8 X-RAY GENERATORS

Although the x-ray generator is the most complicated piece of conventional radiographic equipment, there is no need to be concerned with its complexity nor be "afraid" of evaluating it (see Thompson, 1978; Rausch, 1981). It is easy to make noninvasive tests that not only will tell you if the generator is performing properly, but will also assist the service engineer in quickly repairing or recalibrating the components that are not performing properly. For example, you could tell the service engineer that the generator is "shooting light," and that you have verified this by making a radiograph of the PEP. If this is all the information the engineer has, he must check the kVp, timer, and mA calibration as well as the linearity, repeatability, and phototimer accuracy. However, using the tests described in this chapter you will be able to determine the nature of problem with the generator and the engineer will be able to make the appropriate adjustments in much less time.

It is very important to verify the calibration of the x-ray generator with your test tools after the engineer has completed his work, *before he leaves,* and, most importantly, make a radiograph with the PEP to assure that the problem has been corrected. In fact, if you work closely with the engineer you can make the tests before he disconnects his test equipment so that if other adjustments are required they can be made with a minimum of additional effort.

kVp CHECK

The kVp can be checked to an accuracy of 1 or 2 kVp using a modified Ardran and Crookes cassette, which is available from most x-ray vendors and has been described in detail in the literature (Jacobson et al., 1976). Although the test film produced with this cassette can be evaluated visually, accurate and repeatable results can only be obtained by using a densitometer to read the patches on the film.

In some cases your test results may not agree with the measurements made by the service engineer, but this is usually because of differences in the kVp waveform. The test cassette determines the effective or average kVp, whereas the test devices used by most service engineers determine the true peak of the waveform. If there is a significant amount of ripple or a small spike on the waveform the results obtained with the test cassette will be lower than those obtained by the engineer.

Electronic kVp test devices that measure the output of the x-ray tube are now available. These are much more rapid to use although they are more costly than the test cassette. If you obtain one of the electronic test devices, follow the manufacturer's instructions very closely.

EXPOSURE TIMING AND X-RAY OUTPUT WAVEFORMS

The exposure time you set on the x-ray generator must be accurate and repeatable if you wish to obtain properly exposed radiographs each time an exposure is made. Older generators using low mA values and long exposure times are not as sensitive to small variations in exposure time, but the new, high-powered generators being used with high-speed screen-film systems must be able to time exposures accurately down to a few milliseconds. The spinning top or motorized synchronous top timers are suitable under somewhat limited conditions, whereas the

more sophisticated dosimeters offering timing features as well as the electronic pulse counter-timer systems offer much more flexibility.

Ideally, the x-ray output waveform should be a perfect square pulse with the leading and trailing edge rising and falling instantly (Figure 8.1a). However, this is seldom the case and makes the measurement of the x-ray exposure time quite difficult. If the voltage rises and falls slowly (Figure 8.1b), exactly where on the waveform do you measure the exposure time?

Most engineers measure the exposure time at a point that is 70% of the peak value of the waveform. Since this is measured on the *input* to the x-ray tube it is necessary to measure the output waveform at a level of about 50% of the peak value. Both the dosimeters with built-in timers and the electronic timers allow for this adjustment.

The waveform itself provides a considerable amount of information about the function of the x-ray equipment (Figure 8.2). For example, are all three phases of the generator producing the same output? Is there a high-voltage spike on the waveform indicating arcing or other problems? Is the output stable during the exposure? Many problems can be diagnosed from these waveforms; consequently, we feel that the waveform should be monitored as part of the QC room check. This requires the use of a solid-state detector and a storage oscilloscope. In place of the solid-state detector some dosimeters now offer, as an option, an output that provides a signal proportional to the waveform. It is important to remember that the waveform you record from the output of the x-ray tube will be different from the kVp waveform the engineer looks at, since the output waveform contains information about the kVp and mA as well as the exposure time and any effects that may result from cable capacitance (a problem encountered at low mA

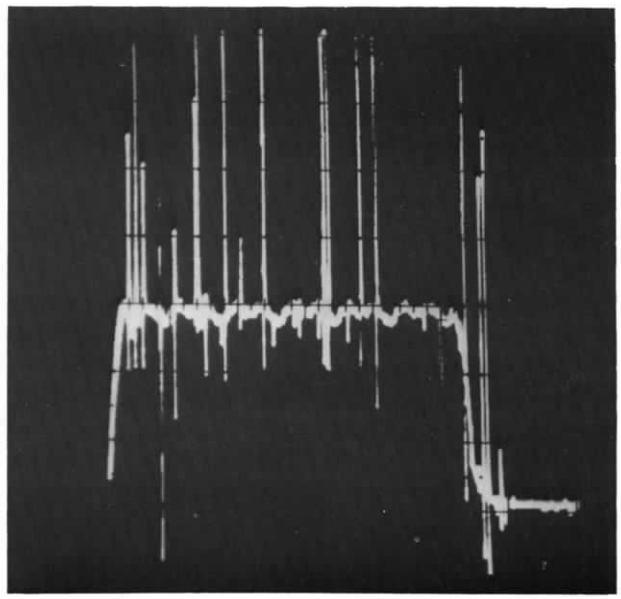


Figure 8.2a. Excessive spikes on x-ray output waveform.

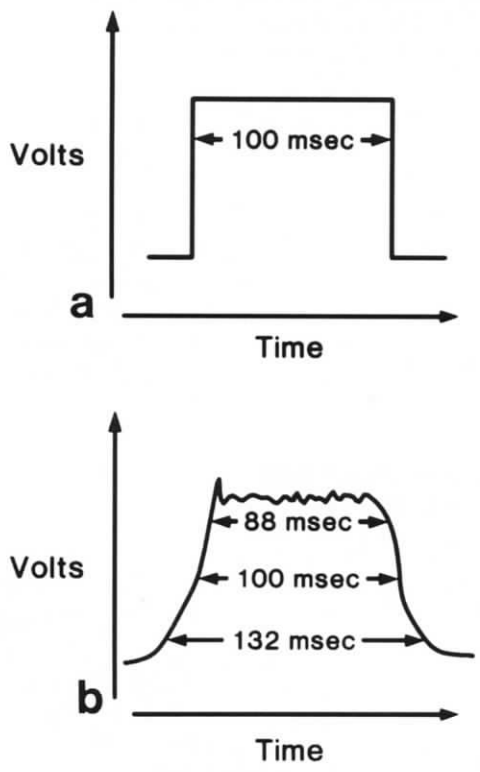


Figure 8.1. X-ray output waveforms. (**a**) Schematic drawing of a "perfect" waveform, which you will never see. (**b**) Typical waveform that creates difficulty in measuring the exposure time.

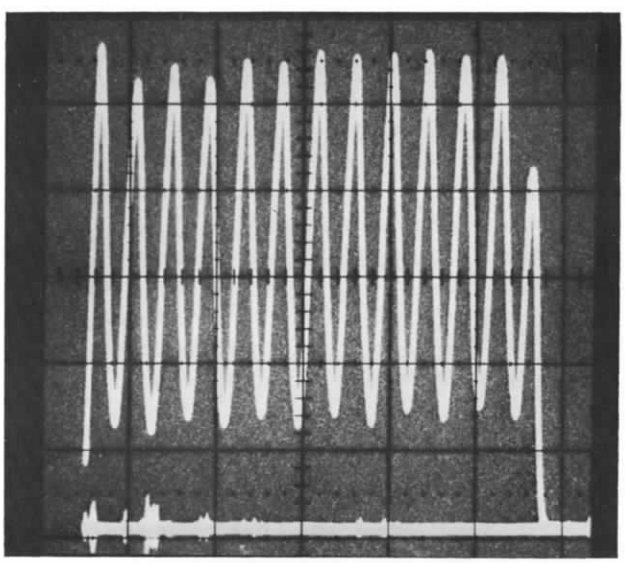


Figure 8.2b. One of three phases missing in x-ray output waveform.

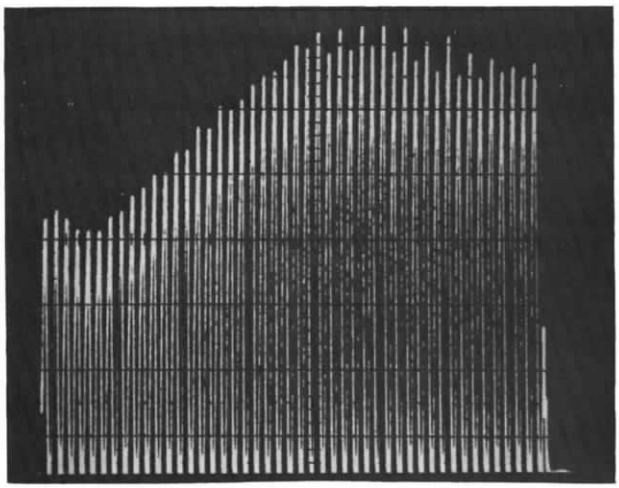


Figure 8.2c. Output waveform of a single-phase unit that is not stable with time.

values when long cable lengths are required between the generator and the x-ray tube).

