7

X-RAY TUBES AND COLLIMATORS

RATING CHARTS AND OVERLOAD PROTECTION

It may seem superfluous to spend time discussing x-ray tube rating charts, but it has been our experience that most problems associated with premature tube failures result from the appropriate charts not being properly used. This is particularly significant since it should normally be the responsibility of the quality control technologist to develop the technique charts for use in all x-ray procedure rooms.

X-ray tubes represent a significant investment since they range in price from about $5,000 to in excess of $15,000 for special procedure tubes. In addition to the cost of the tube, replacement means a considerable amount of downtime for a room, especially if x-ray tubes are not stocked by your institution or locally by the manufacturer.

Naturally, you would like to assure maximum life from every x-ray tube. This can be done by following the rating charts closely in developing technique charts and, whenever possible, not developing technique charts that require the x-ray tube to be operated in excess of 80% of the rated capacity of the tube or housing. Every technologist, including the QC technologist, should warm up the x-ray tube prior to use, following the manufacturers' instructions. If a room is not used continuously this means that the tube may have to be warmed up several times a day. These additional exposures will not shorten the life of the tube, but rather will reduce the possibility of premature failures caused by anode cracking when a cold anode is "hit" with a heavy technique.

Although overload protection is a function of the x-ray generator, it is included with the material on rating charts. The overload protection circuits should not allow the technologist to select techniques that exceed about 80% of the single exposure rating of the tube. If higher techniques can be selected tube damage can result, and if the generator limits you to techniques much less than 80% of the single exposure rating then the full capabilities of the generator and the x-ray tube cannot be realized. In either case the service engineer should adjust the overload protection circuit appropriately.

X-RAY TUBE FOCAL SPOT SIZE MEASUREMENTS

These measurements are particularly important during the acceptance testing of new x-ray equipment and whenever an x-ray tube is replaced. Although some firms may accept the results of the star resolution measurement for all sizes of focal spots, the National Electrical Manufacturers Association (NEMA) standard does specify that a pinhole camera must be used for focal spots larger than 0.3 mm nominal measurement (National Electrical Manufacturers Association, 1974). In addition, the standard specifies the use of dental x-ray film, which in combination with the pinhole camera results in techniques ranging up to 50,000 mAs, putting a severe load on an x-ray tube even if multiple exposures are made. A complete discussion of pinhole camera problems and modifications can be found in the literature (Gray and Trefler, 1980).

We acceptance-test all of our x-ray tubes using the star test pattern and an extremity cassette screen-film system. If the focal spot appears to be larger than specified we will then produce a pinhole image with the pinhole camera, again using the extremity cassette screen-film system, if the manufacturer will not accept the star measurement. If the focal spot still appears to be oversized then we will resort to the use of the NEMA-recommended pinhole camera and direct x-ray exposed film. However, it is far better to make arrangements with your manufacturer's representatives in advance so that they will accept the star pattern measurements as a means of acceptance testing.

Should x-ray focal spot measurements be made on an on-going basis for QC purposes? We do carry out the star pattern measurements as part of each room QC check since we have found a few significant changes in the size of the focal spot that have occurred before x-ray tube failures.

X-RAY FIELD, LIGHT FIELD, BUCKY ALIGNMENT, AND EXPOSURE CONSISTENCY

With the requirement for automatic collimators, tests for the alignment of the light field and x-ray field have become more important. Some institutions require that the edges of the collimators be visible on every film. Others add small pieces of lead to the edges of the collimator leaves so that these "tic" marks are visible on each radiograph. In any case the alignment must be checked to assure that only the appropriate film area is being exposed. All collimators should allow the technologist to cone *down* from the full-film size, even in completely automatic operation.

In addition to the above information, a dosimeter reading made at this time will provide the entrance exposure in air for the standard phantom (and average patient). This will allow you to compare patient exposure from room to room for consistency. In rooms with similar equipment, the exposures should be within fairly close levels, but it will be difficult to make comparisons if the equipment is different, if different tabletops are used, or if different screen-film combinations are used.

HALF-VALUE LAYER MEASUREMENTS

Half-value layer (HVL) measurements are extremely important, especially after any service that requires that the collimator be removed from the x-ray tube. The half-value layer, expressed in millimeters of aluminum, is not—we repeat, *is not*—the amount of aluminum in the x-ray beam. Instead, it is the amount of aluminum that is required to reduce the exposure to one-half of its original value, assuming the kVp and mAs remain fixed. This might sound like quite a technical definition but in reality the HVL is merely a number that specifies the "hardness" of the x-ray beam. Figure 7.1 clearly shows that the HVL is not the same as the total aluminum filtration in the beam. In addition, you can see that, as the beam becomes harder (a higher HVL), more aluminum must be added to the beam to change the HVL by 0.1 mm as compared to the softer beam (lower HVL).

An increase in filtration (resulting in an increased HVL) for a fixed kVp has very little effect on the higher-energy x-rays present in the beam, but the increase in HVL indicates that more of the soft x-rays have been removed from the beam. Since the majority of softer x-rays in the beam will not be transmitted through the patient to form an image but will be absorbed by the patient, increasing the HVL will decrease the patient dose. For example, increasing the HVL from 2 mm to 3 mm of aluminum reduced the entrance exposure to the patient from 600 mR to 390 mR, a 35% exposure reduction (based on calculations, see Figure 7.2).

A close look at Figure 7.2 can provide useful insight into the effect of added aluminum filtration. This graph was plotted from data calculated using a computer simulation system. As it is easy to see, the addition of the first fractions of a millimeter of aluminum changes the entrance exposure to the patient dramatically, with the addition of more aluminum giving less, but still significant, exposure reductions. Note that this graph was plotted assuming that the density on the films was to be maintained at the same level after the beam passed through a 20-cm patient.

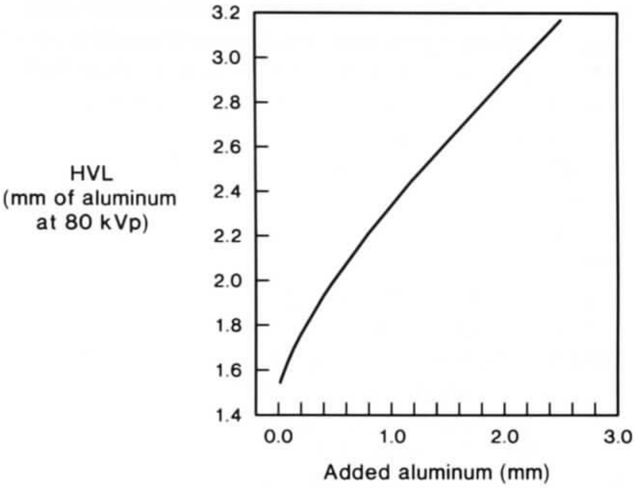

Figure 7.1. Half-value layer as a function of added aluminum. The HVL, although expressed in millimeters of aluminum, is a measure of the hardness, or softness, of the x-ray beam and is not the same as the added aluminum filtration. In addition, if the added aluminum is increased from 1.0 to 2.0 mm the HVL changes much less, by approximately 0.5 mm of aluminum.

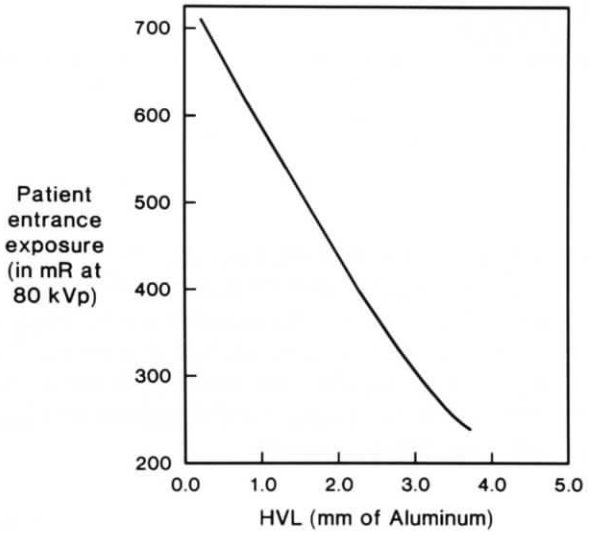

Figure 7.2. Patient entrance exposure as a function of HVL. The entrance exposure to the patient drops dramatically as the HVL increases since a higher HVL means less soft radiation, radiation that will be absorbed by the patient and not used to make an image. For this figure the patient exit exposure was kept constant, meaning that the same density was produced on the films.

Although this required a slight increase in the mAs as more aluminum was added, the entrance exposure was constantly reduced with added filtration.

Although the Bureau of Radiological Health requires that manufacturers ensure an HVL of 2.3 mm of aluminum at 80 kVp upon installation of the x-ray equipment, we feel that it is prudent to increase this to 3.0 mm of aluminum, for an exposure reduction of about 25% with no change in the density or film quality, and we have done this throughout our institution. (The service engineer should also assure that proper filtration is added to the beam upon replacement of an x-ray tube or collimator, but this may be neglected, so it is especially important to check the HVL after tube changes or removal of the collimator.) In fact, we have been able to match the HVLs of our tubes to 3.0 ± 0.2 mm of aluminum (at 80 kVp) with little difficulty.

The accuracy of HVL measurements when carried out by different people is important. Using the same data four individuals plotted the values on semi-log paper (as described in the protocol in this chapter) and obtained values of 3.68, 3.55, 3.60, and 3.60. This indicates that the plotting procedure is quite accurate and eliminates necessity for complicated calculations or computer analysis of the data. With different individuals making the measurements at different times, as well as plotting the data and determining the HVL, we have found that we can expect accuracies of ± 0.1 mm of aluminum.

Since the HVL indicates the "hardness" of the x-ray beam, and kVp will also affect the hardness of the beam, you must be sure that the kVp is measured and correct before making HVL measurements. As can be seen from Figure 7.3 a change of 2 or 3 kVp will result in a change of approximately 0.1 mm in the HVL (when measured at 80 kVp).

We have one final tip on measuring the HVL that we find useful. We normally set up our initial technique at 80 kVp and select the mAs so that we obtain an exposure reading of 300 mR. This assures that you have a high enough exposure to make the measurements accurately and also assures that your data can be plotted on semi-log paper where the scale is easy to read.

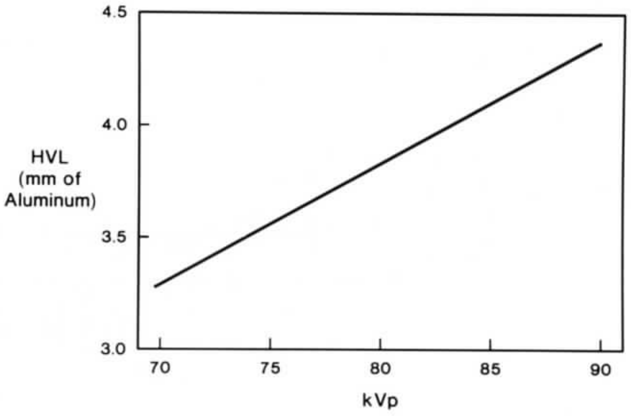

Figure 7.3. HVL as a function of kVp. Over this energy range the HVL does vary, although not rapidly, with kVp. Consequently, the kVp must be correct before determining the HVL in a diagnostic imaging system.

PROCEDURES

7.1. X-RAY TUBE RATING CHARTS

Purpose

To assure that departmental exposure techniques (combination of kVp, mA, and time) are within the ratings of the tubes and housings. During the production of x-radiation, a great deal of heat is produced at the surface of the x-ray tube's anode. It is essential that the rate at which this heat is produced is at a level that will not result in melting the surface of the anode and that the total quantity of the heat produced from a single or a series of exposures does not exceed the thermal capacity of the anode itself. In addition, it is essential that the rate of heat dissipation of the x-ray tube housing to its surrounding and its heat capacity be considered to avoid overheating with resultant damage to the rotor bearings and other structures within the x-ray tube.

Equipment

X-ray tube and housing rating charts for each type of tube and housing used in the department

Procedure—Single Exposure Rating

1. Select the single exposure rating chart for the specific x-ray tube used and for the conditions of use, e.g., focal spot size, single- or three-phase generator, 60 or 180 Hz stator rotation (Figure 7.4).
2. Refer to the technique chart for the room and determine the maximum exposure used for the thickest body part. A typical technique for a localized lateral view of the lumbar spine may be 100 kVp, 200 mA, and 1 sec, with a three-phase generator and a medium-speed screen-film combination.
3. Determine whether this technique is permitted by reference to the single exposure rating chart.

