checked.

Some units are equipped with semi-automatic PBL collimators which do not automatically adjust the x-ray field size to the image receptor size. Instead, they

lock out exposures until the operator has manually adjusted the x-ray field to be smaller or equal to the size of the image receptor.

The function and sizing accuracy of the PBL should be checked at least annually or after any repairs to the PBL sensors in the cassette holder, drive motors in the collimator, or electronics of the PBL.

I-7. Primary Radiation Beam Characteristics

The penetrating quality of an x-ray beam is characterized by its half value layer (HVL). Undesirable low energy x-rays are edliminated from the beam by adding a filter which increases the HVL. Minimum half-value layers are specified in Reference #1. These specifications are based on recommendations for single phase generators found in Reference #2. The minimum required half value layers for diagnostic x-ray equipment are listed in Table I below (Reference #l).

The minimum HVL requirements can be met if the equipment is installed with the proper amount of filtration in the x-ray tube housing and collimator. The total equivalent Aluminum filtrations that will meet the minimum HVL requirements of Table I are listed in Table II (Reference #2).

No maximum total Aluminum filtration values are established. However, excessive filtration needlessly reduces the x-ray intensity with little gain in the effective beam energy and possible shortened x-ray tube life.

The HVL is a function of x-ray tube age (use), the tube voltage waveform, and the kVp. As the x-ray tube ages, the target's surface pits and becomes rough which increases the inherent filtration of the tube. Therefore, if the kV calibration of the generator and the added filtration remain constant during the lifetime of the tube, the HVL will increase and the radiation output will decrease. Thus, a modest change in HVL from one survey to the next does not necessarily mean that the kV calibration has changed.

The values for minimum HVL in Table I under the "Other X-ray systems" heading for the kVp range of 30-50 apply to dedicated mammographic units (Reference #6). The radiologic physicist should verify that Molybdenum added filtration is used with Molybdenum anode mammographic x-ray tubes if the machine allows the operator to choose,

Materials other than Aluminum (Copper, Molybdenum, and rare earth elements), or specialty filters (trough filters, and wedge filters) are occasionally used. If such a filter is not permanent, it must be removed during

the HVL measurement.

The test protocols of the following two sections describe methods to measure the HVL to determine compliance with minimum filtration requirements. Since the HVL is a function of the actual high voltage applied to the x-ray tube, the protocols assume the unit's kV calibration is correct. If such is not the case, the

Table I. Minimum HVL Requirement

Designed Operating Potential (kVp)	Measured Operating Potential (kVp)	Minimum HVL (mm of Al)	
		*Dental	Other X-ray Systems
Below 51 kVp	30	1.5	0.3
	40	1.5	0.4
	50	1.5	0.5
51 to 70	51	1.5	1.2
	60	1.5	1.3
	70	1.5	1.5
Above 70	71	2.1	2.1
	80	2.3	2.3
	90	2.5	2.5
	100	2.7	2.7
	110	3.0	3.0
	120	3.2	3.2
	130	3.5	3.5
	140	3.8	3.8
	150	4.1	4.1

*Manufactured after December 1, 1980 and Designed with Intraoral Image Receptors

Table II. Minimum Total Aluminum Filtration

Operating Tube Potential (kVp)	Total Aluminum Filter Thickness (mm) (Inherent Plus Added)
below 51	0.5
51 through 70	1.5
above 70	2.5

measured HVL may lead to an erroneous conclusion

concerning compliance with minimum filtration requirements. For example. if the actual kV is lower than indicated on the operator's console, the measured HVL might not meet the minimum HVL specifications even though adequate filtration is in the beam. Likewise, if the kV is higher than indicated, the measured HVL might appear to be adequate even though the filtration in the beam is inadequate.

I-7-A. Determination of HVL

The HVL of the x-ray beam should be measured at least annually, after replacement of the x-ray tube assembly, or change in the added filter. The measured HVL is affected by the amount of scatter radiation at the ionization chamber (Reference #7). In three phase units the choice of tube current and exposure time setting also affect the measured HVL due to the effects of capacitance of the high voltage cables (Reference #21). These influences can be minimized by using "good geometry" (Reference #7), tube currents greater than 200 mA, and exposure time settings greater than 0.050 sec (Reference #21). Comparison of measured HVLs from survey to survey are meaningless unless the chosen geometry, tube current, exposure time settings, and kVp remain constant.

Test Method I: Manual Timing

1) Disable the Automatic Exposure Control (ARC) and operate the unit in the manual mode.
2) Position the ionization chamber (which should be calibrated for the diagnostic x-ray energy range) 100 cm from the focal spot. If 100 cm is not practical, use the largest distance allowed. The ionization chamber should be free standing, a few inches away from the table top or wall cassette holder to minimize back scatter.
3) Collimate the x-ray field to a size slightly larger than the ionization chamber.
4) Select an appropriate tube potential (e.g. 80 kVp for radiographic, 30 kVp for mammographic), a typical clinically used tube current (eg. 200-400 mA for radiographic, 50-100 mA for mammographic), and an exposure time greater than 50 msec. Make output measurements with no additional attenuating material between the focal spot and the ion chamber.
5) Make additional output measurements with varying thicknesses of 1100 alloy Aluminum filters located near the face of the collimator.
6) Use interpolation to estimate the HVL.

7) Compare the measured HVL against "Table I-Minimum HVL Requirement" to determine compliance.

Test Method II: Units With No Manual Timing

1) Place the unit in Automatic Exposure Control (AEC).
2) Place the ionization chamber a few inches away from table top or wall cassette holder to reduce backscatter. The chamber should be positioned over the center of the AEC sensor.
3) Collimate the x-ray field to a size slightly larger than the larger of the ionization chamber or AEC sensor.
4) Select 80 kVp or the closest available kV setting.
5) Achieve an exposure in the 10-20 mAs range by placing an-appropriate thickness of Aluminum or Copper attenuator in front of AEC sensors, but behind the ionization chamber.
6) Place an additional 4-5 mm Aluminum (1100 alloy) in front of the AEC sensors at the location chosen in step #5.
7) Record the exposure for this 0 mm data point.
8) Remove 1 mm of the 1100 alloy Aluminum from behind the ionization chamber and place it in front of the chamber near the face of the collimator.
Record the exposure.
10) Repeat steps 8-9 with additional thicknesses of Aluminum removed from behind the chamber and placed in front of it.
11) Use interpolation to estimate the HVL.
12) Compare the measured HVL against Table I minimum HVL's to determine compliance.

I-7-B. Simplified Filtration Test

If one is interested only in compliance and not in an accurate measurement of the HVL, a two exposure technique can be employed.

In step (5) of Test Method I, Section I-7-A, use Table 2 "Half-value layers as a function of filtration and tube potential for diagnostic units", on page 17 in Reference #8 to determine the minimum required HVL for the selected tube potential. Place this thickness of Aluminum in the beam. If the output of the unit is greater than one half of the output measured without any additional filters in the radiation beam, the minimum filtration requirement is met. If the exposure is less than half the zero filter measurement, additional

filtration may be necessary as discussed in Section 1-7-A. This abbreviated test method can also be applied to step #8 in Test Method II in section I-7-A.

I-7-C. Radiation Exposure and Expected Output

After verifying correct filtration of the unit, the radiation output of the x-ray unit should be measured at several tube potentials with the tube current stations routinely employed clinically. The ionization chamber can be placed in air 24" (61 cm) from the focal spot for the 40" (100 cm) SID (clinical) geometry. Use tube potentials of 60, 80, and 100 kVp. These encompass the most often employed x-ray tube potentials in Diagnostic Radiology except for mammography and high kV chest radiography. If the unit operates only in the Automatic Exposure Control (AEC) mode, the mAs can be adjusted by placing attenuators directly in front of the AEC detectors and noting the indicated mAs of each exposure. These measurements may be used to estimate the patient exposure when such a need arises.

The expected radiation output in mR/mAs [(1000/kg = (μC/kg)/mAs] of diagnostic x-ray units with different types of kV waveforms has been measured or calculated (References 9, 21, 22, 23, and 24). These expected values are listed in Table III. The final column of values applies to three phase units, constant potential generators, mid frequency units, and battery inverter mobile units. All the output data assumes a total filtration of 2.5 mm Al and a 24-inch distance between the ionization chamber and x-ray source. The output values in each column can be mathematically predicted by:

$$\text{Output} = C \times kVp^{n} \qquad [1]$$

(Reference #24) using the fitted values for the constants n and C listed in Table III. If the total filtration exceeds 2.5 mm Al, the expected output values in Table III should be reduced. For example, at 80 kVp, 15% or 10% reductions to the listed values, single or three phase respectively, should be applied for every half millimeter of Aluminum filtration added (Reference #24). Technically, radiation output (mR/mAs) is a function of:

(a) High Voltage (kVp) calibration,
(b) Tube current (mA) calibration,
(c) Exposure timer accuracy,
(d) The total filtration in the x-ray tube housing-collimator assembly,
(e) The electrical phase, method of rectification, and capacitance of high tension cables,
(f) The distance from the focal spot, and

(g) X-ray tube age.