A standard set of waveforms at various kVp and mA values should be recorded with a camera and placed in the QC room log, clearly labeled as to the date, kVp, mA, and exposure time as well as oscilloscope settings used. It is not necessary to photograph and record waveforms each time you evaluate the room, but the images of the waveforms on the storage oscilloscope should be compared to the standard set in the QC room log to assure that no changes have occurred.

The x-ray output waveforms have been one of the most valuable tests we have used in troubleshooting x-ray equipment problems. They have provided valuable insight to both our QC technologists and our service engineers concerning problems that could not have been diagnosed in any other way. Consequently, we feel that the evaluation of the output waveforms is an essential part of any quality control program.

mR/mAs

The output of an x-ray tube varies with kVp, mA, and exposure time, so in order to better compare the output and reduce the number of variables in the exposure measurement it is convenient to determine the mR/mAs—the exposure output per mAs input to the tube. This can be measured in two locations: in air (above the PEP), or under the phantom. Many service engineers prefer to determine the mR/mAs in air since the measurements are much more sensitive to small changes in the x-ray tube output (the phantom will filter out a significant proportion of the soft x-ray output). However, we have adopted as our standard the measurement of the mR/mAs under the phantom since this more closely represents the radiation as seen by the screen-film combination.

Regardless of where the mR/mAs is determined, it provides a quick check on the consistency of the output of the x-ray system. Only a dosimeter and phantom are required to determine if the output of the x-ray tube is the same as it was when the room was last evaluated. However, the mR/mAs does *not* provide specific information concerning any changes in output that may have occurred, such as changes in the kVp, mA, or timer calibration, although inferences may be made. It does provide a quick way to evaluate the linearity and repeatability of the generator and provides an additional tool for the QC technologist to use in evaluating the performance of the x-ray systems in general.

In quality control, we do have *noninvasive* methods to determine the exposure timer accuracy and the accuracy of the kVp calibration, but we do not have a simple and accurate way to check the mA calibration of a generator. However, by using mR/mAs measurements, along with exposure time and kVp measurements, you can make some assumptions, or inferences, about the mA calibration. If an mA station appears to be providing an output, as measured in terms of the mR/mAs, that is different than that of the neighboring mA stations, and the exposure time and kVp measurements are within acceptance limits, then you may assume that the calibration of that particular mA station may be incorrect.

STUDY OF EFFECTS OF CHANGES ON mR/mAs

A series of measurements were made under a PEP to evaluate the effect of various changes on the mR/mAs values. In addition, it was necessary to determine the correlation between changes in the mR/mAs values and our acceptance limits for film density variation so that we could determine the amount of variation in mR/mAs that would be acceptable in the diagnostic setting. All measurements for this series were carried out on the same three-phase generator in cooperation with our service engineers using a Machlette Dynalyzer to determine the actual kVp, mA, and exposure time for each exposure.

First we wanted to determine the effect of added filtration on the mR/mAs values. The collimator was removed and 1, 2, 4, and 6 mm of type 1100 aluminum were added to the x-ray tube port, with measurements being made both under the phantom and in air. The collimator was then replaced and additional measurements made adding 1 and 2 mm of type 1100 aluminum (in addition to the inherent filtration of the collimator). All measurements were made at 80 kVp

dialed with Dynalyzer readings ranging from 78.9 to 81.2 kVp.

As expected, the mR/mAs measurements made under the phantom were less sensitive to changes in the filtration of the x-ray beam than those made in air (Figures 8.3 and 8.4). In addition, it is apparent that the data on both figures are consistent for measurements made with and without the collimator in place. The in-air mR/mAs values dropped 36% with the addition of 2 mm of aluminum (with 2 mm already in the beam), whereas the change for measurements under the phantom was only 19%.

Another series of measurements compared the changes in mR/mAs in air and under the phantom with changes in kVp. Figures 8.5 and 8.6 show that measurements made under the phantom are more sensitive to changes in kVp than those made in air. For example, a change of 3–4 kVp is required to obtain a 10% change in mR/mAs as measured in air, whereas a change of only 2 kVp will produce the same change in mR/mAs values as measured under the phantom. The majority of photons transmitted through the phantom are higher energy, and it appears as if these have a predominate effect on the measurements.

In the final series, we wanted to determine the relationship between changes in mR/mAs measured through the phantom and film density (Figure 8.7). A variation of ±10% in mR/mAs readings produced a change in density of ±0.12, a level that we feel is acceptable in the clinical setting. When an mR/mAs measurement is made under the phantom, all technical factors are being considered, including kVp, mA, and time. Consequently, if you assume that the error

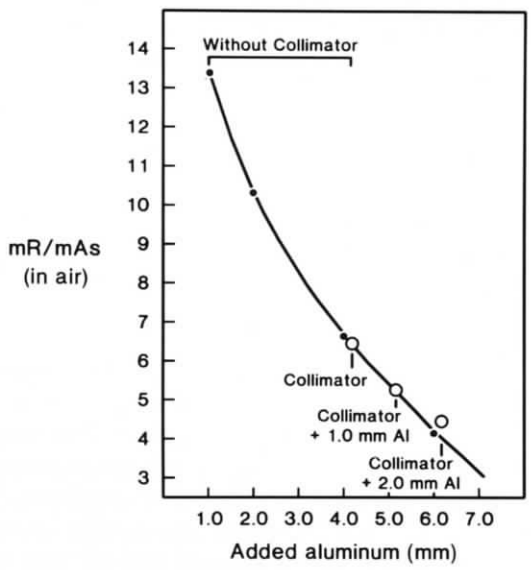


Figure 8.3. mR/mAs as a function of added aluminum filtration (with exposures measured in air).

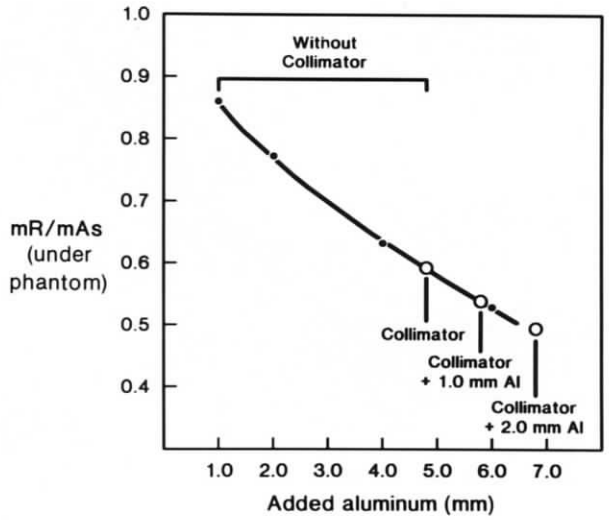


Figure 8.4. mR/mAs as a function of added aluminum filtration (with exposures measured under the PEP).

in output due to calibration is equally divided among all three factors, then a change of ±6% would be allowed in each. However, we are still interested in the total change in output, regardless of how the change is apportioned among the factors—if we see more than 10% variation in x-ray output under the phantom, it is time for generator calibration.

USE OF mR/mAs MEASUREMENTS

Although mR/mAs measurements are the only method we can use to infer mA calibration, the mR/mAs measurements can be used in other ways. For example, we can determine:

Repeatability—the ability of the generator to reproduce the same exposure for the same technique.

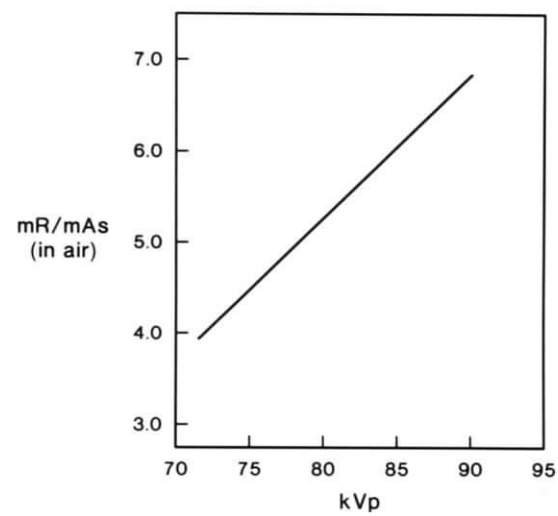


Figure 8.5. mR/mAs as a function of kVp (with exposures measured in air).