Problems and Pitfalls

1. There are as many as eight single exposure rating charts for each x-ray tube. It is essential that the correct rating chart be used. These eight charts include:

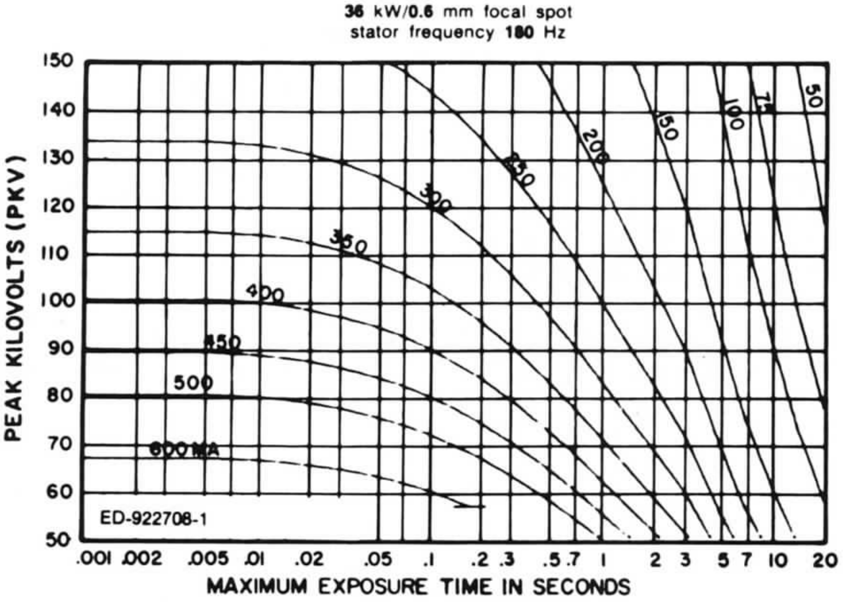

Figure 7.4. Single exposure rating chart for a 36-kW anode with a 0.6-mm nominal focal spot size with the anode operated at high-speed rotation on a three-phase, full-wave, rectified generator. Courtesy of Machlett Corporation.

	Small focal	Large focal
Single phase	60 Hz stator	60 Hz stator
	180 Hz stator	180 Hz stator
Three phase	60 Hz stator	60 Hz stator
	180 Hz stator	180 Hz stator

2. High mAs exposures may be permitted at low mA and long exposure times (200 mA, 1 sec), but may not be permitted at high mA and short exposure times (1,000 mA, 0.2 sec).
3. Operation of the x-ray tube within the single exposure rating limits does not prevent overheating the tube with a filming series.

Acceptance Limits

Most exposure techniques used with a specific x-ray tube must not exceed about 80% of the limits provided on the single exposure rating charts.

Corrective Action

Whenever possible, exposure techniques that exceed 80% of the single exposure ratings should be modified. It is usually possible to operate within the ratings by doing one or more of the following:

1. Use the large focal spot
2. Use high speed rotation
3. Reduce the mA and increase the exposure time
4. Increase the kVp and reduce the mA or time
5. Switch to a higher-speed screen-film combination

Procedure—Anode Thermal Characteristics

1. Select the appropriate thermal characteristics rating chart.
2. Determine the number of exposures and technique required for a study, e.g., a 10-exposure tomographic series at 70 kVp, 50 mA, and 6 sec.
3. Refer to the single exposure rating chart to determine if one exposure at the desired technique is permitted before proceeding. If not, modify the technique.
4. Compute the heat units for a single exposure and then multiply this value by the number of exposures in the series.

$$\text{Heat units (HU)} = \text{kVp} \times \text{mA} \times \text{time} \times 1.35$$

   (The 1.35 factor applies to three-phase generators only.) For example,

$$70 \text{ kVp} \times 50 \text{ mA} \times 6 \text{ sec} \times 1.35 = 28{,}350 \text{ HU}$$
$$28{,}350 \text{ HU} \times 10 \text{ exposures} = 283{,}500 \text{ HU09}$$

5. Refer to the anode thermal characteristics chart and find the maximum number of heat units that may be safely stored in the anode. From Figure 7.5 you can see that the maximum is 135,000 HU. Consequently, the 10-exposure tomographic series, which generates 283,500 HU, cannot be completed without allowing time for the anode to cool between exposures.
6. Divide the maximum heat storage capacity of the anode by the heat units produced by each exposure to find the maximum number of exposures than can be made without waiting for cooling between exposures.

$$\frac{135{,}000}{28{,}350} = 4.76$$

   In the example, four exposures can be made without waiting, but five cannot.
7. Multiply the number of heat units for each exposure by the number of exposures allowed in a series to determine the number of heat units stored in the anode.

$$4 \times 28{,}350 \text{ HU} = 113{,}400 \text{ HU}$$

8. Round off the values to 30,000 HU and 115,000 HU and determine the amount of time required for the anode to cool by 30,000 HU when 115,000 HU are stored. This is slightly less than 1 minute (Figure 7.5).
9. The 10-exposure tomographic series may be safely carried out within the ratings if 4 exposures are made in a series and the remaining 6 exposures made with 1-minute intervals between each exposure.

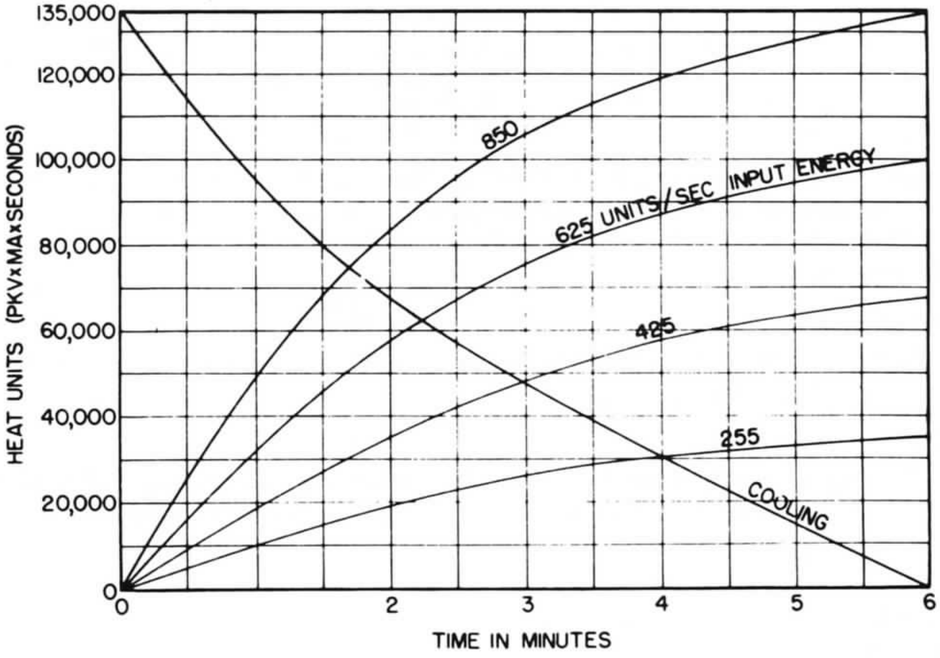

Figure 7.5. Anode thermal characteristic chart for the tube in Figure 7.4. Courtesy of Machlett Corporation.

Problems and Pitfalls

1. The above example assumes that the anode is cool (initially at 0 HU).
2. In general, a 6-minute period between patient procedures will allow the anode to cool sufficiently to start the set of exposures (4 exposures, then 1 each minute) again.

Procedure—Housing Cooling Chart

1. Select the appropriate housing cooling chart.
2. Note the number of heat units that may be safely stored in the x-ray tube housing, e.g., 1,250,000 HU in Figure 7.6.
3. The housing cools from its maximum storage of 1,250,000 HU down to about 800,000 HU in 15 minutes if the x-ray tube is equipped with an air circulator and in 30 minutes without a fan.

Problems and Pitfalls

1. It is essential that the single exposure rating chart and the anode thermal characteristic rating chart be referenced to assure that a single exposure and the proposed series of exposures are permitted.
2. Although the tube housing heat storage capacity is quite large when compared to the heat storage capacity of the anode, conditions that lead to exceeding the tube housing heat storage capacity can and do occur in:
   a. High-use radiographic and fluoroscopic situations
   b. High-use complex motion tomography
   c. Special procedures that involve fluoroscopy, filming, and cineradiography
   d. Frequent rotor starts (1600 HU per start)

Acceptance Limits

Exposure series that exceed the x-ray tube housing rating are unacceptable.

Corrective Action

1. Modifications of procedures may be required to allow sufficient time for the x-ray tube housing to cool.
2. If procedural modifications are not possible consider:
   a. Installation of an air circulator
   b. Replacement of the existing x-ray tube housing with a housing of greater heat storage capacity
   c. Replacement of the existing housing with a housing that is equipped with recirculating cooling system.

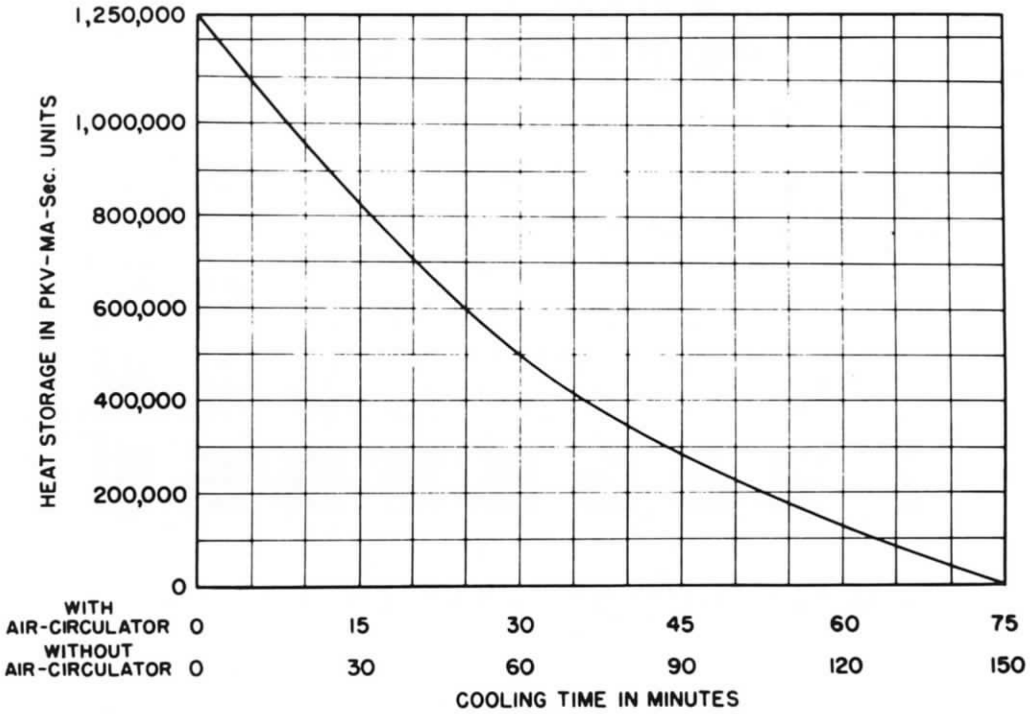

Figure 7.6. Housing cooling chart for use with the tube in Figure 7.4. Courtesy of Machlett Corporation.

Procedure—Angiographic Ratings

1. Select the proper angiographic rating chart (Figure 7.7).
2. Determine the exposure factors to be used for the individual exposures of the angiographic series, the number of exposures and the rate at which the exposures will be made, e.g., 2, 4, or 6 per second.
3. Refer to the x-ray tube single exposure rating chart to assure that technical factors are permitted.
4. Compute the number of heat units for a single exposure.
5. Compare the number of heat units computed in Step 4 to values in the angiographic rating chart to determine if the number of exposures planned in the series can be made without overheating the tube and housing.

Problems and Pitfalls

1. This procedure assumes that the x-ray tube and housing are cool.
2. In heavily used procedure rooms it will be necessary to determine both anode and housing heat storage conditions and allow an appropriate interval between filming procedures for cooling.

Acceptance Limits

The angiographic series must be within the angiographic rating.

Corrective Action

The desired combination of exposure factors, the number of exposures, and the filming rate will have to be modified if the maximum heat load exceeds the x-ray tube angiographic rating. This may be accomplished by:

1. Reducing the total number of exposures in the series
2. Changing to a slower filming rate
3. Increasing the kVp and reducing the mA and/or exposure time
4. Using a faster screen-film system

Procedure—Cine Radiographic Ratings

1. Select the appropriate cineradiographic rating chart.
2. Determine the number of heat units for a single-frame exposure.