If the measured radiation output deviates more than 40-50% from the appropriate value suggested in Table III, the generator may need a complete kV, mA, and time calibration. However, previous generator calibration and radiation output measurements should be consulted. The values in Table III are not applicable to falling kV generators such as capacitor discharge units which do not have constant mR/mAs values at different mAs stations. For detailed discussion of x-ray generator performance testing, refer to AAPM Report No. 14, "Performance Specifications and Acceptance Testing for X-ray Generators and Automatic Exposure Control Devices" (Reference #10).

Table III: Expected Exposure*

Source Chamber Distance = 24 inches (61 cm);
Total Filtration = 2.5 mm Al

	Single Phase Half Wave or Full Wave		Three Phase 6 or 12 Pulse, Mid Frequency Units, or Battery Invertor Mobiles	
kVp	mR/mAs	(1000/kg)**	mR/mAs	(1000/kg)**
60	8	(2.1)	12	(3.1)
80	14	(3.6)	21	(5.3)
100	22	(5.5)	32	(8.1)
125	35	(9)	48	(12)
150	52	(13)	68	(17)
Fitted Parameters for equation #1				
n	2.1	2.1	1.9	1.9
C	0.0014+	0.00035++	0.005+	0.0013++

*Not applicable to falling kV systems such as capacitor discharge units.

**1000/kg = (μC/kg)/mAs

+mR/(mAskVp^2)

++1000/(kgkVp^2)

On three-phase units (excluding grid controlled machines) residual charge due to the capacitance of the

high voltage cables contributes to the actual output of each exposure (Reference #21). While this contribution to the measured mR/mAs is less than 5-10% for tube currents above 200 mA and exposure time settings greater than 0.05 seconds, exposure measurements obtained with tube currents less than 25 mA and exposure time settings less than 0.005 seconds can be two to three times higher than the predicted values in the last column of Table III (Reference #21). Due to the influence of timer setting and tube current on expected radiation output, the same technique settings should be used from one survey to the next to track the consistency of radiation output over the lifetime of the tube.

I-7-D. Instrumentation

A good quality ionization chamber and electrometer capable of integrating the collected charge is necessary for HVL and output measurements. Since both the intensity and effective energy of the x-ray beam changes as a function of added filtration, the ion chamber should have a relatively constant energy response between 10-120 keV. The collection efficiency should be 95% or greater for the peak x-ray intensities to be measured. In addition, no linear dimension of the sensitive volume of the chamber should exceed 6 cm. This allows the x-ray field cross section to approximate good geometry during HVL measurements.

I-8 Radiographic Technique Chart

Verify the availability of a radiographic technique chart. The chart should contain the following information:

(a) Exam and projection,
(b) Radiographic technique factors as a function of anatomical size,
(c) Type and size of image receptor,
(d) SID, and
(e) Type and placement of gonadal shielding.

I-9 Identification of the Person Conducting the Evaluation

The report should contain a section that identifies the radiologic physicist conducting the survey, his/her title, and any appropriate professional certifications.

I-10. Recommendations and Suggestions

A section which lists identified non-compliance

items should be included on the survey forms. A recommendation or a suggestion should accompany each item in an effort to bring the unit into full compliance with the effective radiation rules and regulations. It may also be necessary to contact service engineers to rectify identified problems.

The radiological physicist should also bear in mind that x-ray equipment operators may not have received any formal radiological training concerned with the safe operation of a particular piece of equipment. Therefore, incorrect operating procedures may be found and may require correction.

Checklist Outline for
Radiographic Installations

I-2. SYSTEM INFORMATION
- A. Installation
  1. Date of survey
  2. Room number
     Department/Building
  3. Institution
  4. Unit identification number
- B. Generator
  1. Manufacturer
  2. Model type, model number, serial number
  3. Maximum high voltage (kVp)
  4. Maximum tube current (mA)
- C. X-ray Tube Insert
  1. Manufacturer
  2. Model type
  3. Serial number
  4. Nominal focal spot sizes
     a. Large
     b. Small
  5. Leakage technique factors
- D. X-ray Tube Housing
  1. Model number
  2. Serial number
  3. Added filtration

I-3. BEAM-ON CONTROLS AND INDICATORS
- A. Beam On Indicators
  1. mA meter: present and functional?
  2. Warning light: present and functional?
  3. Audible signal: present and functional?
- B. Exposure Switch
  1. Deadman type
  2. Location
     a. Fixed unit: Location within control booth
     b. Mobile unit: Length of exposure cord

I-4. SHIELDING DEVICES AND APPAREL
- A. Aprons
  1. Available
  2. Employed
- B. Gloves
  1. Available
  2. Employed
- C. Gonadal Shields
  1. Available
  2. Employed
- D. Mobile Shield

E. Other Specialized Devices

I-5. SOURCE-TO-IMAGE RECEPTOR DISTANCE
- A. Focal Spot Localization (when x-ray tube is replaced)
- B. SID indicators
  1. Accuracy of numerical indicators
  2. Accuracy of detents
  3. Accuracy of tape measure
- C. Mobile or portable SSD accuracy

I-6. RADIATION BEAM RESTRICTORS AND LIGHT LOCALIZERS
- A. X-ray Field/Light Field Congruence (at least annually or after removal of collimator)
  1. Large cassette
  2. Small cassette
- B. X-ray Field/Cassette Tray Alignment (at least annually or after repair to alignment light)
- C. X-ray Field/Numerical Indicator Accuracy (at least annually or after repair to collimator blades or dial indicators)
  1. Large cassette
  2. Small cassette
- D. Positive Beam Limitation (PBL) System (at least annually or after repairs to cassette tray or collimator drive motors or electronics)
  1. Table cassette holder
     a. Small cassette
     b. Large cassette
     c. Key override function
     d. Auto return from manual reduction
     e. Repeat a-d for other clinically used SIDs
  2. Wall Cassette Holder
     a. Small cassette
     b. Large cassette
     c. Key override function
     d. Auto return from manual reduction
     e. Repeat a-d for all clinically used SIDs

I-7. PRIMARY RADIATION BEAM CHARACTERISTICS
- A. Half Value Layer at Specified kVp (at least annually or after replacement of X-ray tube, generator recalibration, or filter thickness change)
- B. Appropriate Type of Added Filter on Mammographic Units
- C. Radiation Output: mR/mAs at specified kVp, total filtration, and distance from focal spot

(at least annually or as in I-7.A)

I-8. RADIOGRAPHIC TECHNIQUE CHART
- A. Availability
- B. Use
- C. Completeness

I-9. IDENTIFICATION OF PERSON CONDUCTING EVALUATION
- A. Name
- B. Title
- C. Professional Certification

I-10. RECOMMENDATIONS AND SUGGESTIONS

I-11. POSSIBLE ADDITIONS
- A. In-room Stray and Scatter Radiation Levels (see Section IV-3)
- B. Protective Barrier/Shielding Survey (See Section IV-4)
- C. Leakage Radiation (See Section IV-2)
- D. Use and Presence of Personnel Monitoring Devices

Part II. Medical Fluoroscopic Installations

II-l. Introduction

Pages 34-37 contain a checklist of the physical parameters which require evaluation and the information important to the radiation protection survey of fluoroscopic installations. Some of these parameters and information are similar to those of radiographic installations. While this part's checklist is complete, only the parameters and information unique to fluoroscopic installations are discussed here.

II-2. Exposure Switches and Interlocks

Hand or foot-operated fluoroscopic exposure switches shall be deadman switches. The exposure switch for radiographic spot filming, full size cassette film, or photofluorographic camera should be hand operated. However, some units are hand or foot operated. Special procedure examination rooms may employ either hand or foot operated switches for photofluorographic imaging using a photospot camera or a cine camera.

The image intensifier spot film device and tower must be interlocked to prevent fluoroscopic exposures when the image intensifier tower does not intercept the entire useful x-ray beam cross section (Reference #1). If the system allows the removal of the image intensifier from its tower, an additional interlock is necessary to prevent fluoroscopic exposures when the image intensifier is detached, regardless of the tower position with respect to the x-ray beam. If the unit allows the x-ray tube to be taken out of alignment, the x-ray tube positioning must also be interlocked. These interlocks are easily verified with fluorescent screen or dosimeter intercepting the position of the useful beam while simultaneously activating the exposure switch and positioning the image receptor.