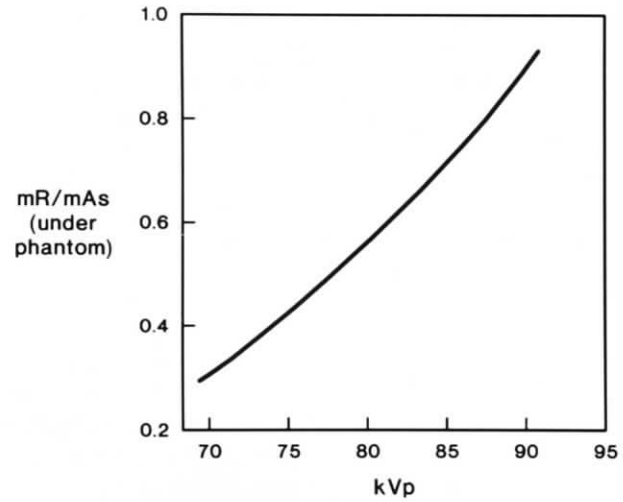


Figure 8.6. mR/mAs as a function of kVp (with exposures measured under the PEP).

Linearity—similar generator output for the same kVp and mAs regardless of the mA station used.

Room-to-Room Consistency—helps to assure that x-ray rooms using similar generators and tubes produce the same output so that the same technique charts may be used.

As an example of the room-to-room consistency, consider our 10-room general radiographic section. These rooms have the same type of generators and x-ray tubes. All 10 rooms have the same technique charts, which results from the fact that the mR/mAs output (at 80 kVp) for each room is within ±7%, which is better than our ±10% acceptance limit. Phantom film densities, measured over a 2-week period, showed density variations of ±0.14 (at a density of 1.0 above the base-plus-fog). This density

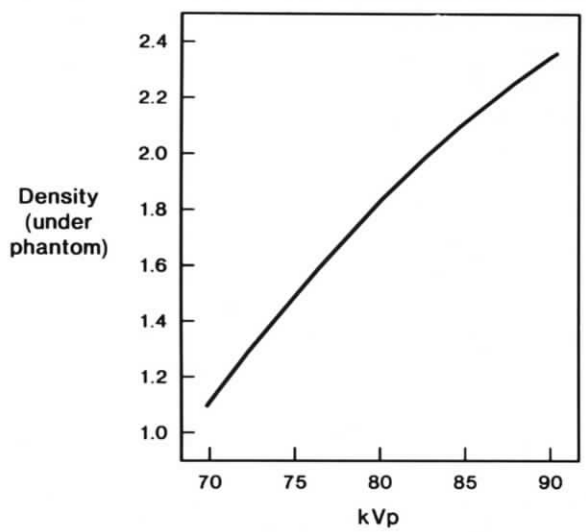


Figure 8.7. Film density for films exposed through the PEP as a function of kVp.

spread is wider than we would like to see, but it does include all sources of variation, such as film processing (±0.10), manufacturing film speed variations (±0.10), and all of the inherent variations in the generators. It must be noted here that variations of this magnitude in film density are acceptable to our radiologists for clinical purposes. Another point worth noting is that it is necessary to limit the variation of each component of the imaging process to ±0.10 in density since, in practice, all of the variables may add together, resulting in larger variations in the total system than are seen in any of the individual components.

Comparing mR/mAs measurements for equipment by different manufacturers is a rather difficult problem. In general, we have found similar results for all single-phase generators, all three-phase, six-pulse generators, and all three-phase, twelve-pulse generators, but there are some exceptions. The use of smoothing circuits by some manufacturers, or capacitive smoothing resulting from long, high-voltage cable lengths (especially at low mA values) will change the mR/mAs measurements. In general, we have seen slightly higher mR/mAs measurements with American-made equipment as compared to European equipment, but this is a general statement, and we have not made measurements on all of the various American or European equipment. Three-phase, six-pulse generators will have mR/mAs outputs less than three-phase, twelve-pulse generators. This again is related to the amount of ripple in the x-ray waveform.

Capacitor discharge equipment will have different mR/mAs measurements depending on the mAs used. This is because the kVp is continuously dropping during the exposure with this type of equipment. Capacitor discharge units, using a 1-microfarad capacitor, will drop 1 kVp for every 1 mAs used for exposure. For example, if 80 kVp is set on a capacitor discharge unit, the actual kilovoltage will be 80 kVp at the beginning of the exposure but will drop to 70 kVp at the end of a 10-mAs exposure.

It becomes obvious that mR/mAs measurements can be valuable in comparing equipment. However, you must only compare such measurements on similar equipment and never expect the mR/mAs measurements to be the same on single-phase, three-phase six-pulse, three-phase twelve-pulse, and capacitor discharge generators.

The x-ray output may also vary for the same generator as the x-ray tube ages. This usually results from the surface of the anode becoming roughened with use, which tends to reduce the amount of radiation emitted by the tube. Contrary to popular opinion, this decrease in output is usually not due to increased deposition of tungsten in the x-ray tube,

since the HVL does not change and the thickness of the tungsten layer deposited is insignificant relative to the energy of the x-rays used in diagnostic radiology. For newly installed x-ray tubes, the mR/mAs measurements may be higher at first, dropping slightly (a few percent) to a stable level in a short period of time. Slight decreases will then become apparent, but for the most part, these changes are minor and do not affect the density of the films produced. However, for older tubes, we have found mR/mAs measurements 20–25% below normal, even after repeated efforts by our service engineers to assure proper generator calibration. Replacement of the x-ray tube will normally resolve this problem. If you experience similar problems, it would be valuable to make your mR/mAs measurements along with your service engineer to assure that the generator calibration is correct while the measurements are being made. This way you can be assured that the output of the x-ray tube is at fault, and, considering the cost of replacing x-ray tubes, it is certainly worth the extra effort!

Off-focus radiation, or extra-focal radiation, will also affect the mR/mAs measurements. It has been shown that the off-focus radiation can be as much as 25% of the total radiation in the x-ray beam (Rao, 1966; Weaver et al., 1975; Thomas et al., 1981). In addition, image degradation can be noted in terms of decreased contrast and decreased resolution due to off-focus radiation. The amount of off-focus radiation can vary from tube to tube for the same brand and model of tube and with different models of collimators.

Once sufficient data have been collected, mR/mAs measurements are very useful for troubleshooting purposes. You can use mR/mAs measurements to quickly confirm or rule out generator miscalibration or component failure by comparing the data with data collected during past QC room checks for the specific unit in question.

mR/mAs measurements can be misleading in some instances. For example, it is possible for the kVp and mA calibrations to drift in opposite directions and yield an mR/mAs measurement that is within the acceptance limits. Therefore, in troubleshooting a room it is reasonable to check the kVp at one station in question and also to do a quick timer-check to verify your conclusions before calling a service engineer.

mR/mAs MEASUREMENT ACCURACY

In order to collect reliable mR/mAs measurement data, great care must be taken to design a procedure that is easily reproduced. (It is then necessary to strictly follow that procedure each time the measurements are made.) All factors, such as distance, control of backscatter, and x-ray field size, must be specified and the same factors used each time. In addition, it is very important to use the same method of setting the kVp, mA, and exposure time, i.e., these must be dialed in the same manner each time. With care and consistency, the mR/mAs measurements will provide valuable data for a QC program, but *care* and *consistency* are essential in order to minimize potential errors that will lead to erroneous data.

Our procedure for determining mR/mAs starts with the use of a 36-inch (90-cm) source-to-tabletop distance. This distance is measured with a tape measure each time, rather than relying on the SID indicator of the tube crane. If the mark indicating the position of the focal spot in the x-ray tube housing is not visible, we assume the focal spot is located 1 inch (2.5 cm) up from the bottom edge of the housing end cap. Even if the focal spot is not located at this point, and we have no way of knowing with many tubes, the measurements are done the same way each time for consistency. The only time we deviate from this procedure is when we are dealing with an x-ray tube with a fixed SID, and, for comparative purposes, we can correct for this difference using the inverse square law.

Our mR/mAs measurements are made with the dosimeter chamber under the phantom and the x-ray field size set so that the entire 12 × 12-inch (30 × 30-cm) area of the PEP is irradiated. If it is not possible to cover the entire phantom, the mR/mAs measurement data cannot be used for comparison purposes with measurements made when the entire phantom is irradiated, since the amount of scattered radiation measured by the ionization chamber will be different.

To control backscatter, a 12 × 12-inch (30 × 30-cm) sheet of $^1/_8$-inch (3-mm) thick lead is placed under the phantom and ionization chamber. This assures that differences in tabletop construction and supporting structures, as well as Bucky trays, do not produce different amounts of backscatter.

kVp, mA, and exposure time are always selected in a consistent manner. Normally, mA selection with push buttons should not create problems. However, kVp and time selection with dials (continuously variable scales) and even kVp selection with push buttons may not be repeatable unless you approach the setting of interest in the same manner each time. For example, if we are going to set 80 kVp on the generator control panel, first 70 kVp is set, whether using a dial or push button–type selector. Next, the selector

is *slowly* moved to 80 kVp, with care taken not to pass the 80 kVp point on the selector. If the kVp selection is made with push buttons, the kVp should be set first at a value of at least 10 kVp below the kVp desired and then increased in 1-kVp steps until the desired kVp is reached. This technique should be used not only for mR/mAs measurements but for all measurements and for clinical radiography.