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EFFECTIVE FOCAL SPOT SIZE 0.60 MM
STATOR FREQUENCY 180 HERTZ

TOTAL NUMBER OF EXPOSURES

EXPOS. PER SEC	2	5	10	20	30	40	50	60
	MAXIMUM LOAD IN PKV X MA X SEC PER EXPOSURE (*)							
1	20500	13800	9000	5800	4400	3600	3100	2700
2	12600	9600	6800	4500	3400	2900	2500	2200
3	9200	7200	5800	3800	3000	2500	2150	1950
4	7200	5900	4800	3400	2700	2250	1950	1750
5	6000	5000	4100	3100	2450	2050	1800	1600
6	5100	4300	3600	2900	2300	1950	1700	1500
8	4000	3400	2950	2400	2050	1700	1500	1340
10	3300	2900	2500	2050	1800	1550	1380	1240
12	2850	2500	2150	1800	1600	1460	1280	1140

* SUBJECT TO LIMITATION OF THE SINGLE EXPOSURE RATING CHART AS APPLICABLE TO THE INDIVIDUAL EXPOSURE OF THE SERIES

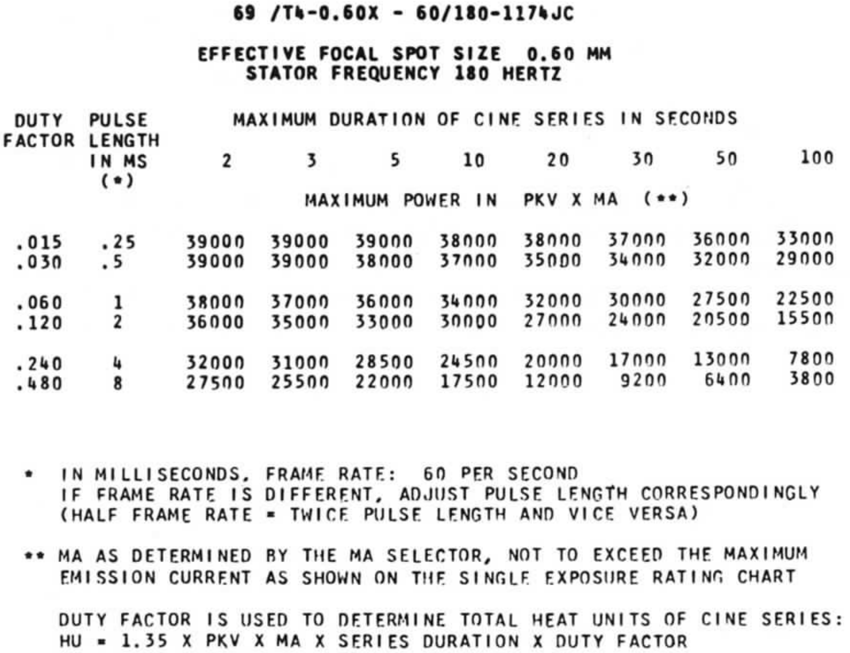
Figure 7.7. Angiographic rating chart for the same tube as in Figure 7.4. Courtesy of Machlett Corporation.

3. Assure that the single-frame exposure does not exceed the single exposure ratings for the x-ray tube.
4. In Figure 7.8, find the appropriate column under the heading "Maximum Duration of Cine Series in Seconds" and select the entry that corresponds to the "Pulse Length in ms." This value is the maximum allowable product of the kVp and mA for the length of the cine run selected and for the pulse length. [**Note:** This is not in terms of heat units (kVp × mA × time) but rather in terms of kVp × mA.]

   Example: Heat Units = 80 kVp × 100 mA × 0.004 sec = 32 HU. This obviously does not exceed the single exposure rating. Assuming a 20-sec cine run at 4 msec we find that the maximum allowable kVp × mA product is 20,000. The product for the combination we have selected is 80 kVp × 100 mA = 8000. This technique is acceptable.
5. If cine runs of lengths other than those given in the chart are anticipated it will be necessary to interpolate to determine the maximum kVp × mA combination.

Problems and Pitfalls

1. The cine radiographic rating chart must be selected properly, with consideration of the focal spot size, stator frequency, three-phase or single-phase generator, etc.
2. The ratings assume that the anode is starting from a cold condition. If previous cine runs have been carried out then it will be necessary to take the cooling characteristics of the anode into account.
3. You must also consider the housing cooling characteristics and heat loading capabilities to assure that the housing is not overheated. Remember that, especially for AP, the heat added to the tube and housing during fluoroscopy may reduce the loading characteristics significantly.
4. Most cine systems use some type of automatic exposure control, so it will be difficult to estimate the factors before the run. However, the technologist should have an idea of the maximum techniques used for specific patient thicknesses and can determine the maximum duration of the cine run, considering the pulse width, from this information.
5. Most cineradiographic rating charts assume a frame rate of 60 frames per sec. If the frame rate is 120 frames per sec, the values in the column labelled "Pulse Length" should be doubled, i.e., from 4 ms to 8 ms. If the frame rate is 30 frames per second, then the values in the column labelled "Pulse Length" should be cut in half.
6. You must be certain not to exceed the maximum mA as shown on the single exposure rating chart.
7. For more specific information on your x-ray tubes used in cine applications, contact the tube manufacturer.



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EFFECTIVE FOCAL SPOT SIZE 0.60 MM
STATOR FREQUENCY 180 HERTZ

DUTY FACTOR	PULSE LENGTH IN MS (*)	MAXIMUM DURATION OF CINE SERIES IN SECONDS							
		2	3	5	10	20	30	50	100
		MAXIMUM POWER IN PKV X MA (**)							
.015	.25	39000	39000	39000	38000	38000	37000	36000	33000
.030	.5	39000	39000	38000	37000	35000	34000	32000	29000
.060	1	38000	37000	36000	34000	32000	30000	27500	22500
.120	2	36000	35000	33000	30000	27000	24000	20500	15500
.240	4	32000	31000	28500	24500	20000	17000	13000	7800
.480	8	27500	25500	22000	17500	12000	9200	6400	3800

* IN MILLISECONDS, FRAME RATE: 60 PER SECOND
IF FRAME RATE IS DIFFERENT, ADJUST PULSE LENGTH CORRESPONDINGLY
(HALF FRAME RATE = TWICE PULSE LENGTH AND VICE VERSA)

** MA AS DETERMINED BY THE MA SELECTOR, NOT TO EXCEED THE MAXIMUM
EMISSION CURRENT AS SHOWN ON THE SINGLE EXPOSURE RATING CHART

DUTY FACTOR IS USED TO DETERMINE TOTAL HEAT UNITS OF CINE SERIES:
HU = 1.35 X PKV X MA X SERIES DURATION X DUTY FACTOR

Figure 7.8. Cine radiographic rating chart for the same tube as in Figure 7.4. Courtesy of Machlett Corporation.

Acceptance Limits

The techniques selected should at not time exceed the cineradiographic, single exposure, or housing ratings.

Corrective Action

1. If ratings are exceeded another technique must be selected.
2. If ratings are consistently exceeded consider using a faster film or having the service engineer open the aperture on the cine camera, adjusting your techniques accordingly. This will also require complete readjustment of the exposure control system.
3. If, after checking housing cooling charts, you find that the heat build-up in the housing is approaching the maximum it will be necessary to:
    a. Use less fluoroscopic time and/or reduce the length of the cine runs in all future cases
    b. Add a cooling system to the housing
    c. Improve the geometry of the x-ray tube-intensifier system
    d. Use a lower frame rate
4. Consider adding a tube heat monitor to your system. This will display the percentage of heat loading remaining. (This device also has an audible alarm that can indicate when you are approaching the maximum allowable loading.)

Procedure—Fluoroscopic Ratings

Most fluoroscopic units are equipped with systems that automatically adjust kVp and/or mA. Prior to proceeding with this section, it is necessary to observe actual operation to determine the usual operating level (kVp and mA), the maximum operating level, the amount of fluoroscopic time used on average per patient, the average time interval between patients, and the average number of factors for the spot films made during the procedures. The following instructions and examples assume that this has been done.

1. Select the appropriate rating charts:
    a. Fluoroscopic (Figure 7.5, graphs labelled heat units/sec input)
    b. Single exposure rating chart (Figure 7.4)
    c. Housing cooling chart (Figure 7.6)
2. Determine the usual and maximum heat unit/sec input rate.

Example usual value: 2.5 mA × 100 kVp = 250 HU/sec
Example maximum value: 5.0 mA × 125 kVp = 625 HU/sec

3. Figure 7.5 shows that neither the usual nor the maximum heat unit/sec input rates stated will exceed the x-ray tube rating during 6 minutes of continuous operation.

Problems and Pitfalls

1. The fluoroscopic rating chart assumes that the anode is starting from a cold condition. If previous fluoroscopic examinations have been carried out, it will be necessary to take the cooling characteristics of the anode into account.
2. This test does not assure that the spot film exposures are within x-ray tube ratings. It is essential that the Single Exposure Rating and Anode Thermal Characteristics procedures be carried out to determine that the spot film exposures do not result in exceeding the x-ray tube ratings.
3. This test does not assure that the x-ray tube's housing rating will not be exceeded during a morning's fluoroscopic exams. Follow the Housing Cooling Chart procedure.

Acceptance Limits

The techniques selected should at no time exceed the fluoroscopic, single exposure, anode cooling, or housing ratings.

Corrective Action

1. If ratings are exceeded, another technique must be selected.
2. If anode cooling or housing ratings are routinely exceeded, consider:
   a. Extending the interval between patients
   b. Reducing the fluoroscopic time or number of spot films taken per procedure
   c. Installing a circulating fan and vent system to exchange the air inside the fluoroscopic table
   d. Installing a larger capacity x-ray tube

7.2. OVERLOAD PROTECTION

Purpose

To assure that the maximum exposure techniques that the x-ray generator overload-protection circuit will allow are within the 80% limitations of the x-ray tube rating chart.

Equipment Needed

Single exposure rating charts for the specific model of the x-ray tube

Procedure

1. Select the appropriate single exposure rating chart for your x-ray tube, focal spot size, type of generator, and anode rotational speed (for example, 0.6-mm focal spot, three-phase full wave rectification, and 180-Hz stator frequency).
2. Set the x-ray generator controls appropriately, e.g., to the small focal spot setting, the high speed rotor, and 100 kVp.
3. Refer to the single exposure rating chart and determine 80% of the maximum exposure time at 100 kVp allowable for each mA setting available on the generator control that can be used with the x-ray tube small focal spot. For example:

mA	Rated exposure time (sec)	80% rated exposure time (sec)
400	0.01	0.008
300	0.40	0.32
200	2.2	1.76

4. Set the generator controls to the "80% Rated Exposure Time" factors, one combination at a time, and observe the x-ray tube overload indicator.
5. If the tube protection circuit does not indicate tube overload, increase the exposure time until the tube overload circuit indicates an overload. DO NOT make an x-ray exposure.

6. If the tube protection circuit indicates a tube overload in Step 4, reduce the exposure time in steps at each mA setting to determine the point at which the tube overload protective circuit is set.
7. Repeat Steps 1 through 6 using values from the appropriate single exposure rating charts for the large focal spot.
8. Record the values in the QC room log.

Problems and Pitfalls

1. It is essential to check the function of the x-ray tube overload protection circuit on each mA station that may be used with each of the focal spots.
2. On x-ray generators that offer continuous control of mA, check the function of the tube overload protection circuit at the maximum obtainable mA with each focal spot and at approximately one-half and one-fourth of this value.
3. Overload protection circuits do not protect the tube from overheating that may occur from exposures made in a series.

Acceptance Limits

The x-ray overload protective circuit should indicate tube overload and prevent an x-ray exposure at about 80% of the x-ray tube rating and should function within ±10% of that value.

Corrective Action

1. Immediate adjustment by a qualified service engineer is indicated if the overload protection circuit fails to indicate an overload for a combination of exposure factors that exceeds the single exposure rating.
2. Adjustment of the overload protection circuit by a qualified service engineer may be desirable if exposure factors of 80% of the x-ray tube's single exposure ratings cannot be obtained to avoid unnecessarily restricting the use of the equipment.
3. Function of the overload protection circuit should also be checked whenever the x-ray tube is changed.

7.3. X-RAY TUBE FOCAL SPOT SIZE MEASUREMENTS

Purpose

To assure that the x-ray tube focal spot size is within acceptable limits.

Equipment Needed

1. Star test pattern (1.5° or 2°; Figure 7.11a)
2. Screen-film extremity cassette, 8 × 10 inch (20 × 25 cm)
3. Lead letters, A and C
4. Clear plastic centimeter ruler
5. Pinhole camera test stand (Figure 7.9) with appropriate-sized pinholes
6. Small fluorescent screen
7. Spirit level
8. A 6× magnifier with reticle scale in 0.1-mm divisions

Procedure—Star Pattern Test for Focal Spots 0.3 mm or Smaller

1. Tape a star test pattern to the bottom of the collimator face plate while centering the star to the cross hair with the centering light or on a test stand (Figure 7.10).
2. Adjust the x-ray tube mount to the center, perpendicular position.
3. Place the image receptor on the x-ray table top. Set the focal spot-to-film distance to 24 inches (60 cm) and collimate the beam so that the total test pattern is included in the field.
4. Place the lead letters A and C on the film holder to denote the anode and cathode orientation of the x-ray tube.
5. Expose the radiographs using technical factors of 75 kVp and half the maximum rated mA at 0.1 sec for each focal spot. Use an exposure time appropriate to obtain 10–15 mAs.