Fluoroscopic x-ray tubes may also be interfaced to produce radiographic exposures other than spotfilming (en. 35 cm x 35 cm cut film changers). In this case. the comments made in Section I-3 concerning beam on indicators, non dead-man type exposure switches, and exposure switch location and cord length apply.

II-3. Fluoroscopic Timer

A timer shall be present which presets the fluoroscopic cumulative "ON" time to maximum limit of 5 minutes. An audible signal shall warn the operator of

the completion of the elapsed preset time. Re-initiation of the fluoroscopic exposure without resetting the timer shall restart the audible warning (Reference #l). Older. non-certified units and some certified units may terminate the exposure as an alternate to the audible warning.

The operation of the timer and audible warning should be checked. One should verify that the timer activates the signal (or shuts off the-radiation) at the termination of the preset time. Since this timer may be used to measure the total fluoroscopic exposure time per case, the radiologic physicist should verify the elapsed exposure time accuracy of the timer (exposure time vs indicated time), if exposure time is indicated.

II-4. Lead Protective Devices

Three types of lead protective devices are unique to fluoroscopic equipment. A lead drape hanging from the fluoroscopic tower or other image intensifier support intercepts scatter radiation from-the patient. It should be in good condition. The operator should be able to move it so it can be positioned between the operator and patient at all times. A lead drape normally is not found in special procedure rooms because its presence might violate sterile fields on the surface of the patient.

The shield of the slot for the cassette holder is a second type of protective device; it intercepts leakage radiation from under table x-ray tubes. The Bucky slot shield may consist of folding steel arms, a hinged steel door, and/or a lead or steel erectable panel. Verify that it is operating properly. One or more of these designs may be found on the 'same unit.

The table-end shield is a third type of protective device which intercepts leakage radiation. While newer fluoroscopic tables have end shields, some older units may not because they are modified radiographic tables. The table end shields may simply be the steel covers of the table skirt panels.

II-5. Minimum Source to Skin Distance (SSD)

A minimum allowed Source to Skin Distance (SSD, focal spot to skin distance) has been established (Reference #l) within Federal Standards to minimize entrance skin exposure during fluoroscopic examinations. The minimum SSDs are:

(a) Stationary fluoroscopes - 38 cm (15")
(b) Mobile fluoroscopes - 30 cm (12")

"Stationary" means any fixed installation.. Thus, the 38 cm minimum SSD applies to remote control over-table x-ray tube fluoroscopic systems with or without tomographic

capabilities. The 38 cm SSD also applies to lateral plane x-ray tubes found in biplane fluoroscopic systems. Since automatic collimators required on certified stationary fluoroscopic units are usually large in size, the minimum SSD in these cases usually cannot be violated. In fact, many current under table fluoroscopic units are designed with an SSD of 46 cm (18").

The Federal Standard makes one exception to the mobile image-intensified fluoroscopic SSD when used for specific surgical application. The minimum SSD may be reduced to as little as 20 cm (8") (Reference #l). Please note that this standard applies only to specific surgical situations. Therefore, the reduced SSD should be allowed only if the surgeon can demonstrate that a 30 cm (12") SSD would render the specific procedure impossible. Be aware that the surgeon is concerned with surgical procedures and may be unaware of the high patient skin exposure at short SSDs.

II-5-A. Measurement of SSD

On a mobile C-arm type fluoroscopic systems, the SSD can be directly measured if the location of the focal spot is known. If this location is not marked on the x-ray tube housing, triangulation (Section I-5-A) can be used to locate the position of the focal spot. Triangulation may be used to measure the SSD on an undertable X-ray tube fluoroscope. One radiopaque ruler is placed on the table top and another is taped on the underside of the spot film device (Reference #5). Their relative magnification can be varied by raising or lowering the image intensifier tower. When the fluoroscopic image of the markings on the tabletop ruler are twice those on the ruler taped to the spotfilm device, the vertical distance between the rulers is equal to the SSD. This method can be used if the SSD exceeds the maximum vertical distance between the tabletop and spotfilm device by using rulers with appropriately spaced markings and an appropriate multiplier. If this test is completed when the equipment is new, it should be repeated only if the type of x-ray tube or its mounting is changed.

****

CAUTION: The image intensifier must be protected from excessive radiation levels during the test to protect the TV camera. This can be achieved by using the automatic brightness control mode and by placing l-2 mm copper or l-2 in Aluminum sheets of appropriate cross section on the table top.

****

II-6. Radiation Beam Restriction and Alignment

This section describes the evaluation of the collimator's ability to automatically restrict the x-ray field size to the size of the selected portion of the image receptor. This parameter should be evaluated at least annually or after any repair or adjustment to 1) collimator drive motors or blades, 2) collimator electronics, 3) image intensifier tower SID sensing device, or 4) cassette holder within spot film device. In addition, this section evaluates the alignment of the x-ray beam central ray with the center of the image receptor. Misalignment can occur due to:

(a) Incorrect positioning of the fluoroscopic tower with respect to the focal spot,
(b) Incorrect positioning of the image intensifier within the fluoroscopic tower.
(c) Incorrect positioning of the cassette within the conventional spot film device,
(d) Incorrect centering of the photospot camera, or
(e) Incorrect centering of the television camera or monitor.

Alignment should be evaluated at least annually or after any repair or adjustment which could affect alignment in a-e above.

II-6-A. Test Method

The following test method (Reference #11) may be used to evaluate x-ray beam alignment and beam restriction. The outline is listed here to illustrate the scope of this testing procedure. The only test equipment required are commercially available ready pack direct exposure film and a beam restriction test tool. This test-tool simply consists of a 1/2" Aluminum attenuating block 8" x 8" in cross section on 1/2" legs. An orthogonal set of slide channels are cut into the block to accept radiopaque bars made of brass.

Fluoroscopic Mode

1) Adjust the tower vertically to result in the minimum SID.
2) Place the test tool on the tabletop and select the image intensifier's largest field of view. Record the distance from the top of the test tool to the level of the cassette in the spotfilmer. Record the distance from the tabletop to the top of the test tool.

3) During fluoroscopy, center the test tool. This process is normally easier if one of the two pair of collimator blades is closed to give a "slit image" with edges parallel to one of the orthogonal channels.
4) Lock the fluoroscopic tower in place when centering is complete. Tape the test tool to the tabletop.
5) Place the collimator in the automatic mode of operation. If automatic mode is not present, open collimator completely using the manual mode.
6) Insert the brass radiopaque slides in their channels of the test tool.
7) During fluoroscopy, adjust the slides until their edges are just visible at the edge of the fluoroscopic image.
8) Place a penny on the test tool within the fluoroscopic field of view. Place a ready pack film on ton of the test tool and penny. The penny is used to determine orientation on the processed film.
9) Make a fluoroscopic exposure of approximately 100 mAs at 80 kVp.
10) Process the test film: verify sufficient density on the film to image-the test tool and radiation field.
11) If the image intensifier has more than one field of view (eg. 9"-6"-4"), repeat steps 6-10 for each remaining field of view.
12) If the system is equipped with automatic collimator sizing as a function of SID, repeat steps 1-11 with the tower positioned vertically at the maximum SID.

Spot Film Mode Alignment

13) Repeat steps l-4 above.
14) Place a loaded cassette in the spot film device.
15) Select the full size spot film mode.
16) With the collimator in the manual mode reduce the size of the x-ray field until the edges of the collimator blades are visible on the fluoroscopic image.
17) Expose, process, and verify density on the spot film.
18) Repeat steps 14-17 for each available spot film format. For each format make enough exposures to fill the image receptor (eg. four exposures when the 4 on 1 mode is selected).

19) If any question concerning alignment as a function of SID exists, steps 13-18 should be repeated with the tower positioned vertically at the maximum SID.

Spot Film Field Sizing

20) Repeat steps l-4 above.
21) Place an unloaded cassette in the spot film device.
22) Place the collimator in the automatic mode and select the full size spot film mode.
23) Place a ready pack film on top of the test tool on the table top.
24) Make three exposures using the technique of step 17.
25) Process the film. Verify the correct density.
26) Repeat steps 21-25 for each available spot filmer format
27) Repeat steps 20-26 with the tower positioned vertically at the maximum SID.