Before undertaking mR/mAs measurements for our QC program, we carried out several tests to determine the accuracy of these data. In order to determine the repeatability of the dosimeter, a sequence of six sets of exposures were made, with three individual exposures in each set. These were made at 30-minute intervals without moving any of the components and without changing the technical factors. The variation in exposure measurement was found to be ± 1.4% (2 standard deviations). This variability includes some generator variation over time, but the variation in each set of three exposures was minimal (less than a fraction of a percent).

To determine the repeatability of measurements due to changes in the equipment setup, one individual made measurements once a day for 5 days, making one three-exposure set of measurements each day with the same generator, technical factors, and measurement equipment. This resulted in mR/mAs measurement variability of ± 5.6% (2 standard deviations).

In order to determine the amount of variability introduced by different individuals, the four authors, using the same procedure, made six sets of three individual exposures each within 1 hour, taking down the complete equipment setup and changing the technical factors each time. The mR/mAs measurement variation was found to be ± 2.0%, ± 2.3%, ± 3.6%, and ± 8.8% for each individual's measurements. The variation of all of the mR/mAs measurements made by the four individuals in 2 days was ± 15.6% (2 standard deviations).

As you can see from these data, the variability of the particular instrumentation used to make the measurements is minimal. The short-term setup variabilities for each of the four authors (six sets of exposures in 1 hour) show the importance of extreme care in the setup procedure. The ± 2.0 to ± 3.6% errors are probably acceptable, but the ± 8.8% error is unacceptable considering our acceptance limits of ± 10%. The long-term variability of 5.6% (5 sets of measurements in 5 days by one person) probably includes some generator variation, but again it points to the necessity for extreme care in the setup procedures. It also provides some assurance that the data from one visit to the next are accurate to within approximately ± 6%. However, these data do support the necessity of repeating the measurements, including the complete setup procedure, if the data are at all in question.

The variability of ± 15.6% in mR/mAs measurements among the four authors does indicate that having one individual making the measurements is ideal. Unfortunately this is not always possible, but for maximum accuracy and efficiency a minimum number of well-trained individuals should be making the measurements.

LINEARITY AND REPEATABILITY

Many times a technologist may wish to reduce the exposure time (e.g., for small, uncooperative children or older patients that cannot hold their breath) and must increase the mA proportionally in order to do so. Although the same mAs may be selected, the output of the tube may be different and the resultant radiograph is less than satisfactory. This is especially true when the highest mA stations are used. The linearity test determines the output of the x-ray tube, using mR/mAs, for various mA and timer station combinations. Unless the output is maintained within close tolerances, it will not be possible to interchange mA and time combinations, even at the same mAs, and produce consistent quality radiographs.

The Bureau of Radiological Health, through federal regulations, requires that all new x-ray equipment maintain linearity of ± 10% from mA station to mA station. This means that if your x-ray generator has six mA stations it would be possible to have linearity of ± 50% and still meet the federal requirements. We have found that the linearity can be maintained to ± 10% over the entire working range of the generator (e.g., from 100 to 600 mA) regardless of the number of mA stations, not only from station to station. In fact, we have found that it is necessary to maintain the linearity to this tighter standard in order to eliminate problems and repeat radiographs as the technologists change from one mA station to another.

kVp and linearity are only part of the problems in x-ray generator calibration. If the generator is not repeatable then optimal kVp calibration and linearity will be of little value. When we speak of repeatability we do not mean that the output of the tube is the same if you make three exposures in a row at the same technique—most generators can do this without much difficulty. However, a generator must be repeatable within reasonable limits every time you change technique and then come back to the same kVp, mA, and exposure time. This especially becomes

a problem as generators age and the mechanical components begin to wear.

You may find that with some older, as well as some newer, generators you may have to approach the kVp setting you desire from the same direction each time and slowly; e.g., if you want to obtain 80 kVp you may have to dial down to 70 kVp first and approach 80 kVp slowly. In many generators, this problem cannot be corrected, but if you advise the technologists of this problem they can set the techniques properly each time and obtain consistency in their radiographs.

With a proper evaluation of the x-ray generators you can be assured that they are calibrated properly and you will be better able to diagnose problems that may previously have gone uncorrected. In addition, some problems that may not be easily or inexpensively corrected (a new generator may be the only solution) can be identified and it may be possible to work around those problem areas.

PHOTOTIMER EVALUATION

Phototimers are considered by many to be one of the best innovations in radiography, whereas many others consider them the component that causes the most difficulty. With phototimers patient positioning becomes more critical since a slight mispositioning, which may be acceptable diagnostically, can result in a significant change in the exposure of the radiograph. Although they have their problems, phototimers are here to stay.

The evaluation of phototimers must include the consideration of many factors. What is the backup time, i.e., what is the maximum time the system will allow before terminating the exposure? If the backup time is too short you will produce radiographs that are too light on heavier patients. If the backup time is too long you may be unnecessarily exposing a patient if, for example, the kVp is set too low. What is the shortest exposure that the phototimer can accurately time? With high-mA generators and new high-speed screen-film systems the phototimers must work in the range of milliseconds accurately and repeatably.

Can the phototimer be properly compensated for the screen-film combination you are using in your department? Many systems will show excessive changes in density over the working kVp ranges since the sensitivity of the intensifying screens to radiation is not the same as that of the detectors used in the phototimers.

In general, the new phototimers available today can perform quite adequately, but it is still essential to evaluate them on a regular basis. In addition to being concerned about kVp, mA, and conventional timer calibration when problems arise, you must also consider the possibility that the phototimer itself is not functioning properly. It is also necessary to measure the phototimed exposure to the PEP regularly since if the kVp drifts you can still produce adequate radiographs (the phototimer will compensate for changes in the x-ray tube output), but the exposure to the patient will increase significantly if the kVp decreases and the contrast will become degraded if the kVp increases.

Phototimers may make the staff technologists' job easier but for the QC technologist, phototimers mean more work, more measurements, and more potential problems, all of which can be handled following the procedures outlined in this chapter.

MAMMOGRAPHY AND XERORADIOGRAPHY

Mammography and xeroradiography are two areas that require particularly close attention for several reasons. First of all, these procedures do deliver a relatively high dose to a radiation-sensitive organ. Second, the imaging requirements are probably the most demanding in diagnostic imaging since both minute particles of calcium and low-contrast masses must be faithfully reproduced. Finally, there has been an extensive amount of public concern over mammography and xeroradiography and these patients tend to question the radiologist and technologist concerning the exposure from this exam as well as the necessity for it.

Since radiographs are made with extremely low energy radiation, it is essential to use the appropriate instrumentation. Dosimeter chambers designed for conventional radiography will filter out much of the softer radiation used in mammography and xeroradiography, giving a false, low reading. Likewise, specially designed phantoms must be used to provide information about the ability of the system to produce consistent, high-quality mammograms and xeroradiograms.

TECHNIQUE SELECTION FOR GENERATOR QUALITY CONTROL

All techniques selected for the purpose of evaluating the generator, whether for acceptance or for QC testing, should be those typically used in the clinical setting. Most manufacturers state broad acceptance limits for kVp and mA since they are expected to maintain those limits over the entire range of the generator. Consequently, by selecting the working range appropriately, it is possible to maintain the generator calibration to much tighter standards than those specified by the manufacturer. For example,

our institution maintains kVp calibration to better than ± 2 kVp between 60 and 120 kVp, as compared to manufacturers' specifications that sometimes run as wide as ± 5% plus 2 kVp (i.e., ± 7 kVp at 100 kVp).

The mA stations that should be evaluated as part of the QC program should include those used clinically plus one station on either side. For example, if a room is only used at 200 and 400 mA, then 100, 200, 400, and 600 mA should be evaluated.

kVp, in most instances, should be evaluated at 60, 80, 100, and 120 kVp, although the 120-kVp station may be ignored if 100 kVp is never exceeded on the technique chart. Likewise, the mR/mAs should be evaluated at the same kVp and mA values. For units used for mammography, the measurements should be made at the low kVp values of interest clinically. Most importantly, kVp, mA, and exposure time should be evaluated over a *range* of values that encompass the factors used clinically.

The linearity should be determined at the kVp where the generator is most heavily used. For example, on a generator used in general radiography, a kVp range of 60 to 100 kVp may be used. The majority of the work will be done at approximately 80 kVp so the linearity should be evaluated at this level. However, if the generator is also heavily used at lower or higher kVp values, the linearity should be checked in these areas as well.