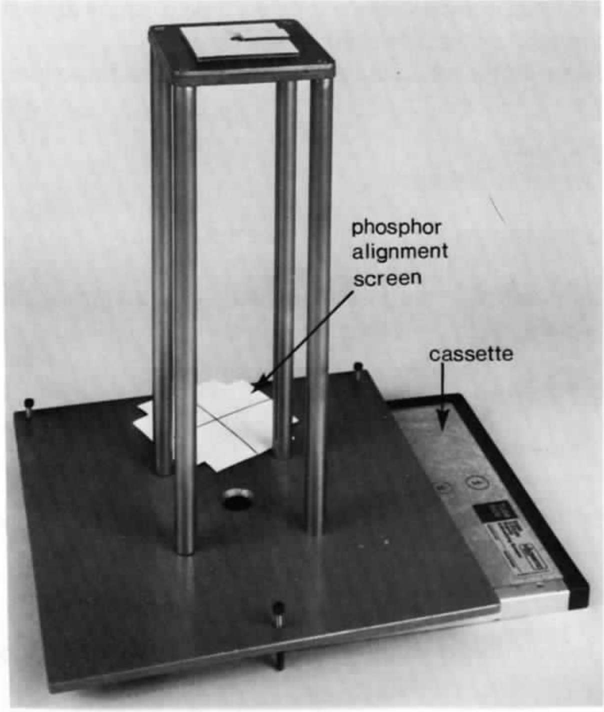

Figure 7.9. A commercially available pinhole camera has been modified by the addition of a large leveling base, which also allows the use of an 8 × 10-inch (20 × 25-cm) extremity cassette system. In addition a lead rubber mask has been placed on top of the camera to attenuate the radiation that passes through the large alignment holes and to eliminate an artifact produced as a result of poor fitting of the pinhole assembly. For further details of the modifications see Gray and Trefler (1980). (Reproduced with permission from: Gray, J. E., and Trefler, M. 1980. Pin-hole cameras: Artifacts, modifications, and recording of pin-hole images on screen film systems. *Radiologic Technology* 52:277-282.)

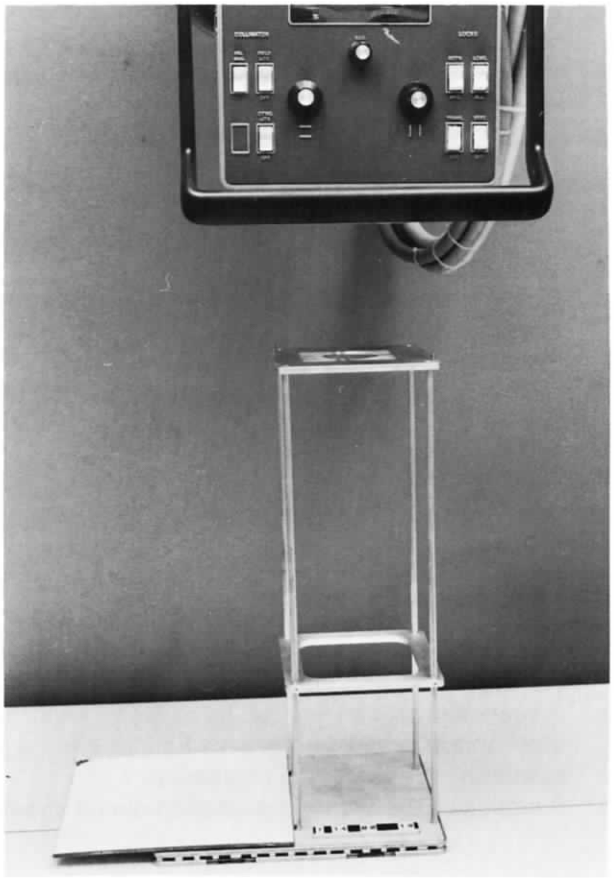

Figure 7.10. X-ray tube focal spot size star measurement test setup. The star test target (see Figure 7.11) is placed on top of the stand and an image is produced using an extremity cassette system. Images made with both the large and small focal spot can be placed on the same sheet of film.

6. Measure the total diameter of the star pattern image on the radiograph. This dimension should be about 90 mm ± 2 mm, assuming a 45-mm star target.
7. Starting at the outside edges of the star test pattern and in the same direction as the anode-cathode axis, move toward the center of the image and make sharp lead pencil marks on both sides where the bars first disappear (Figure 7.11b). Repeat the procedure in the other direction, i.e., 90° to the anode-cathode axis.
8. With a clear plastic ruler, measure and record the distance between the pencil marks made in Step 7 and record these dimensions with respect to the anode-cathode axis.
9. Compute the focal spot size. The width is determined by the measured dimension along the anode-cathode axis and the length is computed from the dimension measured at 90° to the anode-cathode axis. For a 2° star, the focal spot size is:

$$\frac{\text{Diameter of blurred area}}{28.65\left(\dfrac{\text{Diameter of star image}}{45\text{ mm}}-1\right)}$$

For a 1.5° star, the focal spot size is:

$$\frac{\text{Diameter of blurred area}}{38.2\left(\dfrac{\text{Diameter of star image}}{45\text{ mm}}-1\right)}$$

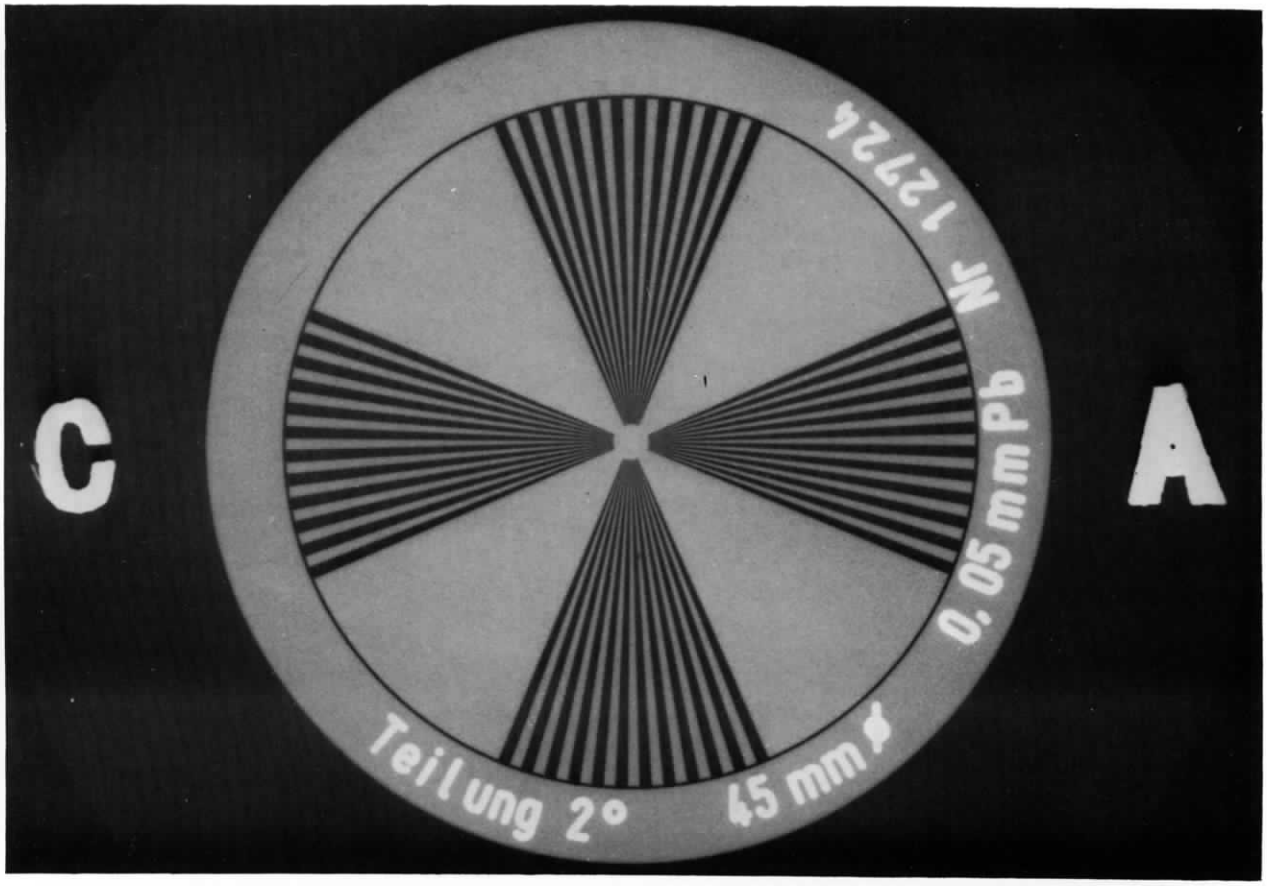

Figure 7.11a. Contact radiograph of star test target made of 0.05-mm thick lead with 2° angles for the bars and spaces.

For example, the distance between the blurred regions of a 1.5° star target along the anode-cathode axis is 15 mm, giving a focal spot width of:

$$\frac{15\text{ mm}}{38.2\left(\frac{90\text{ mm}}{45\text{ mm}}-1\right)} = 0.39\text{ mm}$$

10. Record the results in the QC room log.

Problems and Pitfalls

When the star pattern radiographs are viewed it is frequently observed that the star images are first lost and then reappear toward the center of the image. This is known as false resolution. Ignore this reappearance. For the purpose of these measurements, the first point at which star images cannot be resolved is the point of interest.

Acceptance Limits

The National Electrical Manufacturers Association (NEMA) specifies that focal spots with a nominal size of 0.3 mm or less should be measured with a star pattern. The measured size may be 50% greater than the nominal, or stated, size and still be within specifications. This means that a 0.3-mm focal spot may be as large as 0.45 mm when measured using the star technique and still be considered as a 0.3-mm focal spot.

For focal spots larger than 0.3 mm, NEMA requires that the focal spot measurements be made with a pinhole camera for acceptance testing purposes. However, some manufacturers may agree to the use of the star target measurement for acceptance testing of focal spots larger than 0.3 mm. This should be discussed with the vendor prior to tube purchase and the acceptance limits should be established at this time. At our institution, we do use star target measurements, and our acceptance limits are those specified by NEMA for the pinhole measurements except that the 0.7 correction factor (see the following pages) is not applied.

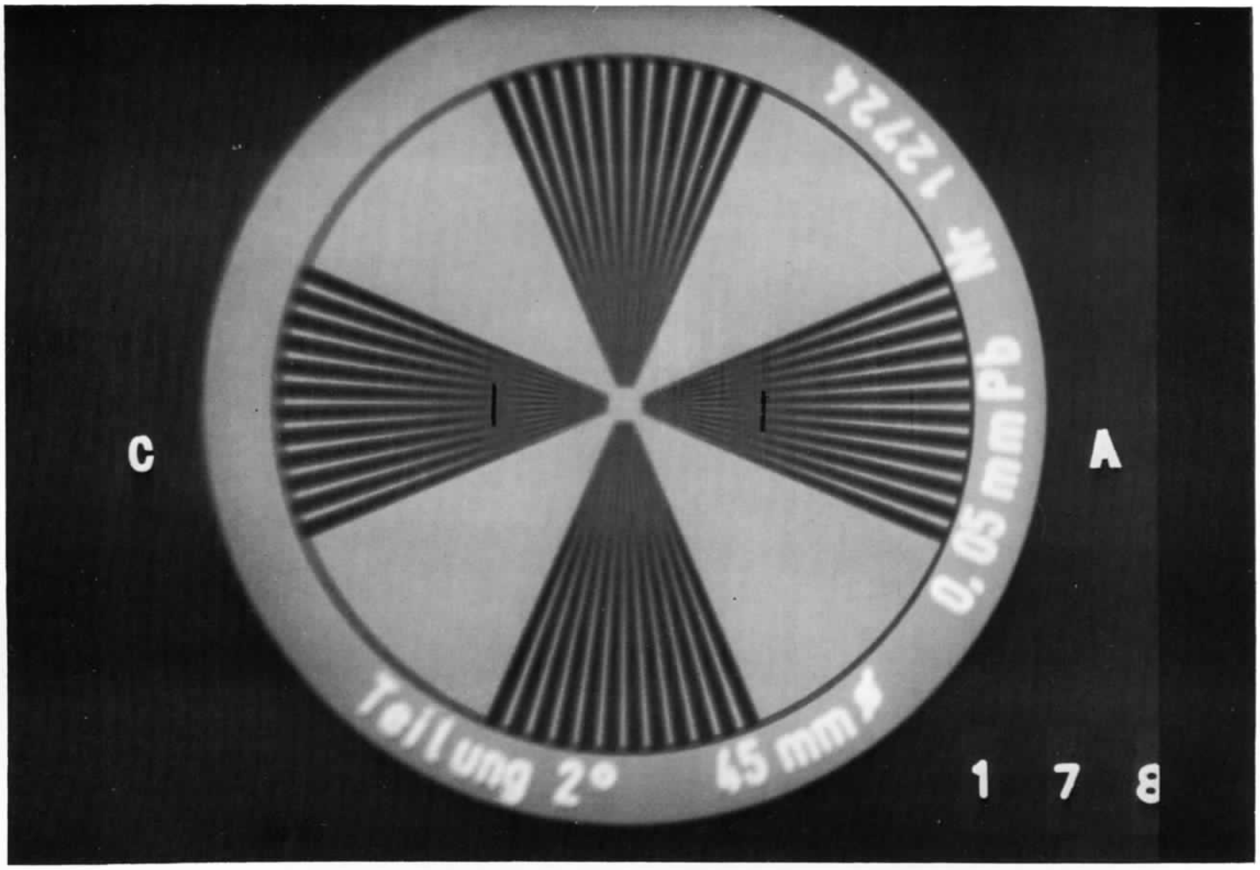

Figure 7.11b. Star target image made under the geometry described in the text with a 0.6-mm focal spot. Measurements should be made of the first blur patterns, moving in from the outside of the star, where the bars first disappear.