The above test method is used when the x-ray tube is under the tabletop. The test method, steps l-12 and 20-27, also assumes automatic collimation is present and is the routine choice for clinical work. If this is not the case, the unit should be evaluated in the manual collimator mode. If the x-ray tube is overhead, (eg. remote unit) the ready pack film must be placed underneath the test tool directly on the tabletop. Normally, a mobile fluoroscope can be evaluated with the x-ray tube below the image intensifier. A stretcher can be used in this case to provide a tabletop.

II-6-B. Evaluation of Congruence Between X-ray Field/ Field of View of Imaging Chain

Steps l-12 of Section II-6-A allow evaluation of the congruence between the x-ray field and each field of view of the imaging chain as a function of the SID. On the images, the inside edges of the radiopaque slides mark the field of view of the imaging chain. The darkened area on the film defines the actual radiation field size and location. The center of the radiation field is determined by drawing diagonals from the corners of the darkened area. The center of the test tool marks the center of the field of view of the imaging chain.

For certified equipment, the congruence of the radiation field size with respect to the imaging chain's field of view shall be within an accuracy of 3 percent of the SID. The sum, without regard to sign, of these differences along any two orthogonal dimensions

intersecting at the center of the field of view shall not exceed 4 percent of the SID (Reference #1).

II-6-C. Evaluation of Spotfilm Alignment

Steps 13-19 of Section II-6-A allow evaluation of the alignment of the central ray of the x-ray field and the center of each selected portion of the image receptor within the spotfilm device as a function of the SID. On each image, the diagonals drawn from the corner of each darkened area mark the center of the x-ray field. The center of the selected portion of the film can be determined from diagonals and measurements on the film. The alignment of the x-ray field center and center of the selected portion of the image receptor in the spotfilm device should agree to within 2% of the SID (Reference #1).

II-6-D. Evaluation of Spotfilm Field Sizing

Steps 20-27 of Section II-6-A allow evaluation of the size of the x-ray field with respect to the size of each selected portion of the image receptor within the spotfilm device as a function of the SID. On the images one can measure the x-ray field size at the location of the test tool. The magnification factor can be calculated since the following distances are known:

(a) From focal spot to tabletop (Section II-5),
(b) From tabletop to test tool top, and
(c) From test tool top to image receptor.

The magnification factor is applied to the x-ray field at the test tool to calculate the field size at the image receptor level in the spotfilmer. Either the length or the width of the x-ray field shall not differ by more than 3% of the SID with respect to the length or the width of the selected portion of the image receptor. The sum of the absolute values of these length and width differences shall not exceed 4% (Reference #1).

****

CAUTION: This parameter cannot be measured by evaluating the degree of overlap of individual exposure fields made on a loaded cassette placed in the spot film device. Many units contain a second square or rectangular diaphragm between the patient and image receptor in the spotfilm device. If present, this diaphragm reduces the x-ray field to the appropriate size at the image receptor in the spotfilm device if the x-ray field size is too large at the patient position.

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II-6-E. Alternate Test Methods

The test method briefly described in II-6-A is only one of many. While the test equipment required for this method is minimal, many images must be exposed and processed to completely verify a conventional spot film device and imaging chain. Lin has described in detail the design and use of more expensive test tools which drastically reduce the time required to complete the testing (References #5 and #12). Hendee and Rossi (Reference #11) also suggest alternate test tools which reduce testing time. Reference #4 by Gray et. al. is another source of alternate test methods.

II-7. Radiation Output and Beam Characteristics

With the exception of the paragraph on mammography units, all the general comments in Section I-7 apply also to fluoroscopic x-ray beams.

II-7-A. Determination of HVL

The HVL of the fluoroscopic x-ray beam should be measured at least annually, after replacement of the x-ray tube assembly, after generator recalibration, or change in the added filtration. The measurement should be made in "good geometry" (Reference #7). The effects of high voltage cable capacitance on the measured HVL on three phase units (Reference #21) can be eliminated by collecting data with the rate mode of the dosimeter.

On single phase units the measured HVL decreases as the fluoroscopic tube current increases due to the cable capacitance of the high voltage cables (Reference #22). HVL measurements obtained with the dosimeter in the rate mode on these units do not avoid this effect; these HVL compliance measurements should use the maximum fluoroscopic tube current setting.

Comparison of fluoroscopic measured HVLs from survey to survey are meaningless unless the chosen geometry, kVp, and on single phase units, tube current remain constant.

****

CAUTION: During measurement of the HVL of a fluoroscopic beam, an appropriate attenuator should be attached to the face of the image intensifier avoid excessive radiation rates at its input. Failure to do this could damage the image intensifier television chain during HVL measurements. See Section II-5-A for suggested thicknesses of this attenuator.

****

HVLs for Units With Manual Exposure Rate Controls

Fluoroscopic systems with manual exposure rate controls allow use of Test Method I in Section I-7-A with some minor geometry changes. The image intensifier should be set at its maximum SID on under table x-ray tube systems. The added Aluminum test filters are put on the table top while the ion chamber is placed halfway between the table top and spotfilm device. (On over table x-ray tube systems, the geometry suggested in Section i-7-A does not require change.) Fluoroscopy can be used to center the dosimeter, filters, and x-ray beam and to minimize the x-ray field size. An exposure rate measurement during routine fluoroscopy (set kV and mA) or an integrated exposure measurement using the spot film mode (set kVp, mA, and time) can be used.

HVLs for Units Without Manual Exposure Rate Controls

Changing the thickness of test filtration in the primary beam of most Automatic Exposure Rate Controlled systems (AERC) results in a change in the kVp which changes the HVL. Therefore, in the AERC mode of operation, the total thickness of added filtration between the focal spot and image intensifier must remain constant.

HVL Test Method I: Noninvasive, 80 kVp Test Point

1) Extend the imaging chain tower to its maximum SID.
2) Place the ionization chamber halfway between the spot film device and tabletop on undertable x-ray tube systems. Place it halfway between the tabletop and focal spot on overtable x-ray tube systems.
3) Tape two or three 0.8 mm (0.03") copper sheets and 4-5 mm 1100 alloy Aluminum sheets onto the underneath side of the image intensifier tower for undertable systems. Place these attenuators on the tabletop on overtable systems.
4) Adjust the collimator during fluoroscopy to minimize the x-ray field size at the ionization chamber.
5) Add or subtract Copper until 80-85 kVp is obtained during fluoroscopy. adjustment in kVp can be achieved by reducing the SID. (77-83 kVp is acceptable for this measurement.)
6) Record the exposure rate; this is the 0 mm Al data point.

7) Complete steps #8-#12 of Test Method II found in Section I-7-A.

HVL Test Method II: Noninvasive, Maximum kVp Test Point

1) Use identical geometry described in steps 1 and 2 in Test Method I, Section II-7-A.
2) Place an Aluminum or Copper attenuator (1" or 1 mm thickness respectively) in the beam to protect the image intensifier from unattenuated x-rays.
3) Adjust the collimator during fluoroscopy to minimize the x-ray field size at the ionization chamber.
4) Remove attenuators of step 2 and place Lead attenuator directly in front of image intensifier to drive the system to maximum kVp during fluoroscopy.
5) Record the kVp indicated and exposure during fluoroscopy.
6) Complete steps 5 through 7 of Test Method I, Section I-7-A.

The two test methods described above are noninvasive. The following method requires the AERC circuitry to be overridden so the kV and mA can be controlled manually.

Test Method III: Invasive

Most fluoroscopic systems with only AERC contain an override that enables manual control of the fluoroscopic technique factors. In the override manual mode, Test Method I of Section I-7-A may be used. However, the override is usually a service and maintenance feature which is not readily accessible to the operator.

II-7-B. Entrance Exposure Rate

After verifying that the total filtration of the unit is in compliance with Federal Standards. the patient entrance exposure rate must be measured. The entrance exposure rate of fluoroscopic equipment with automatic exposure rate control (AERC) shall not exceed 10 R/min (2.6 mC/(kgmin)) (at the point where the center of the useful beam enters the patient during fluoroscopy (Reference #l). If an optional high exposure rate control is present, the entrance exposure rate shall not exceed 5 R/min (1.3 mC/(kgmin)), unless the high exposure rate control is activated (Reference #l). Continuous manual pressure by the operator shall be required to activate the high exposure rate control (Reference #l). During the activation of this mode, a continuous audible signal to the fluoroscopist shall be available. Federal Standards do not specify a maximum entrance exposure rate

for the high exposure rate mode. However, it is considered good practice to limit this mode to 10 R/min (2.6 mC/(kgmin)) unless a specific clinical need has been identified.