It is not necessary that each of the technique combinations used produce the same mAs for the mR/mAs evaluation. In many instances, one or more of the combinations will produce a different mAs, but by dividing the exposure (in mR) by the actual mAs, the resultant mR/mAs for various combinations can readily be compared.

The mAs values to be evaluated (as well as the mA stations) should be typical of the operating range in the particular room. For example, if the room typically operates from 10 to 100 mAs, then 50 to 60 mAs should be used for measurements.

8.1 kVp CHECK

Purpose

To assure that the x-ray generator is producing the kVp as indicated on the control panel.

Equipment Needed

1. kVp cassette, 8 × 10-inch (20 × 25-cm) film
2. Two sheets of lead [4 × 9-inch (10 × 23-cm) and 9 × 9-inch (23 × 23-cm)]
3. Densitometer

Procedure

1. Place the kVp cassette on the x-ray table with the long axis of the cassette parallel to the anode-cathode axis of the x-ray tube. Center the x-ray tube to the cassette using a 36-inch (90-cm) source-to-tabletop distance (Figure 8.8).
2. Set the generator to the mA at which the kVp values will be checked.

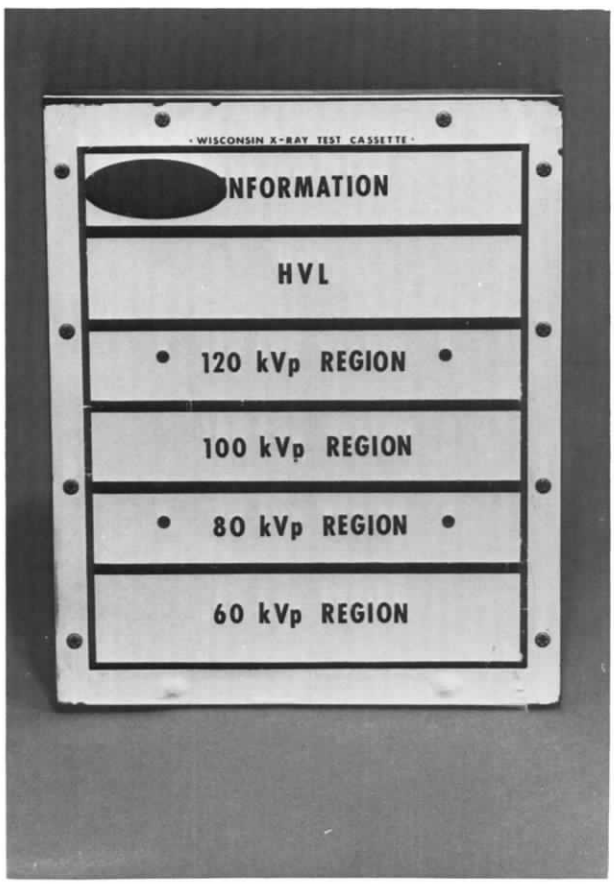


Figure 8.8a. kVp test cassette, sometimes referred to as the modified Ardran and Crookes cassette. The HVL region of the cassette is unreliable and should not be used for HVL measurements (the HVL should be measured using a dosimeter and aluminum filters, see pages 90–94).

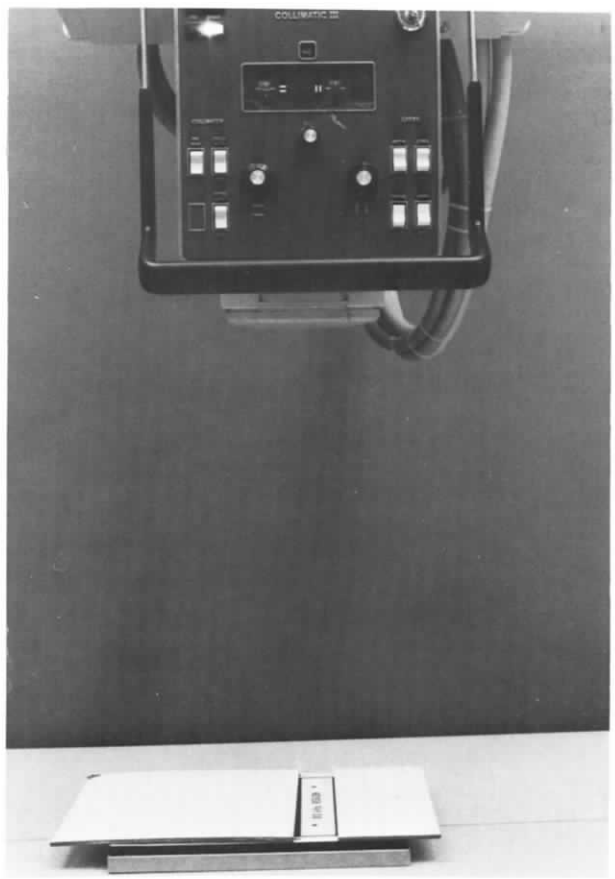


Figure 8.8b. kVp check test setup. Although it may be possible to collimate to the kVp region of interest on the cassette, 1/8-inch (3-mm) of lead should be used to cover the remainder of the areas.

3. Make four radiographic exposures on the appropriate area of the cassette at 60, 80, 100, and 120 kVp. Adjust the time (not the mA) so that a density of about 1.0 (no less than 0.50 nor more than 1.50) is produced on the film in the test region. Be sure to place lead sheets on the cassette to block out the regions of the cassette that are not being exposed (Figure 8.8b).

Approximate mAs techniques*

kVp	Single phase	Three phase
60	500	400
80	75	40
100	15	10
120	12	8

*Using Kodak XL film and a 36-inch (90-cm) SID

4. If the kVp is checked at more than one mA station, expose lead numbers indicating the mA used for the exposures on the information region of the cassette and then process the film.
5. Each kVp region on the film contains two columns of dots (Figure 8.9). Using the densitometer, find a density in the left column that matches the density in the right column. The density of the dots in the right column will generally be uniform; these are referred to as reference dots. The dots in the left column will show a density gradient. A density "match" should occur at one of the 10 steps. If an exact density match is not found, you must interpolate between the steps for best accuracy. For example:

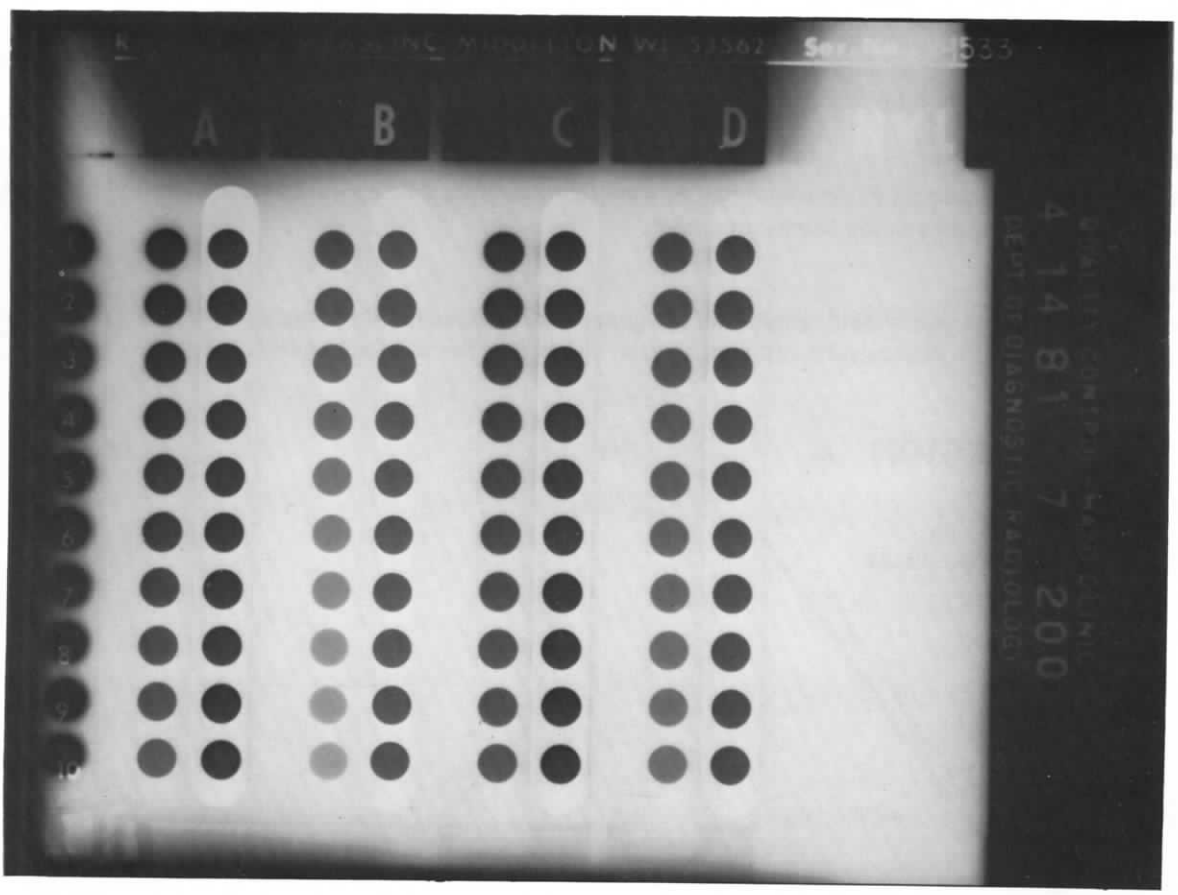


Figure 8.9. kVp check test results. The densities must be in adjacent patches using a densitometer; visual matching will not suffice. It is also necessary to interpolate to determine matches if the match falls between two specific density patches.