Procedure—Pinhole Camera Measurement for Focal Spots Larger Than 0.3 mm

1. Place the pinhole camera test stand on the x-ray tabletop (or other means of firm support) and align the locator holes to the anode-cathode axis of the x-ray tube (Figure 7.12).
2. Check the test stand for perpendicularity and level with the spirit level.
3. Center the x-ray beam to the pinhole camera and adjust the pinhole-to-film distance and x-ray tube focal spot-to-film distance to obtain the proper enlargement factor. For focal spots 2.5 mm in size or smaller the enlargement factor should be 2.0 (pinhole-to-film distance equal to 60 cm and the focal spot-to-pinhole distance equal to 30 cm). For focal spots larger than 2.5 mm the enlargement factor should be 1.0 (pinhole-to-film distance equal to 40 cm and the focal spot-to-pinhole distance equal to 40 cm).
4. Place the small fluorescent screen on the camera base plate.
5. Set a radiographic exposure technique of about 75 kVp, 50 mA, and 2 sec or use the fluoroscopic mode if available.
6. Turn off all room lights and view, on the fluorescent screen, the location of the images projected from the center and the supplemental locator holes. Shift the test stand to assure that the three holes are centered to the cross-hairs on the fluorescent screen.
7. Insert the pinhole of the size appropriate for the focal spot to be measured:
    a. Use 0.030 mm for focal spots smaller than 1.0 mm
    b. Use 0.075 mm for focal spots from 1.0 mm to 2.5 mm
    c. Use 0.100 mm for focal spots larger than 2.5 mm
8. Expose the extremity cassette at factors of 75 kVp, and one-half the maximum rated mA at 0.1 sec. About 50 mAs will be required.
9. Process and view the pinhole image and check that the density of the pinhole image is in the range of 0.8–1.2 above the density of the unexposed film, or is of a reasonable density.

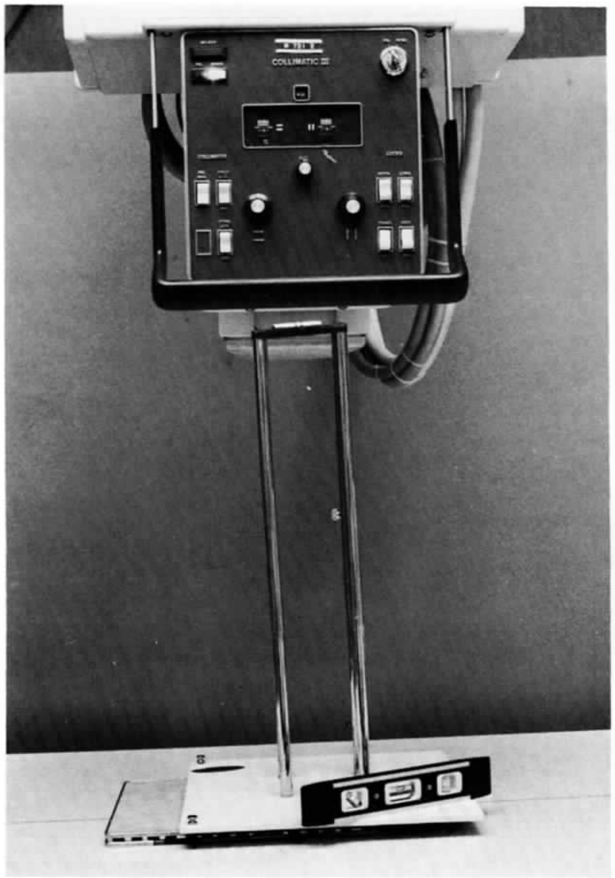

Figure 7.12. X-ray tube focal spot size pinhole measurement test setup. The pinhole camera top plate, containing the pinhole, should be leveled, as has not yet been done in this figure. With the appropriate modifications an extremity cassette may be slid under the camera and multiple exposures can be made on one film.

10. When a satisfactory pinhole camera radiograph has been obtained, measure the image of the focal spot as follows:
    a. Use a magnifying lens with a built-in graticule with 0.1-mm divisions and a 6 × magnification.
    b. Measure the x-ray image in two directions, i.e., parallel to and perpendicular to the anode-cathode axis. Divide the measurements obtained by the enlargement factor in Step 3 to obtain the dimensions of the focal spot. An additional correction factor of 0.7 is applied as a multiplier to the measured dimension made parallel to the anode-cathode axis.

Problems and Pitfalls

1. Misalignment of the pinhole with respect to the anode-cathode axis and the central beam of the x-ray tube can alter the measurements.
2. The focal spot size may change with mA and kVp; therefore, it is essential that measurements be made as specified.
3. Expect to see two areas of density in the pinhole camera image separated by a lesser-exposed central portion (Figure 7.13).
4. The manufacturer may require the use of direct x-ray exposed film instead of an extremity cassette system for acceptance testing.

Acceptance Limits

The National Electrical Manufacturers Association (NEMA) specifies that focal spots with a nominal size of 0.3 mm or less should be measured with a star pattern. For focal spots larger than 0.3 mm NEMA requires that the focal spot measurements be made with a pinhole camera for specification and acceptance testing purposes. For focal spots smaller than 0.8 mm the measured size may be 50% greater than the nominal size. For focal spots from 0.8 mm to, and including, 1.5 mm the measured size may be 40% greater than the nominal size. For focal spots greater than 1.5 mm, the measured size may be 30% greater than the nominal size. (All pinhole measured sizes are those obtained after applying the 0.7 multiplication factor to the dimension parallel to the anode-cathode axis.)

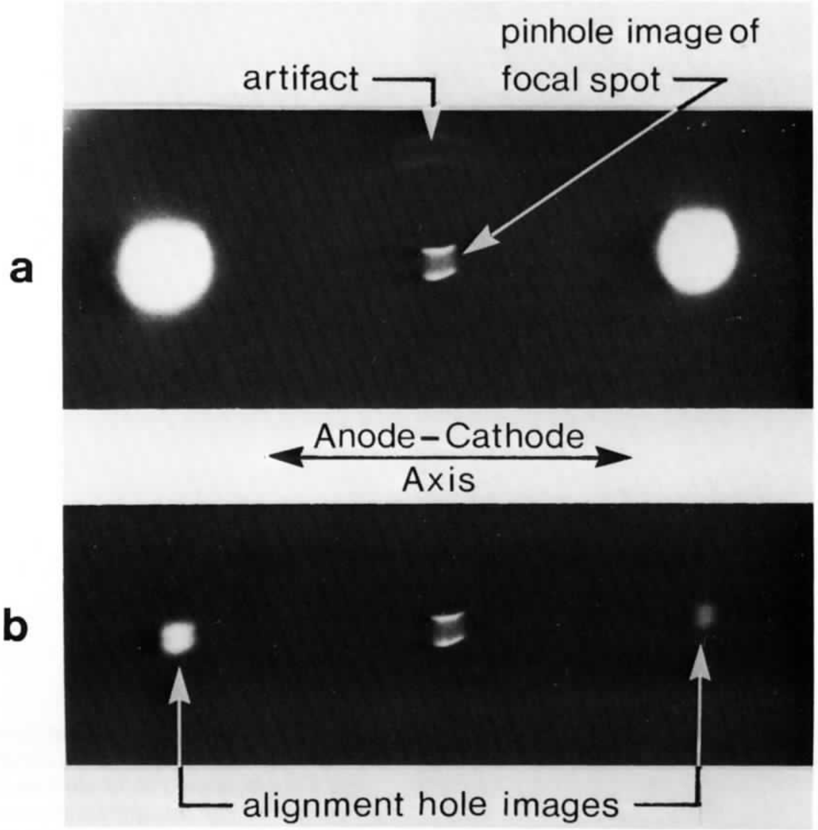

Figure 7.13a and b. Pinhole camera results. (**a**) Result of producing a pinhole camera image without the lead rubber cover described in the literature. (**b**) After placing the lead rubber on the top plate of the camera the artifact is eliminated and the exposure through the alignment holes is reduced, making the measurement of their separation, and hence determination of the magnification, easier. (Reproduced with permission from: Gray, J. E., and Trefler, M. 1980. Pin-hole cameras: Artifacts, modifications, and recording of pin-hole images on screen film systems. *Radiologic Technology* 52:277–282.)

Corrective Action

There is nothing that can be done to correct an oversized focal spot. It is essential to repeat the test if the focal spot is found to be oversized to assure that the measurements are correct. If the focal spot is oversized, request replacement of the x-ray tube by the vendor.

7.4. X-RAY-LIGHT FIELD, X-RAY FIELD, BUCKY ALIGNMENT TESTS, AND EXPOSURE CONSISTENCY

Purpose

1. To assure that the x-ray field and the light field are congruent and that the automatic collimation system adjusts to the cassette size used, or that the film size indicators of a manual system are accurate. Also to assure that the patient entrance exposure is similar from room-to-room.
2. To assure that the central x-ray beam is perpendicular to the table.
3. To assure that the x-ray field is centered to the cassette and to the cassette tray.

Equipment Needed

1. Collimator alignment template marked from center to edge in either centimeters or inches
2. X-ray beam alignment test tool
3. One 10 × 12-inch (24 × 30-cm) single screen extremity or mammographic cassette [**Note:** If a single screen cassette is not available, a conventional cassette with the front screen blocked with a totally blackened sheet of x-ray film will produce similar results.]

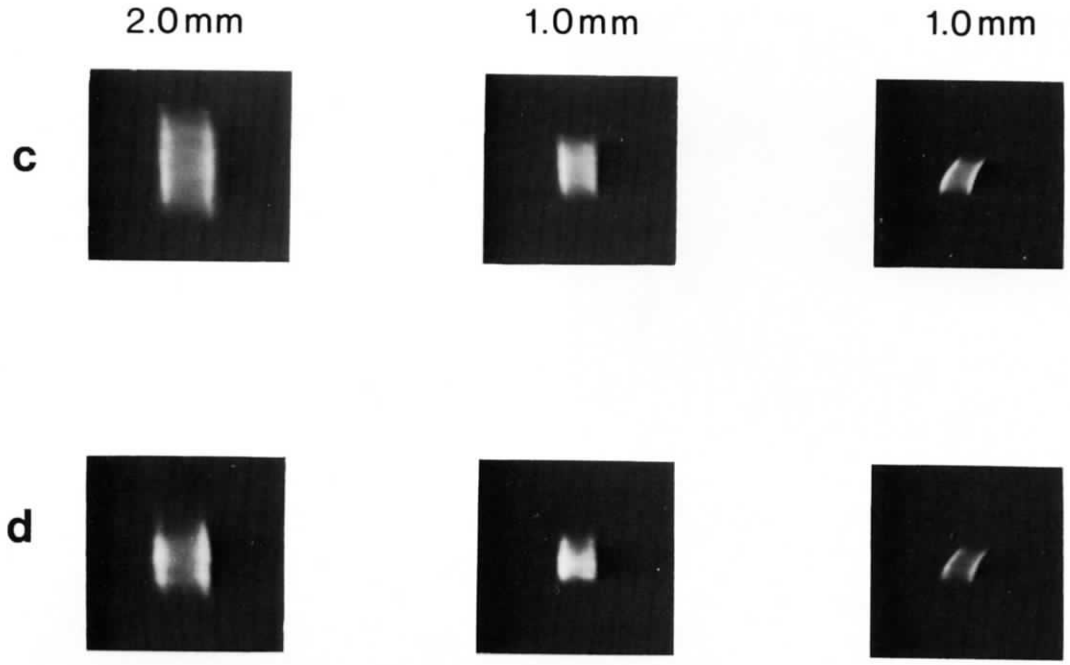

Figure 7.13c and d. Pinhole images of three focal spots with nominal sizes of 1.0 and 2.0 mm made on (**c**) dental x-ray film and (**d**) an extremity cassette system. (Reproduced with permission from: Gray, J. E., and Trefler, M. 1980. Pin-hole cameras: Artifacts, modifications, and recording of pin-hole images on screen film systems. *Radiologic Technology* 52:277–282.)