The entrance exposure rate of fluoroscopic equipment without AERC, shall not exceed 5 R/min (1.3 mC/(kgmin)) during fluoroscopy unless the unit is provided with an optional high exposure rate control (Reference #l). If the unit is provided with this option the comments about high exposure rate control in the previous paragraph apply.

The Federal Standards also specify the location of the entrance plane of the patient at which the above maximum exposure limits apply (Reference #l). The ionization chamber shall be positioned one cm above the tabletop or cradle if the x-ray source is installed under the tabletop. If the source is installed above the table, the ionization chamber shall be positioned 30 cm (12") above the tabletop with the end of the beam-limiting device positioned as closely as possible to the ionization chamber. If the fluoroscope has C-arm type geometry, the ionization chamber should be positioned 30 cm (12") from the input surface of the image intensifier assembly.

While the entrance plane for lateral fluoroscopes is not defined in the Federal Standard (Reference #l), an "FDA Compliance Policy Guide" was issued to manufacturers, assemblers, and field test personnel in 1977. This guide (Reference #13) states that the ionization chamber shall be located 15 cm (6") from the center line of the table in the direction of the lateral x-ray source with the end of the beam limiting device or spacer positioned as close as possible to the chamber. Any movable table ton shall be positioned as close as possible to the lateral x-ray source, with the end of the beam-limiting device or spacer no closer than 15 cm (6") to the table top centerline.

II-7-C. Entrance Exposure Rate Measurements

To test compliance, geometrical arrangement of the ionization chamber, x-ray tube, and image intensifier specified in the previous section should be followed. If it is not practical to do this, the geometry employed should be as close as possible to that recommended, with inverse square law corrections applied to the exposure rate readings. Any clinically used grid should be in position during these measurements.

Measurement of the maximum entrance exposure can normally be achieved by placing a Lead plate of at least 3.2 mm (l/8") at the face of the image intensifier

assembly. When the maximum entrance exposure of a unit is measured, the lead plate protects the image intensifier from excessive entrance exposure rates. Also, it is good practice to avoid long exposures at the maximum factors minimizing the chance of exceeding the thermal rating of the x-ray tube. These measurements should be completed at least annually or after replacement of the x-ray tube, generator recalibration, filter thickness change or adjustment to the AERC.

II-7-D. Qualitative Evaluation of Automatic Exposure late Control Devices

Normally, one should ensure that the automatic exposure rate control device is functioning at least annually or after repairs. The procedure described below is a simple qualitative check. It should not be considered a substitute for the quantitative check which should be completed during the original acceptance testing of the automatic exposure rate control device and subsequent calibrations.

In general, the fluoroscopic system's AERC should select the fluoroscopic techniques listed in Table IV. The various design strategies of accomplishing this are discussed in Reference # 14. These suggested technique factor combinations are only rough guidelines, Equipment kV and mA selections in practice depend on the gain of the image intensifier, AERC sensor f-stop, the SID, the FOV, and the AERC sensor gain adjustment and reference voltage settings. Thus, generally one should not pass judgement on the AERC function unless the operational logic of the AERC is understood.

Table IV. Expected AERC Techniques
SID = 30 inches (76 cm)
9" (23 cm) FOV

Attenuator Aluminum	Copper	kVp Range	mA Range
0.75" or	1.6 mm	70-75	0.8-1.2
1.5" or	3.2 mm	80-90	1.6-2.2
3.2 mm Pb		100-125 (maximum)	3.0-3.5 (maximum)

Checklist Outline for Fluoroscopic Installation

II-l. SYSTEM INFORMATION (See Section I-2)

- A. Installation
  1. Date of survey
  2. Room number
  3. Department/Building
  4. Institution
  5. Unit identification number
- B. Generator
  1. Manufacturer
  2. Model type, model number, serial number
  3. Maximum high voltage (kVp)
  4. Maximum tube current (mA)
- C. X-ray Tube Insert
  1. Manufacturer
  2. Model type
  3. Serial number
  4. Nominal focal spot sizes
     a. Large
     b. Small
  5. Leakage technique factors
- D. X-ray Tube Housing
  1. Model number
  2. Serial number
  3 added filtration

II-2 EXPOSURE SWITCHES AND INTERLOCKS

- A. Fluoroscopic Switches
  1. Deadman type
  2. Hand or foot operated
- B. Radiographic Spotfilming Switches
  1. Deadman type
  2. Hand operated
- C. Special Procedure Room Spotfilming Switches
  1. Deadman type
  2. Hand or foot operated
- D. Radiographic Exposure (eg. Cut Film Changers) Switches (See Section I-3)
  1. Non-deadman type
  2. Location
- E. Fluoroscopic Interlocks
  1. Position interlock on tower
  2. Image intensifier attachment interlock
- F. Radiographic Exposure (eg. Cut film changers) Beam on Indicators (See Section I-3)
  1. mA meter
  2. Warning light
  3. Audible signal

II-3. FLUOROSCOPIC TIMER
- A. Five Minute Maximum Setting
- B. Audible Warning Functional
- C. Accuracy of Elapsed Exposure time (at least annually or after repairs or replacement)

II-4. SHIELDING DEVICES AND APPAREL
- A. Lead Drape
  - 1. Presence
  - 2. Condition
- B. Bucky Slot Shield
  - 1. Presence
  - 2. Working condition
  - 3. Adequacy
- C. Table End shield Presence
- D. Aprons (See Section I-4-A)
  - 1. Available
  - 2. Employed
- E. Gloves (See Section I-4-B)
  - 1. Available
  - 2. Employed
- F. Gonadal Shield (See Section I-4-C)
  - 1. Available
  - 2. Employed
- G. Mobile Shield (See Section I-4-D)
- H. Other Specialized Devices

II-5. MINIMUM SOURCE-TO-SKIN DISTANCE (SSD)
- A. Minimum Fluoroscopic SSD
  - 1. X-ray tube below table (after a change in type or mounting)
  - 2. X-ray tube above table
  - 3. C-arm

II-6. RADIATION BEAM RESTRICTION AND ALIGNMENT
(Sizing checks should be performed at least annually or after repairs or adjustment to the collimator, its electronics, image intensifier tower SID sensing device, or cassette holder within spotfilm device. Alignment checks should be performed at least annually or after adjustments or repairs to the cassette holder of the spot film device, to the photospot camera, to the television camera, or to the television monitor.)
- A. Fluoroscopic Mode Alignment and Sizing (Minimum SID, auto and/or manual mode)
  - 1. Large FOV (14", 13", 12", 11", 10", or 9")
  - 2. Medium FOV (10", 9", 7", or 6")
  - 3. Small FOV (6", 5", or 4 l/2")

B. Fluoroscopic Mode Alignment and Sizing (Maximum SID, auto and/or manual mode)
   1. Large FOV (14", 13, 12", 11", 10", or 9")
   2. Medium FOV (10", 9", 7", or 6")
   3. Small FOV (6", 5", or 4 l/2")

C. Spot Film Alignment (minimum SID)
   1. 1 on 1
   2. 2 on 1
      a. Longitudinal
      b. Transverse
   3. 4 on 1
   4. 9 on 1
   5. etc.

D. Spot Film Alignment (maximum SID)
   1. 1 on 1
   2. 2 on 1
      a. Longitudinal
      b. Transverse
   3. 4 on 1
   4. 9 on 1
   5. etc.

E. Spot Film Field Sizing (minimum SID, auto and/or manual mode)
   1. 1 on 1
   2. 1 on 1
      a. Longitudinal
      b. Transverse
   3. 4 on 1
   4. 9 on 1
   5. etc.

F. Spot Film Sizing (maximum SID, auto and/or manual mode)
   1. 1 on1
   2. 2 on 1
      a. Longitudinal
      b. Transverse
   3. 4 on 1
   4. 9 on 1
   5. etc.

II-7. RADIATION OUTPUT AND BEAM CHARACTERISTICS

A. Half Value Layer at Specified kVp (at least annually or after replacement of x-ray tube, generator recalibration, or filter thickness change)

B. Maximum Entrance Exposure Rate (at least annually or after replacement of x-ray tube, generator recalibration, filter thickness change, or adjustment to AERC)
   1. Automatic exposure rate control (AERC)
   2. Manual exposure rate control

C. Qualitative Evaluation of AERC Device (same frequency as II-7.B

II-8. IDENTIFICATION OF PERSON CONDUCTING EVALUATION
A. Name
B. Title
C. Professional Certification

II-9. RECOMMENDATIONS AND SUGGESTIONS (See Section I-10)

II-10. POSSIBLE ADDITIONS
A. In-room Stray and Scatter Radiation Levels (See Section-IV-31
B. Protective Barrier/Shielding Survey (See Section IV-4)
C. Leakage Radiation (See Section IV-2)
D. Use and Presence of Personnel Monitoring Devices

III. Dental Radiographic Installations

III-l. Introduction

Many items discussed in the Medical Radiographic Installation Section, Section I, are applicable to dental x-ray units. Pages 45-47 contain a checklist of the physical parameters which require evaluation and the information important to the radiation protection survey of dental radiographic installations. While this section's checklist is complete, only information and parameters unique to dental installations are discussed here.