	Density of step	Density of reference dot
Step 5	1.10	1.05
Step 6	1.03	1.05

$$\text{Match Step} = 5 + \left[\frac{1.10 - 1.05}{1.10 - 1.03}\right] = 5 + \frac{.05}{.07} = 5.7$$

6. After the match step has been determined for each of the kVp regions, refer to the calibration charts that the manufacturer provides with each cassette to determine the kVp (Figure 8.10). [***Note:*** There is a separate chart for each kVp region and there is a separate line on each chart for single- and for three-phase generators.] If, for example, the image in Figure 8.9 from the 60 kVp region of the cassette was obtained from a three-phase generator and the match occurred at step 5.7, then the kVp would be 59.
7. Record the results in the QC room log.
8. To ensure that the kVp compensation is working properly, the kVp should be measured at the minimum, middle, and maximum mA stations *normally used* on the generator.

Problems and Pitfalls

1. The HVL should always be measured after assuring that the kVp is correct.
2. The major cause of kVp variation is calibration. Some generators maintain their calibration well and others drift constantly. It is important to note that a change in kVp may not always show as a change in film density because changes in the mA will often compensate for the change in kVp.
3. Since the kVp affects the radiographic contrast, it must be checked to assure that it is within acceptance limits.
4. Other major causes of variations in kVp are line voltage drops and electrical component failure.
5. On some generators, the kVp may measure 5–8 kVp low at high mA settings. This results from the higher percentage of ripple that is present at high mA stations plus, possibly, poor compensation. Since the cassette averages the tube output, lower kVp readings may be obtained from the cassette.

Acceptance Limits

The kVp on a properly calibrated generator can be maintained within ±2 kVp. A variation of more than ±5 kVp requires calibration by a qualified service engineer.

Corrective Action

A qualified service engineer should recalibrate the generator if it does not meet the acceptance limits. Be sure to measure the kVp with the cassette after calibration and *before* the service engineer leaves.

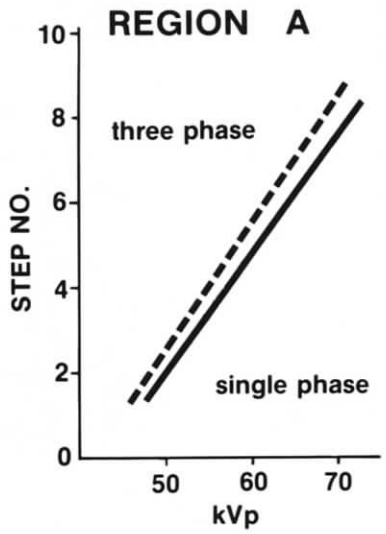


Figure 8.10. Typical kVp test cassette calibration curve.

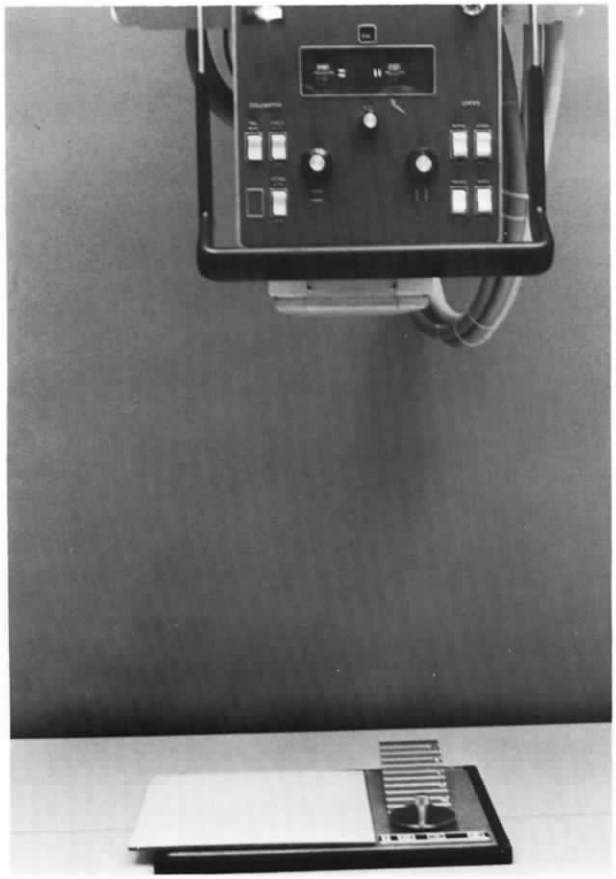


Figure 8.11. Exposure timing test setup for manual spinning top. This spinning top is incorporated into a step wedge, but some are available without the wedge.

8.2. EXPOSURE TIMING

Purpose

To assure that the x-ray generator is producing the exposure time as set on the control panel.

Equipment Needed

1. One of the following: manual spinning top, motorized synchronous top (also known as the mAs-timer test tool), a dosimeter with a timer readout, or timer–pulse counter device
2. Screen-film cassette (for spinning and synchronous tops)

Procedure—Manual Spinning Top (Single-Phase Units Only)

1. Determine the exposure needed to produce a radiograph in which the dots produced from the hole in the spinning top will be visible.
2. Place the top on a cassette and manually start it spinning (Figure 8.11). (The exposure is made while the top is spinning.)
3. Make radiographs of the spinning top at $^1/_5$, $^1/_{10}$, $^1/_{20}$, and $^1/_{30}$ sec using the same mA. Other times can also be checked as long as the dots do not overlap.
4. Process the films.
5. On each radiograph, count the dots (Figure 8.12) and determine the exposure time by dividing the number of dots by 120 if the generator is full-wave rectified or by 60 if the generator is half-wave or self-rectified. For example:

Full-Wave Rectification	Half-Wave or Self-Rectification
$\frac{12 \text{ dots}}{120} = 0.10$ second	$\frac{6 \text{ dots}}{60} = 0.10$ second