4. One 8 × 10-inch (20 × 25-cm) cassette
5. Several straightened paper clips, or solder strips
6. Spirit level
7. Lead letters, A and F
8. One sheet of scrap film for each cassette size to be evaluated
9. Patient equivalent phantom (PEP)
10. Direct readout dosimeter

Procedure—Light Field, X-ray Field Alignment, and Perpendicularity

1. Set the x-ray tube to the transverse center position at the most commonly used SID.
2. Stand at the end and then the side of the table and visually inspect the x-ray tube and collimator assembly for perpendicularity and centering to the tabletop. If problems are found, correct them before continuing.
3. Place the alignment template on top of the 10 × 12-inch (24 × 30-cm) single screen cassette, and center the cassette and template to the center line of the table, or to the collimator if the tabletop is not marked (Figure 7.14).
4. If the unit being tested has a tilting top or a curved top, the template with cassette should be checked with a level both longitudinally and transversely to assure it is level.
5. Place the x-ray beam alignment test tool in the exact center of the template (Figure 7.14).
6. Adjust the collimator light field to the light field alignment marks on the template.
7. If the light field is centered to the template and one or more of the edges of the light field are not on the corresponding field marks, place straightened paper clips, or solder strips, on the edges of the light field to denote their location.
8. Place the lead letter "A" to denote the anode of the x-ray tube, and the lead letter "F" toward you to denote the front of the x-ray table, along with the date and room number.
9. Make a radiographic exposure at the factors of approximately 65 kVp and 10 mAs. [***Note:*** Do not move the cassette-template combination or the x-ray tube.]
10. Securely lock an 8 × 10-inch (20 × 25-cm) cassette in the Bucky tray and center the tray to the Bucky tray centering light.

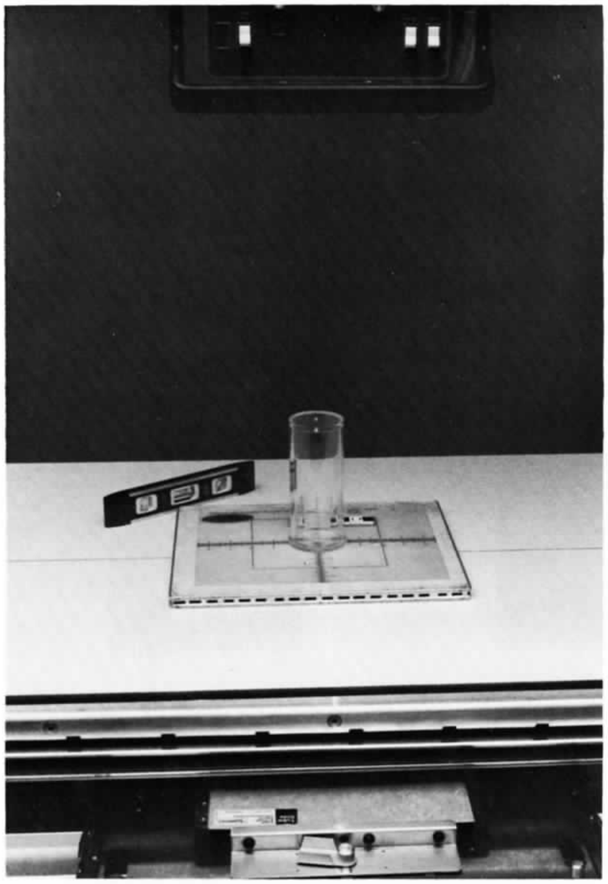

Figure 7.14. X-ray–light field alignment and x-ray beam perpendicularity test setup.

11. If your system has positive beam limitation (PBL), close the tray and allow the system to automatically adjust to the cassette in the Bucky tray. If your system has manual collimation, adjust the field size to the appropriate film size using field size indicators of the collimator. [***Note:*** Make sure the indicator corresponds to the SID being used.]
12. Expose *both* cassettes at approximately 65 kVp and 10 mAs.
13. Process both radiographs to determine beam alignment, x-ray field–light field alignment, and sizing.
14. The twice-exposed *tabletop film* is used to determine the central ray perpendicularity, collimator x-ray field-to-light field alignment, and x-ray field size of the PBL system or field size indicator of a manual system. The film from the *Bucky tray* is used to determine Bucky tray film centering, and for comparison with the tabletop film to determine PBL system or field size indicator accuracy (Figure 7.15).
15. The x-ray field-to-light field alignment is determined by measuring the distance between the image of the inscribed light field alignment marks of the template and the edge of the x-ray field (Figure 7.15).
16. The method of determining the central ray perpendicularity will vary somewhat with the manufacturer of the alignment test tool. In most cases the perpendicularity is checked by measuring the deviation between the upper (magnified) bead and the bead or ring at the bottom of the test tool.
17. To determine PBL system misalignment, or field size indicator accuracy, place both the tabletop and Bucky tray film in the same orientation side by side on a viewbox. First, determine the maximum area of the Bucky tray film by observing the outermost image of the measuring scale (inches or centimeters) seen on the alignment template along all four dimensions of the film. Then with a felt-tip pen mark the corresponding numeric information onto the scale imaged on the tabletop film. Using this scale, or a ruler, measure the difference between the area imaged on the Bucky tray and tabletop films to determine the total misalignment.
18. To assure that the film in the Bucky tray is centered to the x-ray beam, visually check for squareness to the collimator alignment template. Then using the measuring scale of the template, measure the distance from the center of the template to all four edges of the Bucky tray film.

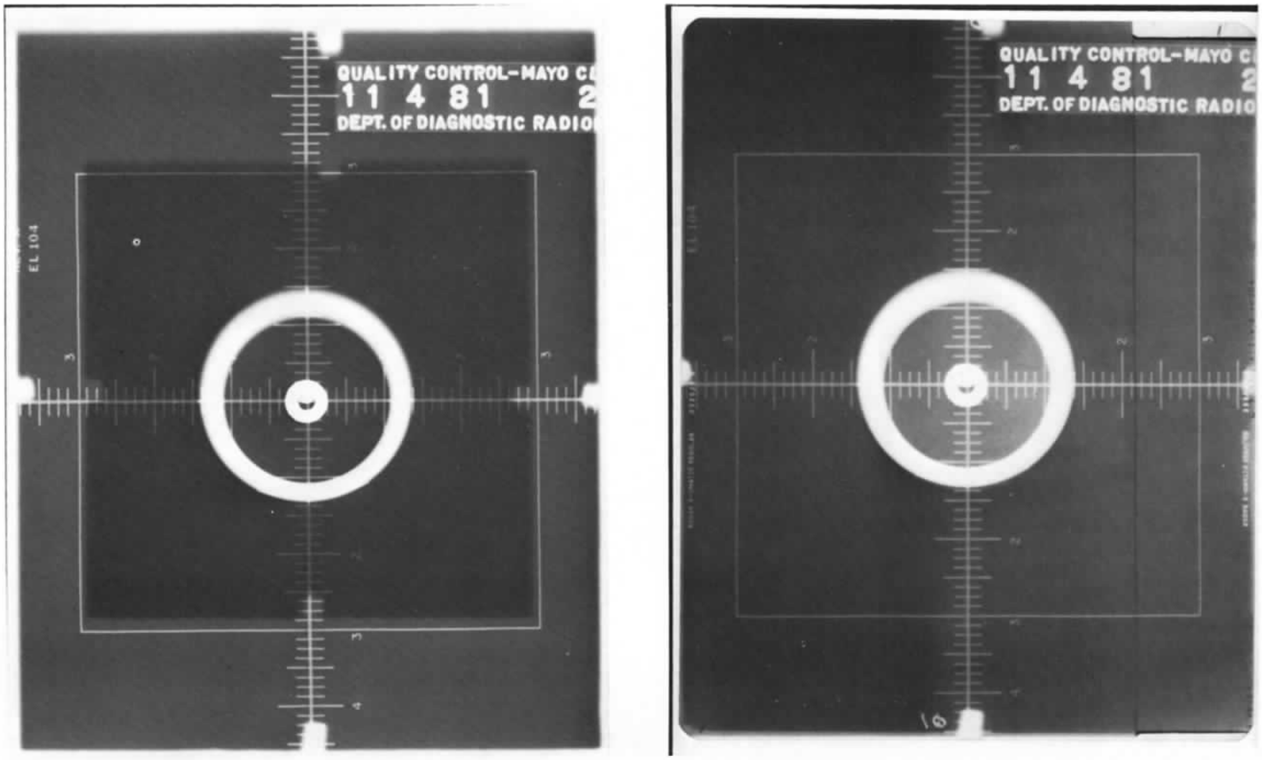

Figure 7.15a. Acceptable x-ray-light field alignment and x-ray beam perpendicularity test results. Left film from tabletop; right film from Bucky tray.

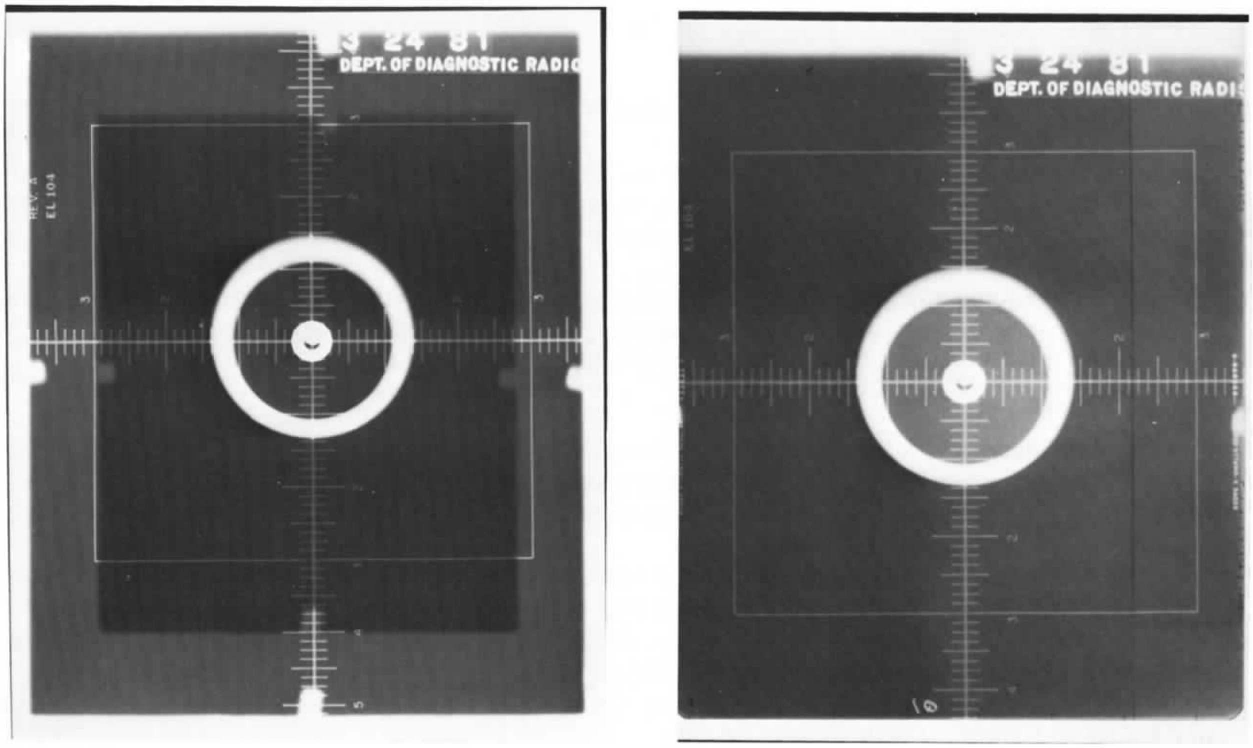

Figure 7.15b. X-ray beam perpendicularity is acceptable but the lower collimator leaf extends out too far (left film) and the film from the Bucky tray (right) indicates that the cassette was not centered properly.