Dental radiographic equipment can be divided into three major categories: intraoral, cephalometric, and panoramic systems. The panoramic x-ray system is a tomographic unit unique to dentistry. It usually has a fixed SID in the range of 18" to 22" (45-56 cm) and an exposure time of 15 to 25 seconds. The radiation beam is usually collimated with two slit collimators, one at the end of a short cone attached to the x-ray tube and the other in front of the image receptor.

The intraoral system uses small image receptors which are held in place by the patient's teeth during the exposure. Therefore, this unit has no attached image receptor holder. Normally, the x-ray beam is collimated by a cylindrical cone.

The cephalometric unit may be dedicated or may consist of an intraoral x-ray tube assembly attached to a mechanical device which supports the image receptor. The image receptor normally is 8" x 10" (18 cm x 24 cm) in size; the SID is from 60" to 65" (152 to 165 cm).

III-2. Beam-On Controls and Indicators

With the exception of the comment on cut film changers, all the statements of Section I-3 apply to dental radiographic installations. In addition to surveying the unit, the physicist should verify that the operators are using the exposure time and the exposure cord properly. Manually terminating the exposure by releasing the deadman exposure switch or not standing as far away from the x-ray source as possible are two possible error.

III-3. Minimum Source Skin Distance: Intraoral Unit

The minimum x-ray source to skin distance (SSD) of a dental unit used with intraoral image receptors shall be 18 cm (7") if the unit is operable above 50 kVp (Reference #1). If the unit operates at or below 50 kVp, the minimum

SSD shall be 10 cm (4") (Reference #L). The distance between the end of the cone attached to the tube head assembly and focal spot usually can be measured with a tape measure. If the location of the focal spot is not indicated or if the tube has been replaced since the previous survey, see Section I-5-A for measurement details.

Federal standards do not specify an SSD for cephalometric or panoramic units. The geometrical requirements of these two units result in SSDs in excess of the specifications for intraoral units.

III-4. Source to Image Receptor Distance: Cephalometric Unit

The measured Source to Image Receptor Distance (SID) should be within 2% of the SID indicated the cephalometric unit (Reference #1). This distance usually can be measured with a tape measure. The location of the focal spot, if unmarked, can be located using triangulation (Section I-5-A). Since this SID requirement does not apply to fixed SID units, it does not apply to Panoramic units. It is also not applicable to intraoral units because operationally the SSD is fixed and the SID is variable due to varying patient anatomy.

III-5. Radiation Beam Restrictors

Beam restriction on a dental unit usually consists of a circular, rectangular, or slit diaphragm mounted at the x-ray tube/cone junction of an intraoral, cephalometric or panoramic unit, respectively. Since light localizers are not used, beam restrictor tests are straight forward. The method is discussed in III.5.A, B, and C. These tests should be completed at least annually or after removal and/or adjustment of the diaphragm.

III-5-A. Intraoral System

For a unit with an SSD equal to or greater than 18 cm (7"), the x-ray field size at the plane of the SSD must be contained within a maximum diameter circle of 7 cm (2.8") (Reference #l). If the SSD is less than 18 cm (7"), the maximum diameter circle must be less than 6 cm (2.4") (Reference #l). "Contained" in this context means that no part of the cross-sectional area of a different shaped x-ray field (eg. square, rectangle, etc.) falls outside the boundary of the circle, The boundary of the x-ray field is defined as the "edge" of the field where the exposure rate is 25% of the maximum exposure rate within the field (Reference #1).

This parameter is measured by making an exposure on

an appropriate image receptor which is larger than the x-ray field placed at the distal end of the cone. The image receptor can be film, fluorescent screen, etc.

III-5-B. Panoramic System

The rectangular slit within the cone mounted on the x-ray tube assembly should restrict the size of the x-ray beam to a size smaller than the slit opening on the image receptor support housing. The alignment of the x-ray tube assembly with respect to the image receptor support housing shall ensure that the entire x-ray beam falls within the slit opening on the image receptor support housing. Vertical beam misalignment results in either top or bottom cone cut on the film. Horizontal misalignment requires increased radiographic technique factors due to attenuation of the x-ray beam by the edge of the slit in front of the image receptor. Both horizontal and vertical misalignment of the slits results in unnecessary patient exposure. The accuracy of the slit's size and alignment can be verified by exposing a film (with appropriate marks) or a fluorescent screen taped on the slit of the image receptor support housing.

III-5-C. Cephalometric System

The alignment of the central ray of the x-ray beam with respect to the center of the image receptor shall be within 2 percent of the SID (Reference #1). The x-ray field shall be restricted so that each dimension does not exceed the image receptor dimension by more than 2 percent of the SID (Reference #1). Since the cassette holder generally permits the image receptor to move horizontally to compensate for different patient mandibular and cranial profiles, the image receptor should be placed in the center of the cassette holder when the alignment is checked.

To verify the alignment and size of the x-ray field, place a 14" x 17" (35 cm x 43 cm) cassette distal to the cassette holder. Measure the source to film distance. Expose the film. The field size in the image is scaled to the field size at the cassette holder. A shadow image of the cassette holder should also be present on the film. This may be used to verify x-ray beam to image receptor alignment.

III-5-D. Labeling of Cones or Apertures

Cephalometric units may use more than one size of image receptor. In this case the system usually uses removable cones or apertures to restrict the x-ray beam to meet the federal requirements listed in III-5-C. Each of

these interchangeable cones. or apertures shall have permanent labels which indicate the image receptor size and SID for which the beam restrictor is designed (Reference #1).

III-6. HVL Measurement

Measurement of radiation beam quality on Cephalometric and Intraoral units is a straight forward process. The comments of Sections I-7, I-7-A, and I-7-B apply.

Special care must be used to make HVL measurements on Panoramic units. These x-ray units have long exposure times. In general, one must wait 5 minutes between Panoramic exposures of 15-25 seconds to ensure that the heat load of the tube's anode is not exceeded. This heat load can be minimized by making exposure rate measurements and terminating the exposure- immediately after the electrometer reading stabilizes. IN EMPLOYING EITHER METHOD, CARE SHOULD BE EXERCISED AND THE MANUFACTURER'S TUBE RATING CHARTS SHOULD BE CONSULTED TO INSURE THAT TUBE LOADING LIMITATIONS ARE NOT EXCEEDED.

One desires stationary geometry of the Panoramic unit when making HVL measurements. Depending on the manufacturer, the rotating motion of the panoramic unit can be disabled by removing the appropriate fuse. The recommended method for this is usually noted in the installation manual. This allows one to position the ionization chamber on a stand in front of the post patient slit aperture.

One more geometry concern for HVL measurements is presented by the slit aperture of the x-ray tube cone. The slit aperture produces a typical x-ray field size of 13 cm x 0.6 cm (5" x 0.25"). The 0.6 cm dimension results in approximately the same partial coverage of the typical ionization chamber regardless of the thickness of test filter in front of the chamber. While each measured exposure is too small, the same test filter thickness is required to reduce the measured value to one half of its measured zero filter value. Therefore, provided the position of the ionization chamber "within" the x-ray field does not change, a sufficiently accurate measurement should result.

Half value layer measurements should be completed at least annually or after replacement of x-ray tube, generator recalibration, or filter thickness change.

III-7. Patient Exposure

Patient exposure is greatly influenced by film processing conditions. The Dental Exposure Normalization Technique (DENT) program, an ongoing study by the Center

for Devices and Radiological Health (CDRH) of the US Department of Health and Human Services (USDHHS), has documented that dental film development is a major problem (Reference #15). In a typical full mouth intra oral radiographic examination, a patient is subjected to 14 to 20 exposures. The entrance exposure of overlapped areas is high and can be excessive unless the film is properly developed. Dental radiographic exposure guidelines have been established by the FDA for a routine intraoral bitewing examination for "D" and "E" Speed Dental Film (Reference #15). These are listed in Table V.