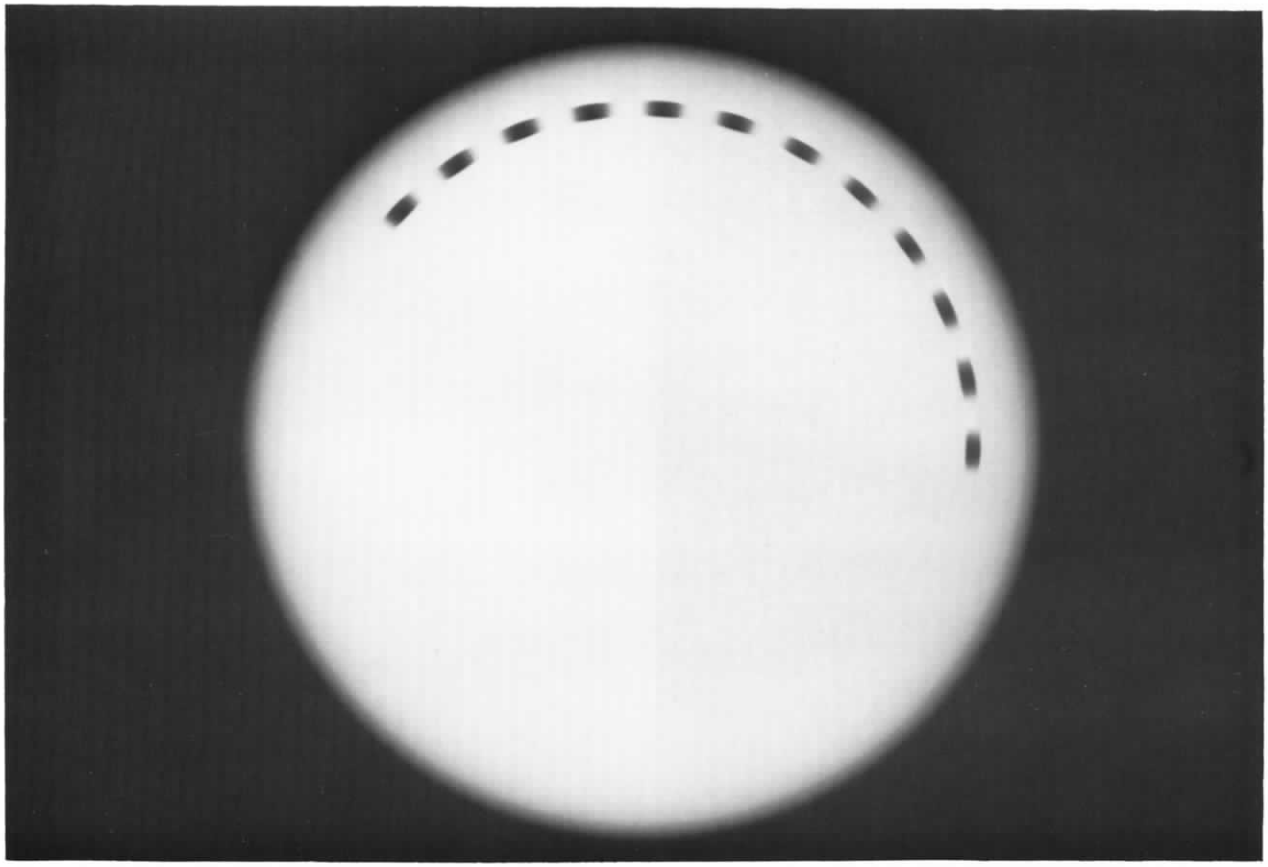


Figure 8.12. Exposure timing results for manual spinning top. The number of pulses, or dark spots, is counted to determine the exposure.

[***Note:*** Be sure you know what type of rectification is used. Half-wave or self-rectification produces 60 dots (pulses) per second and full-wave produces 120 per second.]

6. Record the results in the QC room log.

Procedure—Motorized Synchronous Top (for Single-and Three-Phase Units)

The motorized synchronous top functions similarly to the manual spinning top with the exception that it is turned using a synchronous electric motor. The device also contains a copper step-wedge for determining mAs reciprocity.

1. Place the unit on one half of an 8 × 10-inch (20 × 25-cm) cassette and plug the timer in (Figure 8.13). Be sure to place lead on the other half of the cassette so that side can be used for a second exposure. [Three images of the tool can be made on a 10 × 12-inch (25 × 30-cm) cassette.]
2. Determine the exposure needed to produce a radiograph of acceptable density.
3. Make four exposures using the same mAs, one at each of the following times: $^{1}/_{5}$, $^{1}/_{10}$, $^{1}/_{20}$, and $^{1}/_{30}$ sec.
4. Process the films.
5. Using the protractor provided, measure the length of the trace made on the film for each of the exposures to determine the exposure time (Figure 8.14). The measured exposure time should be within the acceptance lines shown on the protractor. If exposure times other than the above are checked, measure the angle of the trace using the section of the protractor indicating exposure time. (Generator timers that are in fractions can be converted to milliseconds by dividing the numerator by the denominator as follows: $^{3}/_{20}$ second = 0.150 seconds = 150 milliseconds.)
6. Record the results in the QC room log.

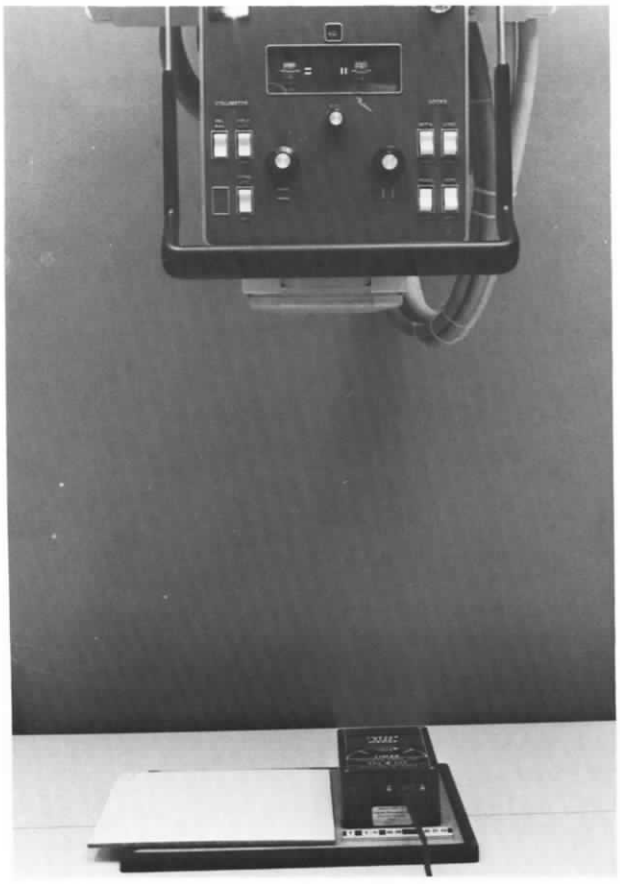


Figure 8.13. Exposure timing test setup for motorized synchronous top.

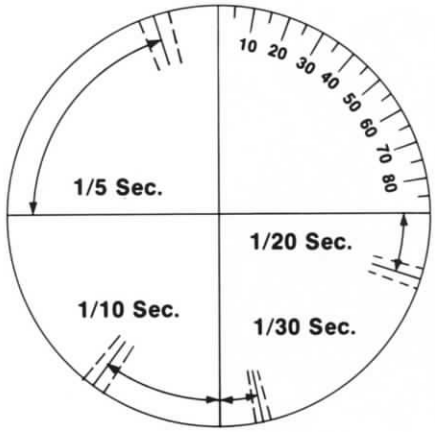
Procedure—Dosimeter or Timer Device (for Single- and Three-Phase Units)

Many of the currently available dosimeters have an added feature that allows the measurement of exposure times. The dosimeter or timing device is the most accurate method of determining exposure times since the actual length of time that the radiation is emitted from the x-ray tube is measured. In addition, this method of measuring exposure times is faster since radiographs are not required. On some devices different threshold levels can be set, allowing exposure times to be measured at any point across the output waveform.

1. Place the dosimeter or timing device on the x-ray table on top of a sheet of lead (Figure 8.15).
2. Center the x-ray beam and collimate to the chamber.
3. Set any exposure time on the generator and make an exposure.
4. Record the results in the QC room log.

Problems and Pitfalls

1. The manual spinning top cannot be used on three-phase generators. Neither the manual nor the electric spinning tops will measure long exposure times (greater than ½ sec). When using a dosimeter or electronic timing device, always set the threshold to the same level each time the exposure times are checked. (We recommend that the threshold be set at the 50% level.) It is not necessary to check all the exposure times on the generator for a routine QC check. Four timer stations, two short and two long, should be sufficient to ensure that the generator timer is working correctly.
2. For generators that use a premagnetization circuit, the low-energy radiation produced may or may not fall below the 50% level. If the exposure time is 12–15 msec longer than expected, increase the threshold level to 80% and repeat the measurement. At this point, the time should drop to near the expected time. In addition to the premagnetization pulse, other abnormalities in the x-ray waveform may affect the time measurements.



TIMER PROTRACTOR

Figure 8.14a. Timer protractor used to determine actual exposure timing test results for motorized synchronous top. This device can be used for both single-and three-phase generators. The dotted lines represent the minimum and maximum limits for the exposure time.