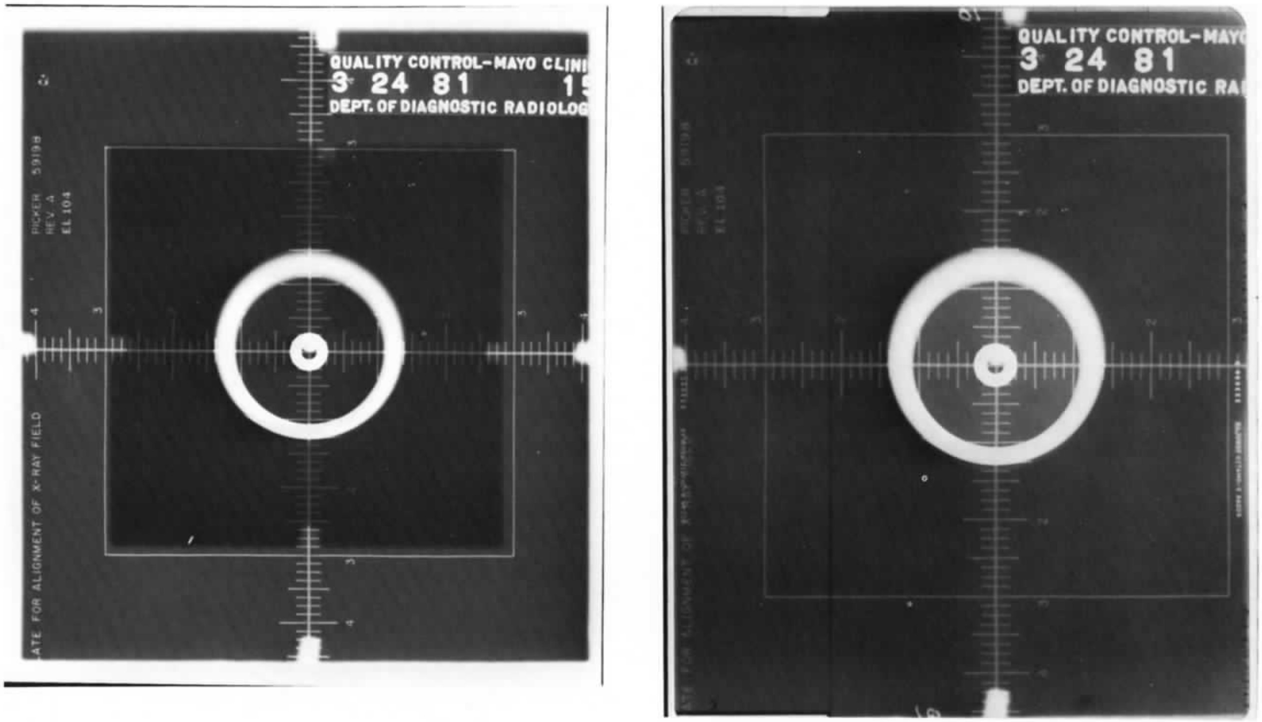

Figure 7.15c. This would be an acceptable result except that the x-ray beam perpendicularity exceeds acceptance limits. Left film from tabletop; right film from Bucky tray.

19. Record the collimator light field-to-x-ray field, PBL or film size indicator, and Bucky tray film alignment in millimeters in the QC room log. A simple "pass" or "fail" for central ray perpendicularity should also be recorded.

Problems and Pitfalls

1. The field edges of the projected light field are fuzzy with some collimators. This makes it difficult to exactly adjust the light field.
2. Balancing the film density between the tabletop and Bucky tray films may be difficult, particularly if a conventional cassette with the front screen blocked is used. If your department has several different screen-film speed combinations, use a higher-speed combination in the Bucky tray and a slower combination on the tabletop.
3. The image of the collimator template will be somewhat magnified on the film exposed in the Bucky tray. This magnification is a result of the divergence of the x-ray beam so the procedures previously described will be accurate, but measurements from the scale of the template will not match the actual size of the film.

Acceptance Limits

1. Federal guidelines allow ±2% of the SID in collimator light-to-x-ray field and PBL system misalignment (e.g., a 100-cm SID would allow ±2 cm) for certified equipment in x-ray field-light field alignment and sizing. However, a ±1-cm acceptance limit is reasonably achievable and is recommended for most modern equipment.
2. The edge of the radiation field should be within ±1 cm of the template markers denoting the location of the light field edges. This should include field edges that do not align with the template marks.
3. For both automatic (PBL) and manual collimation, the maximum area exposed on the tabletop film should be within ±1 cm of the maximum area of the Bucky tray film.
4. The film from the Bucky tray should be centered within 1 cm in all directions from the center of the template and should be square to the alignment template.
5. The image of the upper bead (magnified) should fall within 5 mm of the lower bead or ring, particularly if a high-ratio Bucky grid is in use.

Corrective Action

Resizing of field size and alignment of the light field–x-ray field and/or perpendicularity by qualified service engineers is required if acceptance limits are exceeded.

Procedure—Field Size vs. Cassette Size for PBL Systems.

1. Set the x-ray tube at the SID used for Bucky radiography.
2. Make sure the PBL selector is set to automatic mode.
3. Insert the size of cassette commonly used in the Bucky tray lengthwise and then transverse. Check visually that the changes in the light field size occur with cassette size and that the size of the light field is appropriate by comparing the light field size with an appropriate sized sheet of scrap film placed on the tabletop.
4. Record the results in the QC room log.

Problems and Pitfalls

1. Make sure that the light field to x-ray-field alignment is acceptable by the collimator template or the nine-penny test before doing this test.
2. Due to x-ray beam divergence, the field size at the film during actual Bucky radiography will be slightly larger than as measured on the x-ray tabletop. For this reason, the light field should be slightly smaller than the scrap film sheet.

Acceptance Limits

Federal guidelines for certified equipment allow a variation of ±2% of the SID. Thus, a ±2-cm variation in field size is acceptable. However, a ±1-cm variation is reasonably achievable, and should be the acceptance limit for most modern equipment.

Corrective Action

A service engineer should be called in to readjust the PBL system if acceptance limits are exceeded.

Procedure—X-ray Beam, Bucky Grid Motion and Centering, Image Receptor Alignment, and Exposure Consistency

1. Place the x-ray tube in the transverse center position.
2. Place solder strips on the x-ray tabletop aligned to the light field cross-hairs and tape them in position (Figure 7.16a).
3. Place the patient equivalent phantom on top of the solder strips, center the phantom to the light field, and place the small dosimeter chamber above and in contact with the top of PEP, close to the center (Figure 7.16b).
4. Insert a 14 × 17-inch (35 × 43-cm) cassette transversely in the Bucky tray.
5. Allow the automatic collimator to set the field size. On manual systems, collimate the x-ray beam to the cassette size.
6. Make a radiographic exposure using the factors appropriate for a 21-cm AP view of the abdomen from the technique chart in the room.
7. Record the results (Figure 7.17) and the dosimeter reading in the QC room log.

Problems and Pitfalls

1. The x-ray field–light field alignment test must be done before this test.
2. This test serves to identify whether or not a problem exists, but is nonspecific as to cause.
3. Expect density variation across the phantom image along the anode-cathode axis because of heel effect.
4. Problems caused by cassette tray interference with Bucky motion are frequently not demonstrated unless a 14 × 17-inch (35 × 43-cm) cassette is used transversely.
5. Some Bucky grids have many flaws that may cause artifacts. Replacement of the grid may be the only way to correct such artifacts.
6. Some tabletops may also contain flaws, or residual contrast media on the table or grid may produce artifacts.
7. The dosimeter must be positioned in the same location each time, both along and perpendicular to the anode-cathode axis, to assure consistent results.

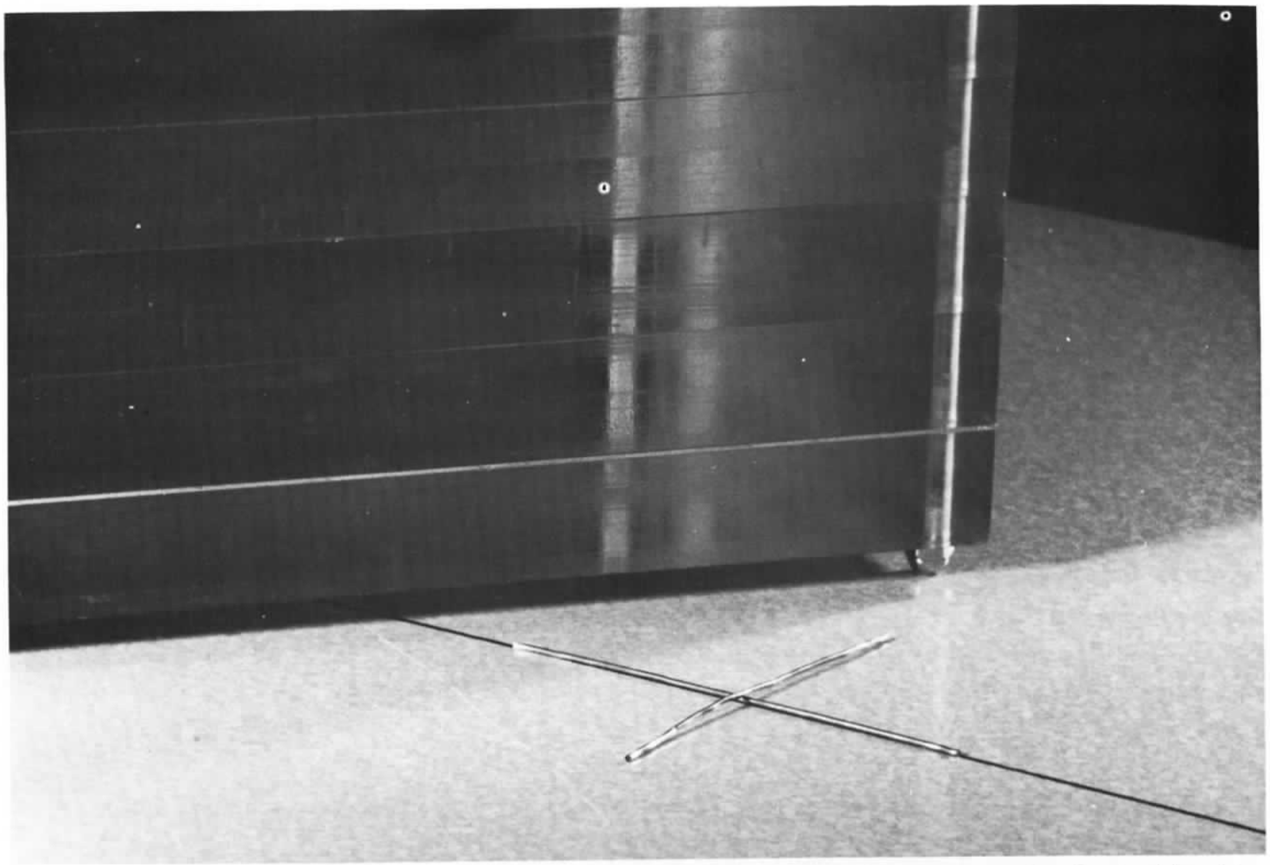

Figure 7.16a. X-ray beam, Bucky grid motion and centering, and image receptor alignment test setup. Lead solder strips should be placed on the tabletop, centered to the collimator cross-hairs, and then the PEP placed on top of the strips.

Acceptance Limits

1. The radiograph should show that the lead solder strips are centered to the cassette within ± 1 cm and the radiograph should appear evenly exposed across the transverse dimension.
2. For rooms using similar generators, tubes, collimators, tabletops, and screen-film combinations, the entrance exposures to the phantom should be within ± 10%. If there is a greater variation, you should investigate the cause, paying particular attention to the HVL, output of the x-ray tube, and any other factors that may affect the exposure to the patient. If rooms do not use similar equipment, then exposure variations will be greater than noted above. However, you should investigate the reason for these variations and consider differences in the tabletops, HVLs, collimator design, x-ray tubes, and any other factors that may affect the output of the x-ray generator and the patient exposure.
3. Three-phase and single-phase generators should produce similar exposures to the patient if the techniques for the single-phase generators are set approximately 10 kVp higher than those for the three-phase generators. This will also result in similar HVLs for the same radiographic projections, and the resultant films should appear identical, assuming that the mAs has been changed to match film densities.

Corrective Action

An evaluation and correction of the grid alignment, centering, and Bucky motion by a qualified service engineer is in order if excessive density variation (greater than ± 0.10) is found transversely on the test film.

7.5. HALF-VALUE LAYER (HVL) MEASUREMENT

Purpose

To assure that the permanently installed filtration at the x-ray tube is maintained at an appropriate level to help minimize patient exposure.

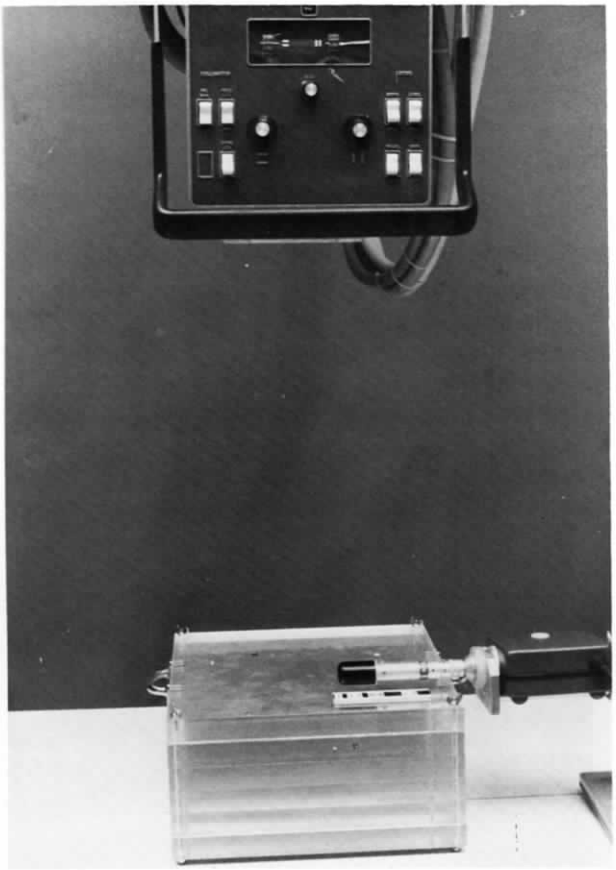

Figure 7.16b. A direct-readout dosimeter and date-room identification marker should be placed in the lower corner of the phantom as shown.