Using the facility's clinical techniques measure the exposure with an ionization chamber positioned at the appropriate SSD. The obtained value should be compared to the appropriate values in Table V. If the exposures per film are higher than the appropriate range, the film is probably being under developed.

If the measured exposures are low and the HVL measured in Section III-6 is not excessive, the film is probably being over developed. This leads to fogging of the processed films which diminishes radiographic contrast and overall image quality. Over or under development normally is caused by an improper combination of film, chemistry, development time and/or temperature.

Table V. Bitewing Examination Exposure Guideline

Operating X-ray Tube Potential (kVp)	Range of Radiation Exposure per Bitewing Film			
	"D" Speed Film		"E" Speed Film	
	mR	(μC/kg)	mR	(μC/kg)
50	425-575	(110-148)	220-320	(57-83)
55	350-500	(90-129)	190-270	(49-70)
60	310-440	(80-114)	165-230	(43-59)
65	270-400	(70-103)	140-200	(36-52)
70	240-350	(62-90)	120-170	(31-44)
75	170-260	(44-67)	100-140	(26-36)
80	150-230	(39-59)	90-120	(23-31)
85	130-200	(34-52)	80-105	(21-27)
90	120-180	(31-46)	70-90	(18-23)
95	110-160	(28-41)	60-80	(15-21)
100	100-140	(26-36)	50-70	(13-18)

Exposure Conditions:

Tube Current	10 mA	10 mA
SSD:	8" (20 cm)	12" (30 cm)
Filtration:	In accordance with Table II of Section I-7	

The general comments of Section I-7-C on measuring radiation exposures apply to dental x-ray units. The ionization chamber and electrometer described in Section I-7-D are appropriate for these measurements on Cephalometric or intraoral units. Most dental units are single phase halfwave or full wave rectified units. The expected exposures at 24" from the x-ray source as a function of kV are listed in Table III, Section I-7-C.

Due to the geometry of the Panoramic unit, the patient tissue exposed to radiation is continually changing. Therefore, the patient entrance exposure (mR/mAs) is less than the expected radiation output (mR/mAs) within the slit beam. The patient entrance exposure per film can be measured by placing the ionization chamber at the location of the patient's skin (at chin support) and by scanning across it using clinical kV and mA settings. The manufacturer's tube rating chart should be consulted to avoid overheating the tube when making multiple exposures.

To measure the exposure within the slit x-ray field (mR/mAs) for comparison with the values in Table III, section I-7-C, use the ionization chamber geometry described in section III-6 and use short exposure times to collect exposure rate date. Correct these readings to mR/mAs values and for error due to partial coverage of the ionization chamber. The correction factor for partial coverage error is the ratio of the total volume of the chamber to the radiated chamber volume. The actual width of the x-ray slit field should be known from measurements in Section III-5.B.

Patient entrance exposures should be measured at least annually or after replacement of the x-ray tube, generator recalibration, filter thickness change or a change in film or development techniques.

III-8. Multiple Tube Configuration

Multiple tube configurations are commonly found in many dental offices and clinics. One generator may be installed to power as many as four x-ray tubes. Only one exposure switch may be present to initiate an exposure from any one of the x-ray tubes, or each x-ray tube may be equipped with its own exposure switch. In such configurations, the x-ray tubes must be interlocked to prevent exposure from more than one x-ray tube at a time. The x-ray tube selected for the exposure should be clearly identified (Reference #1).

III-9. Mechanical Support

Certain states require checks of mechanical supports.

The mechanical support of the x-ray tube on Cephalometric and Panoramic units shall be designed so that the x-ray tube housing assembly remains stable during an exposure after positioning. This should be evaluated on intraoral units by placing the x-ray tube assembly in the positions/angles commonly used clinically. The cephalometric unit should be set up in its clinical geometry to evaluate mechanical stability. While the x-ray tube assembly is not stationary on Panoramic units during exposures; it should be rigidly supported to maintain the vertical and horizontal slit alignment discussed in Section III-5-B.

III-10. Shielding Devices

The comments made in Section I-4 also generally apply to dental installations. Typically a lead apron is placed on the patient to provide 'whole body" and specifically gonadal shielding. Thyroid shields are also effective at reducing thyroid doses As Low As Reasonably Achievable (ALARA) for dental patients.

Checklist Outline For
Dental Radiographic Installations

III-1. SYSTEM INFORMATION (See Section I-2)
- A. Installation
  1. Date of survey
  2. Room number
  3. Department/Building
  4. Institution
  5. Unit identification number
- B. Generator
  1. Manufacturer
  2. Model type, model number, serial number
  3. Maximum high voltage (kVp)
  4. Maximum tube current (mA)
- C. X-ray Tube Insert
  1. Manufacturer
  2. Model type
  3. Serial number
  4. Nominal focal spot sizes
     a. Large
     b. Small
  5. Leakage technique factors
- D. X-ray Tube Housing
  1. Model number
  2. Serial number
  3. Added filtration

III-2. BEAM-ON CONTROLS AND INDICATORS (See Section I-3)
- A. Beam On Indicators
  1. mA meter: present and functional?
  2. Warning light: present and functional?
  3. Audible signal: present and functional?
- B. Exposure Switch
  1. Deadman type
  2. Location
     a. Fixed unit: location outside of exam room
     b. Mobile unit: length of exposure cord

III-3. MINIMUM SOURCE-SKIN DISTANCE: INTRAORAL UNIT
- A. Focal Spot Localization (when x-ray tube is replaced)
- B. SSD Accuracy

III-4. SOURCE-TO-IMAGE RECEPTOR DISTANCE: CEPHALOMETRIC UNIT
- A. Accuracy of Detents
- B. Accuracy of Tape Measure
- C. Accuracy of Markings

III-5. RADIATION BEAM RESTRICTORS
- A. Intraoral System (at least annually or after removal of cone)
  1. X-ray field diameter at SSD
- B. Panoramic System (at lest annually or after removal or adjustment of slit diaphragm)
  1. Slit size
  2. Verticle alignment of slit
  3. Horizontal alignment of slit
- C. Cephalometric System (at least annually or after removal or adjustment of diaphragm)
  1. 8 x 10" (18 x 24 cm) receptor
     a. X-ray beam alignment
     b. X-ray field size
  2. Other receptor size
     a. X-ray beam alignment
     b. X-ray field size
- D. Labeling of Removable Cones or Apertures

III-6. HALF VALUE LAYER AT SPECIFIED KVP (at least annually or after replacement of x-ray tube, generator recalibration, or filter thickness change)

III-7. PATIENT ENTRANCE EXPOSURE (at least annually or as in III-6)
- A. mR/mAs
- B. Intraoral Entrance Exposure/Film

III-8. MULTIPLE TUBE CONFIGURATION
- A. Interlocks
- B. Light Indicators

III-9. MECHANICAL SUPPORT
- A. Lack of Tube Drift

III-10. SHIELDING APPAREL (See Section I-4)
- A. Aprons
  1. Available
  2. Employed
- B. Mobile Shield
- C. Thyroid Shield
  1. Available
  2. Employed

III-11. RADIOGRAPHIC TECHNIQUE CHART (See Section I-8)
- A. Availability
- B. Use
- C. Completeness

III-12. IDENTIFICATION OF PERSON CONDUCTING EVALUATION (See Section I-9)
- A. Name
- B. Title
- C. Professional Certification

III-13. RECOMMENDATIONS AND SUGGESTIONS (See Section I-10)

III-14. POSSIBLE ADDITIONS
- A. In-room Scatter Radiation (See Section IV-3)
- B. Protective Barrier/Shielding Survey (See Section IV-4)
- C. Leakage Radiation (See Section IV-2)
- D. Use and Presence of Personnel Monitoring Devices

IV. Measurement of Area Radiation Levels

IV-l. Introduction

Parts I, II, and III, have concentrated on equipment related radiation safety matters. In addition to these concerns, a radiation survey of the facility should be performed. The following three types of radiation levels in the vicinity of the machine may be of interest:

(a) Scattered radiation inside the examination room,
(b) Stray radiation outside the examination room,
(c) Leakage radiation from the x-ray tube housing.

Measurement of scattered radiation inside the examination room should be checked annually. The measurement of radiation levels outside the procedure room is necessary prior to first clinical use and following room modifications.

IV-2. Leakage Radiation

All certified diagnostic medical and dental diagnostic source assemblies must meet the Federal Standard for the diagnostic source assembly (Reference Cl). This standard results from the definition of a "diagnostic-type protective tube housing" by the NCRP (Reference #2):

> "An x-ray diagnostic source assembly must be so constructed and assembled that the leakage radiation measured at a distance of 1 meter from the source does not exceed 100 mR (25.8 μC/kg) in 1 hour when the tube is operated at its maximum continuous rated current for the maximum rated tube potential."

As stated in NCRP report No. 33 (Reference #2), "in general, modern diagnostic tube housings incorporate sufficient attenuating material to limit the leakage radiation to that permitted in the definition of a diagnostic-type protective housing and it is probably unnecessary to perform leakage tests in the field on modern x-ray machines". Unless one suspects a faulty x-ray tube housing is causing excessive leakage radiation as a result of the housing's age, appearance, history, high measured radiation levels inside the room as noted in Section IV-3, or unless it is required by State Regulations, this survey is generally not necessary.

In general, leakage radiation measurement conditions cannot be precisely met and various technical problems must be overcome. Examples are:

(a) The geometry of "1 meter from the source" vs. actual physical limitations in the examination room,

(b) The lowest tube current station available on the control panel exceeds the maximum continuous rated current for the maximum rated tube potential, and

(c) Dental x-ray tubes may have a specified duty cycle in addition to the maximum continuous rated tube current.

If the ionization chamber cannot be positioned one meter from the source in certain radial directions the readings can be corrected using the inverse square law.

Radiographic x-ray tubes normally have a maximum continuous rated tube current of 3-5 mA at maximum kVp. This value must be obtained from the unit's tube rating chart. If, for example, the lowest mA station on the unit is 50 mA and the maximum "continuous" tube current is 5 mA, an exposure rate leakage reading must be scaled by l/10 (5 mA/50mA) to obtain the leakage rate at the maximum continuous rated tube current. If the mA station and tube ratings remain the same, but an integrated leakage reading using 100 mAs is measured, multiply the measured reading by 180/hr to obtain the correct leakage rate.

$$\frac{\text{(3600 sec/hour) x 5 mA}}{\text{100 mAs}} = \text{180/hr} \qquad [2]$$

An integrated leakage reading is preferred on radiographic x-ray tubes to prevent long exposures and excessive heat loading to the tube.

If the lowest station available 'exceeds the maximum continuous rated tube current on a dental x-ray tube, the correction factor is calculated as described in the previous paragraph. However, many dental x-ray tubes also have a specified duty cycle, eg. 6 seconds/minute. The leakage reading in this case must also be multiplied by this duty cycle, 1/10, to obtain the leakage radiation rate at the tube's maximum continuous tube current.

The following recommendations should be followed during leakage radiation measurements:

1) Select the lowest tube current station.
2) Select an exposure time that is appropriate for the ionization survey meter's response time. (Most survey meters have a response time of 4 to 5 seconds.)
3) Select the highest tube potential allowable. (Consult the tube rating chart.)
4) Do not exceed the total heat capacity of the anode and the x-ray tube housing during the survey.
5) Close-the collimator blades and block the collimator port with at least 10 HVL equivalent of lead.

6) Select positions on the surface of an imaginary sphere of 1 meter radius with its-center located at the focal spot. Include points at a height equal to the plane including the tube housing and the collimator junction.
7) Measure the leakage radiation at the selected positions.
8) Correct any data which could not be collected at 1 meter,

The average reading over 100 square centimeters at 1 meter should not exceed 100 mR in one hour, normalized to the maximum current for continuous operation at the maximum (or the maximum allowable) tube potential. No linear dimension of the 100 square cm area should be greater than 20 cm (Reference #l).

IV-3. In-room Scattered Radiation Measurement

In room stray and scattered radiation level measurements are often necessary for routine fluoroscopic systems or special procedure suites. Measurements around stationary radiographic systems and portable x-ray units may also be necessary to assure that the non-radiation workers are not subjected to excessive amounts of radiation.

The technique factor requirements are similar to those employed in leakage radiation level measurements. A water, plastic, or pressed wood scattering phantom should be placed in the primary beam. It should be approximately 30 cm x 30 cm x 25 cm (width x length x thickness) to simulate an average adult abdomen. Suitable sizes should be employed to simulate other parts of the body, eg. 15 cm x 19 cm x 15 cm for an adult head. Aluminum or Copper are unacceptable as scattering materials.

The equipment should be arranged to simulate the clinical situation. Measurements should be made at the fluoroscopist's, angiographer's, radiographer's, and other ancillary personnel's locations. To assess the total scattered radiation delivered to each point of interest, the measured exposures should be scaled to a weekly exposure using appropriate workload information.

IV-4. Protective Barrier/Shielding Assessment

Shielding provided by room barriers must be adequate to reduce radiation levels to personnel, patients, and the general public to meet the guidelines established by NCRP Report No. 39, "Basic Radiation Protection Criteria" (Reference #16). The actual thickness of shielding required is a function of the following:

(a) Type of material in the barrier,

(b) Orientation of the x-ray beam in the room,
(c) Workload of the x-ray unit,
(d) Size of the room and the equipment layout, and
(e) Degree of occupancy in the adjoining areas.

One cannot arbitrarily assume that a given thickness of Lead will be appropriate on all barriers.

Existing records of room barrier design and the report of the shielding evaluation should be reviewed. Any one of the following conditions should cause a new barrier evaluation to be Initiated.

(a) Records of previous room barrier certification by a qualified expert as defined by NCRP Report No. 49 cannot be found (Reference #17)
(b) Previous room barrier certification is incomplete.
(c) It cannot be established with certainty that changes in equipment, its operation, or the room barriers have not been made since the last barrier certification.

If the facility is new, a complete survey of the facility during and after the construction should be done. This includes visual inspections of shielding integrity during the construction of the room barriers, relative measurements to detect any voids in the barrier with an appropriate radioisotope prior to installation of the radiographic equipment; and quantitative measurements of stray radiation levels outside the room after installation of the radiographic equipment. In this case, "quantitative" means the determination of exposure levels per week outside the room using the installed equipment as the source of radiation. Actual readings must be scaled to reflect the projected workload of the Installation. If the facility's shieldinn has been modified, spot checks should be made.

Actual procedures in the evaluation of protective barriers have been discussed in NCRP Report No. 57, Reference #18) and more recently by K.J. Strauss (Reference #19). NCRP Report No. 49 (Reference #17) and NCRP Report No. 35 (Reference #20) contain information on the design of barriers for routine x-ray rooms and dental x-ray rooms respectively.

IV-5. Instrumentation

The quantitative survey meter used to measure leakage radiation, scattered radiation within the room or radiation levels outside the room barriers must be chosen carefully. An ionization chamber with a sensitive volume of one liter coupled to an electrometer with integrating capabilities is one type of instrument suitable for measuring weak radiation fields of short duration. The

following factors must be considered when quantitative measurements are completed:

(a) Meter's energy response
(b) Meter's directional response
(c) Meter's intensity response
(d) Ion chamber cross sectional area corrections
(e) Meter's calibration
(f) Meter's response time in the rate mode on its most sensitive scales.

The selection and use of survey meters to measure low level radiation fields have been discussed in more detail in References #18 and #19.

Checklist Outline
Measurement of Area Radiation Levels

IV-2. LEAKAGE RADIATION (prior to first patient use or anytime damage to the tube housing is suspected)
- A. Measurement #l
- B. Measurement #2, etc.

IV-3. IN-ROOM SCATTERED RADIATION MEASUREMENT (annually)
- A, Operator Position in Front of Table
  - 1. Table upright
  - 2. Table horizontal
- B. Head End of Table
- C. Foot End of Table
- D. Back Side of Table
- E. Location of Physiological Monitoring Equipment
- F. Other Occupied Locations in Room
- G. Control Booth: Waist High at Operator's Location During Exposure
- H. Behind Control Window

IV-4. PROTECTIVE BARRIER/SHIELDING ASSESSMENT (prior to first patient use or as needed, see Section IV-4)
- A. Visual Inspections During Construction
  - 1. Barrier thicknesses
  - 2. Joint integrity
  - 3. "Wrap" integrity at electrical bores, etc
- B. Relative Measurements With Radioisotope, Prior to Installation of Equipment
  - 1. Control booth
  - 2. View windows
  - 3. Each Wall
  - 4. Floor
  - 5. Ceiling
  - 6. Location of voids
    - a. Wrapped electrical boxes
    - b. Joints
  - 7. Room entrance
    - a. Door
    - b. Maze
- C. Quantitative Measurements With X-ray Unit
  - 1. Control booth
  - 2. View windows
  - 3. Each wall
  - 4. Floor
  - 5. Ceiling
  - 6. Location of voids
    - a. Wrapped electrical boxes
    - b. Joints
  - 7. Room entrance
    - a. Door
    - b. Maze

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