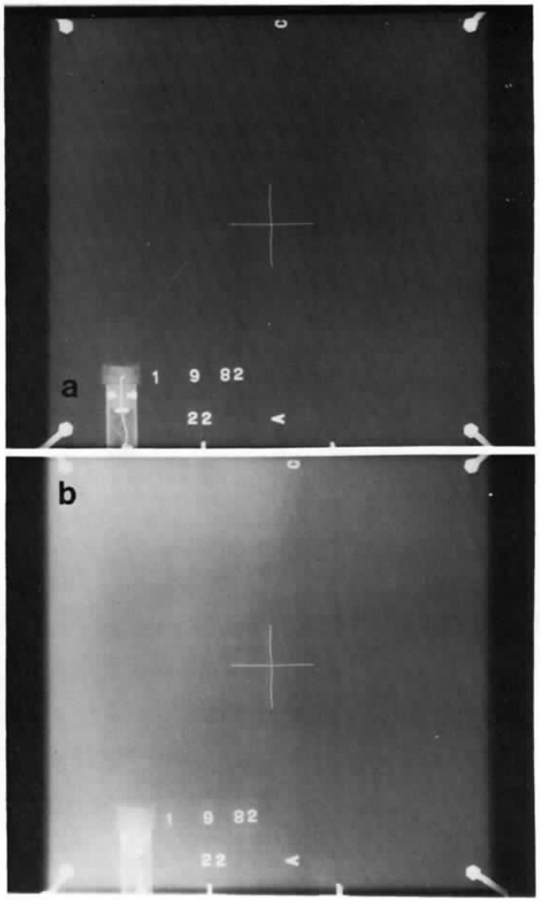

Figure 7.17. X-ray beam, Bucky grid motion and centering, and image receptor alignment test results. (**a**) The film densities should be uniform and on the order of 1.2 above base-plus-fog levels for a 21-cm lumbar spine technique. Some change in density will be noted along the anode-cathode axis. (**b**) This film is exceptionally light, in addition to the fact that the densities are not uniform, indicating a grid alignment, centering, or Bucky motion problem.

Equipment Needed

1. Dosimeter
2. Known thickness of aluminum (1100 alloy):
   a. Four pieces 6 × 6 inch × 1.0 mm thick (150 × 150 × 1 mm)
   b. One piece 6 × 6 inch × 0.5 mm thick (150 × 150 × 0.5 mm)
   c. One piece 6 × 6 inch × 0.25 mm thick (150 × 150 × 0.25 mm)
3. Lead sheet
4. Test stand (Figure 7.18)
5. Semi-logarithmic graph paper

Procedure—Overtable Radiographic and Fluoroscopic Tubes

1. Center the lead sheet on the x-ray tabletop with the test stand on top of the lead sheet (Figure 7.18a).
2. Place the dosimeter chamber on top of the lead sheet directly under the test stand.
3. Set the x-ray tube to a 36-inch (90-cm) source-to-tabletop distance and center the x-ray field through the opening on top of the test stand to the dosimeter chamber below, making sure the entire chamber will be included in the x-ray field.

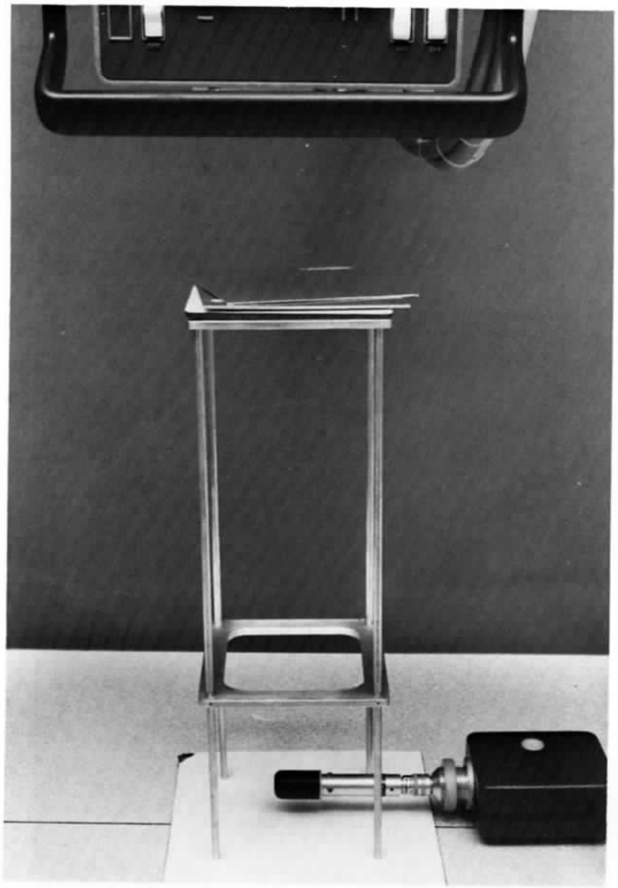

Figure 7.18a. HVL measurement setup for an overtable x-ray tube with a lead sheet under the dosimeter. The geometry for HVL measurements should be selected so that the aluminum filtration being added to make the measurement is placed halfway between the x-ray source and the ionization chamber. The x-ray beam must be collimated to an area just slightly larger than the ionization chamber.

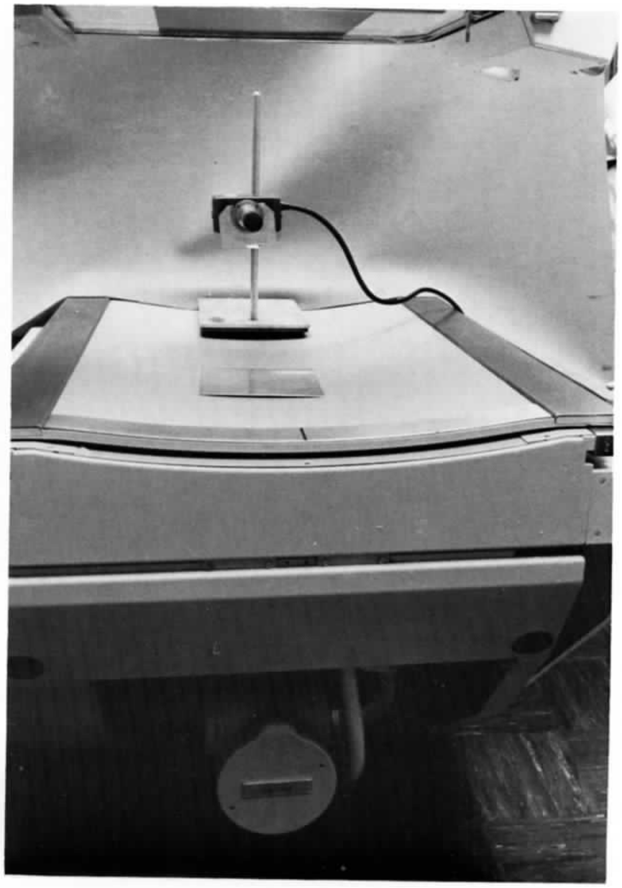

Figure 7.18b. HVL measurement setup for an undertable x-ray tube with the aluminum filtration placed directly on the table and the intensifier raised as far from the ionization chamber as possible.

4. The HVL is measured at a given kVp setting. For general x-ray equipment one HVL measurement at 80 kVp will be sufficient. Mammographic equipment should be measured at 30 kVp if film is used or at 50 kVp for xeroradiography.
5. Set the kVp and use a 0.10-sec exposure with sufficient mA to produce a reading of about 300 mR on the dosimeter.
6. Make one radiographic exposure and record the reading on the graph paper.
7. Proceed to make three additional exposures with 2.0, 3.0, and 4.0 mm of aluminum placed in the x-ray beam on top of the test stand. Plot the individual values for each of these exposures on the graph paper (Figure 7.19). Do not change the technique for the four exposures.
8. Draw a straight line through the three points on the graph corresponding to the exposures made with the 2.0, 3.0, and 4.0 mm of added aluminum.
9. Draw a horizontal line from the point corresponding to one-half of the original exposure (150 mR in this example) to the line drawn through the three exposure points on the graph. Draw a vertical line from that point to the lower horizontal scale and read the HVL (in mm of aluminum) off that scale. For the example shown, the HVL is 2.7 mm of aluminum (Figure 7.19).
10. Record the results in the QC room log.

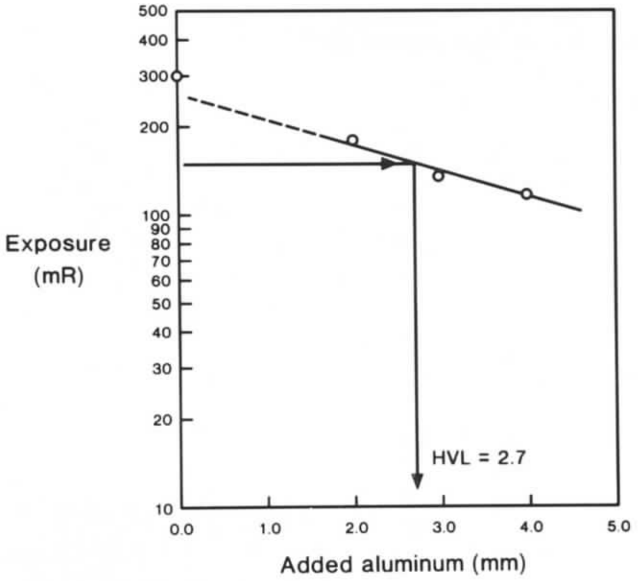

Figure 7.19. HVL data on semi-logarithmic graph paper. The graph paper used for this plot should have a logarithmic scale on the vertical axis. A solid line is drawn between the three points representing 2, 3, and 4 mm of added aluminum. This line will probably not connect with the measurement made with no added aluminum.

Procedure—Undertable Fluoroscopic Tubes

1. Raise the image intensifier tower to its maximum height, and support the dosimeter chamber halfway between the tabletop and the tower. Use fluoroscopy to place the chamber in the center of the fluoroscopic beam, and collimate so the beam will be smaller than the 6 × 6-inch (150 × 150-mm) aluminum sheets when they are placed on the tabletop in the beam. The aluminum sheets must be placed *under* the chamber when measuring the HVL on an undertable tube (Figure 7.18b).
2. Adjust the radiographic spot film device to the *manual* mode and set the kVp to 80. Adjust the mA and time to a setting that will produce a reading of about 300 mR on the dosimeter.
3. Proceed to make the four exposures (refer to Steps 6 and 7 in the overtable tube procedure above).
4. Plot the data in the same manner as for overhead tubes. [***Note:*** If a manual time cannot be set on the fluoroscopic unit, the HVL can be measured as follows: manually set 80 kVp and adjust the mA so a reasonable image is obtained, then set the dosimeter to the "exposure rate" mode and operate the fluoroscope long enough to allow the mR rate reading to stabilize. The four readings obtained in this mode will be "exposure rates" rather than a given exposure value. The kVp and mA must be locked, or manual mode used, to check the HVL using the exposure rate mode.]
5. Record the results in the QC room log.

Problems and Pitfalls

1. The entire dosimeter chamber must be in the x-ray beam. When placing the sheets of aluminum in the beam, be sure that the entire beam is intercepted by the 6 × 6-inch (150 × 150-mm) sheet. Once selected, the technical factors must not be altered for the four exposures.
2. The kVp should be checked before measuring the HVL to ensure that it is within acceptance limits.
3. When measuring the HVL on mammographic equipment (at 30 kVp), place 0.25, 0.50, and 1.00 mm of aluminum in the beam for the measurements.
4. The aluminum used for HVL measurements should be type 1100 and should be located halfway between the x-ray source and the ionization chamber to assure accurate results.

Acceptance Limits

Federal and many state regulations specify minimum required HVLs at various kVp values (Table 7.1). If the HVL is measured at 80 kVp for conventional equipment and at 30 kVp for mammographic equipment, this will assure compliance. Although the minimum required HVL at 80 kVp is 2.3 mm of aluminum, we suggest that this should be increased to at least 3.0 mm of aluminum (but no more than 3.5 mm), thereby reducing the dose to the patient without affecting the radiographic quality.

Table 7.1. Half-value layers required by the Radiation Control for Health and Safety Act of 1968 (Bureau of Radiological Health, 1980)

kVp	HVL for radiographic units	HVL for dental units
30	0.3	1.5
40	0.4	1.5
49	0.5	1.5
50	1.2	1.5
60	1.3	1.5
70	1.5	1.5
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

Corrective Action

Additional aluminum filtration must be added to the x-ray tube–collimator combination by a qualified service engineer if the acceptance limits are not met. If additional aluminum is added, remeasure the HVL and record the new value in the QC room log.