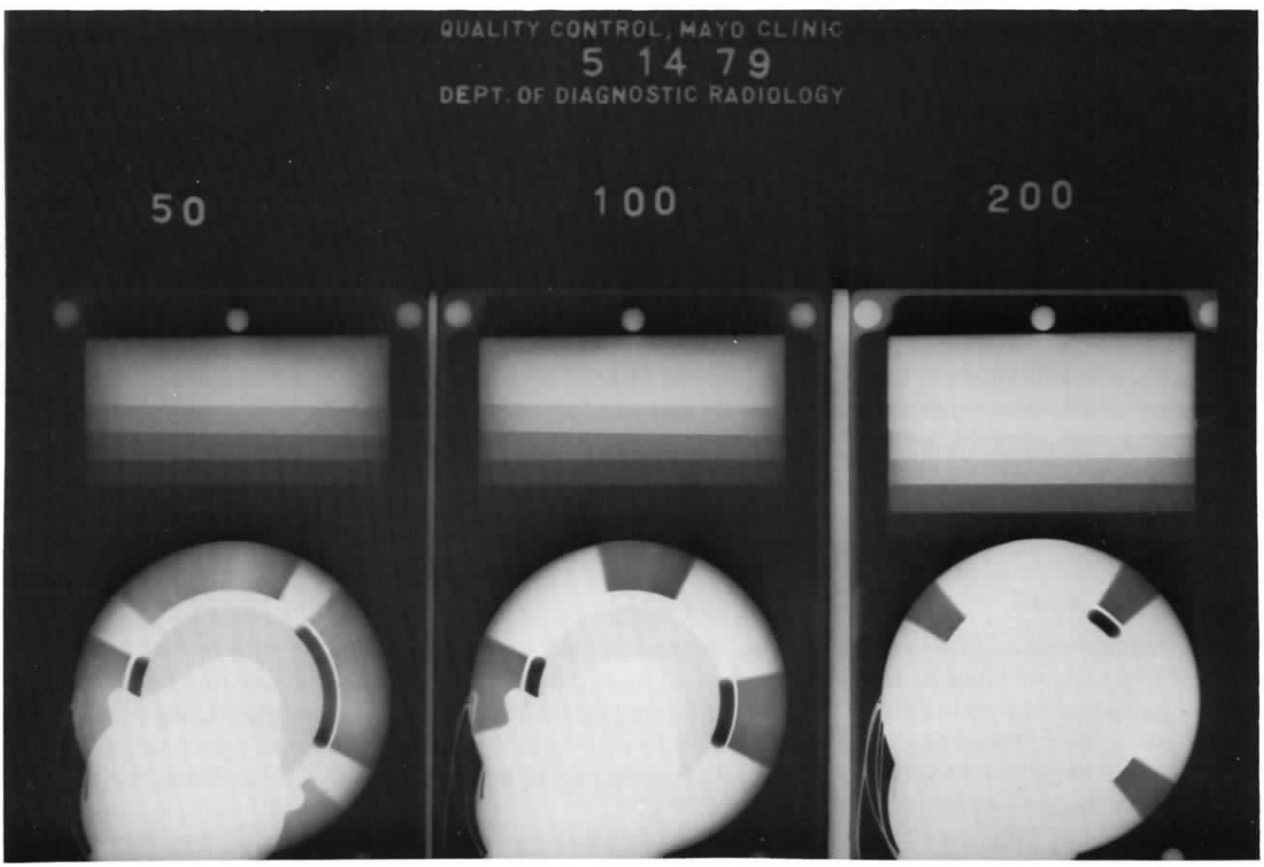


Figure 8.14b. A typical film produced at exposure times of $^1/_5$, $^1/_{10}$, and $^1/_{20}$ second and 50, 100, and 200 mA, respectively. Note that the mAs is constant but the step wedge exposure at the 200 mA station is significantly lighter than the other two. If the exposure time is correct (according to the protractor), this would suggest that the mA calibration is not correct, or that the compensation circuit is not operating properly.

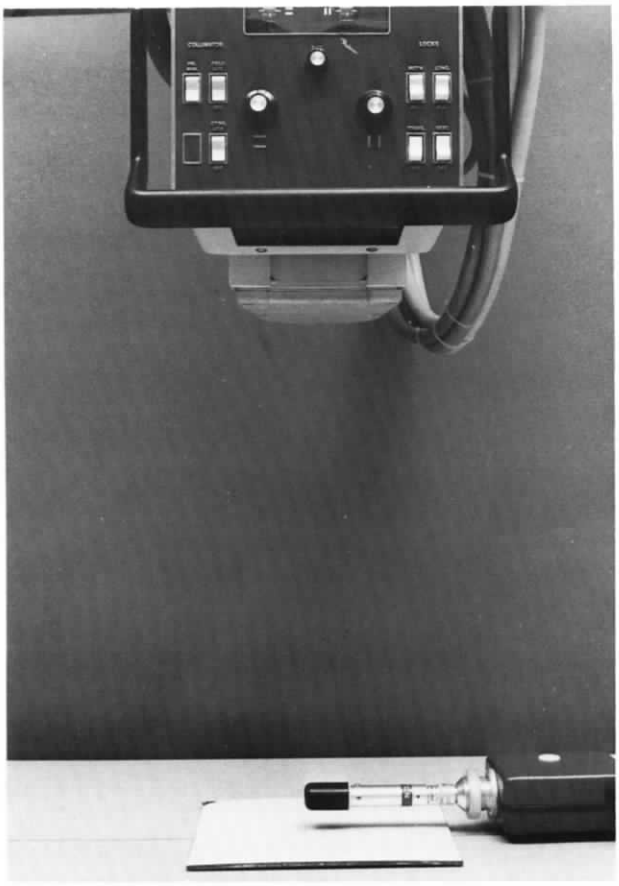


Figure 8.15. Exposure timing test setup for dosimeter or timing device. The ionization chamber of a direct readout dosimeter with the timing function or the timing device should be placed on a sheet of lead. In addition, it is essential to use only the conventional small ionization chamber since larger chambers often exhibit extreme capacitive effects, giving incorrect exposure times.

Acceptance Limits

For single-phase generators using the manual spinning top, we suggest the following:

Time	Pulse
1/5 sec	24 = ± 1 dot
1/10 sec	12 = ± 1 dot
1/20 sec	6 = ± 0 dots
1/30 sec	4 = ± 0 dots

When using the motorized spinning top the time should fall within the lines drawn on the protractor for the 1/5, 1/10, 1/20, and 1/30 time stations. For times other than these the acceptance limit should be ± 5%. The ± 5% acceptance limit is also used for the dosimeter or timing device, except in single-phase equipment where each x-ray pulse is equal to 8.4 msec. As an example, at 1/10 sec, or 100 msec on single-phase equipment 5% will equal 5 msec, but most timers cannot terminate during an x-ray pulse. All times should be within ± 5% of that indicated on the generator.

Corrective Action

A qualified service engineer should be called to recalibrate the timer stations on the generator if it does not meet the acceptance limits. Be sure to check the timer after each calibration and *before* the service engineer leaves.

8.3. X-RAY WAVEFORM MONITORING

Purpose

To evaluate the actual output waveform from an x-ray generator–tube combination to determine if problems exist.

Equipment Needed

1. Storage oscilloscope
2. X-ray detector such as a solid-state detector that can provide a voltage output proportional to the x-ray flux, a photodiode intensifying screen combination, or a dosimeter that has an analog waveform output capability
3. Oscilloscope camera and Polaroid film

Procedure

1. Place the x-ray detector about 50 cm from the x-ray source and in the direct beam, but not in a position where it would interfere with test procedures (Figure 8.16).
2. Connect the detector to the oscilloscope with the BNC connectors and a coaxial cable.
3. Set the trigger levels so that the oscilloscope triggers on the leading edge of the x-ray waveform and not on electronic noise before this (i.e., noise caused by the contactors from the stator motor, etc.).
4. Set up the storage oscilloscopes so that the waveform covers most of the vertical portion of the screen (by varying the voltage per division control) and horizontally by varying the time per division control.
5. Visually monitor every exposure measurement you make during your check of the room.
6. Photographically record any waveforms that do not appear normal. Be sure to record all pertinent information on these photographs, including the oscilloscope settings, the technique that produced the waveform, and any other data that you think may be helpful to the service engineer in isolating the problem.
7. Watch for (Figure 8.17):
   a. Three-phase equipment that has an output that looks similar to single-phase equipment (one or two phases may be missing; Figure 8.17c).
   b. Spikes or valleys in the waveform that are more than a few percent higher or lower than the waveform itself (Figure 8.17d).
   c. Waveforms that appear considerably different, for whatever reason, from the other waveforms that the machine produces.
   d. Waveforms with excessive ripple. Single-phase equipment should have peak heights that are very close to each other. Three-phase equipment should have a minimum amount of variation between the peaks and valleys in the waveform. The percentage of ripple can be determined by measuring the distance of the peaks of the waveform from the baseline (the maximum height) and the distance of the valleys of the

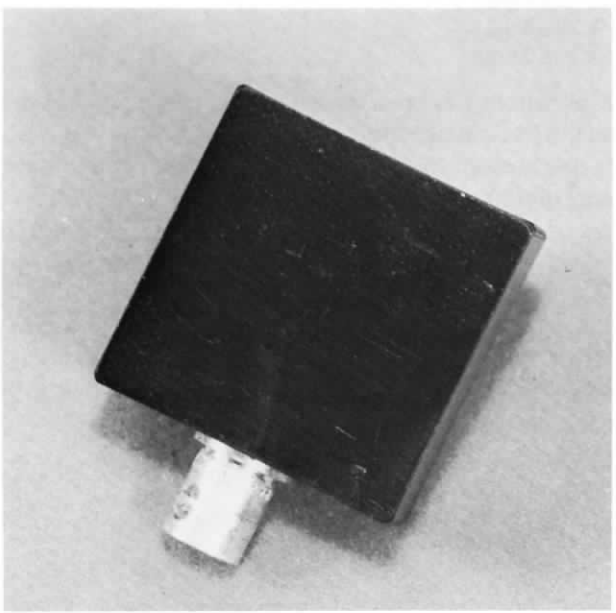


Figure 8.16a. X-ray waveform monitoring test setup. The detector is a small box containing solid-state detectors with its output passing through the BNC connector.

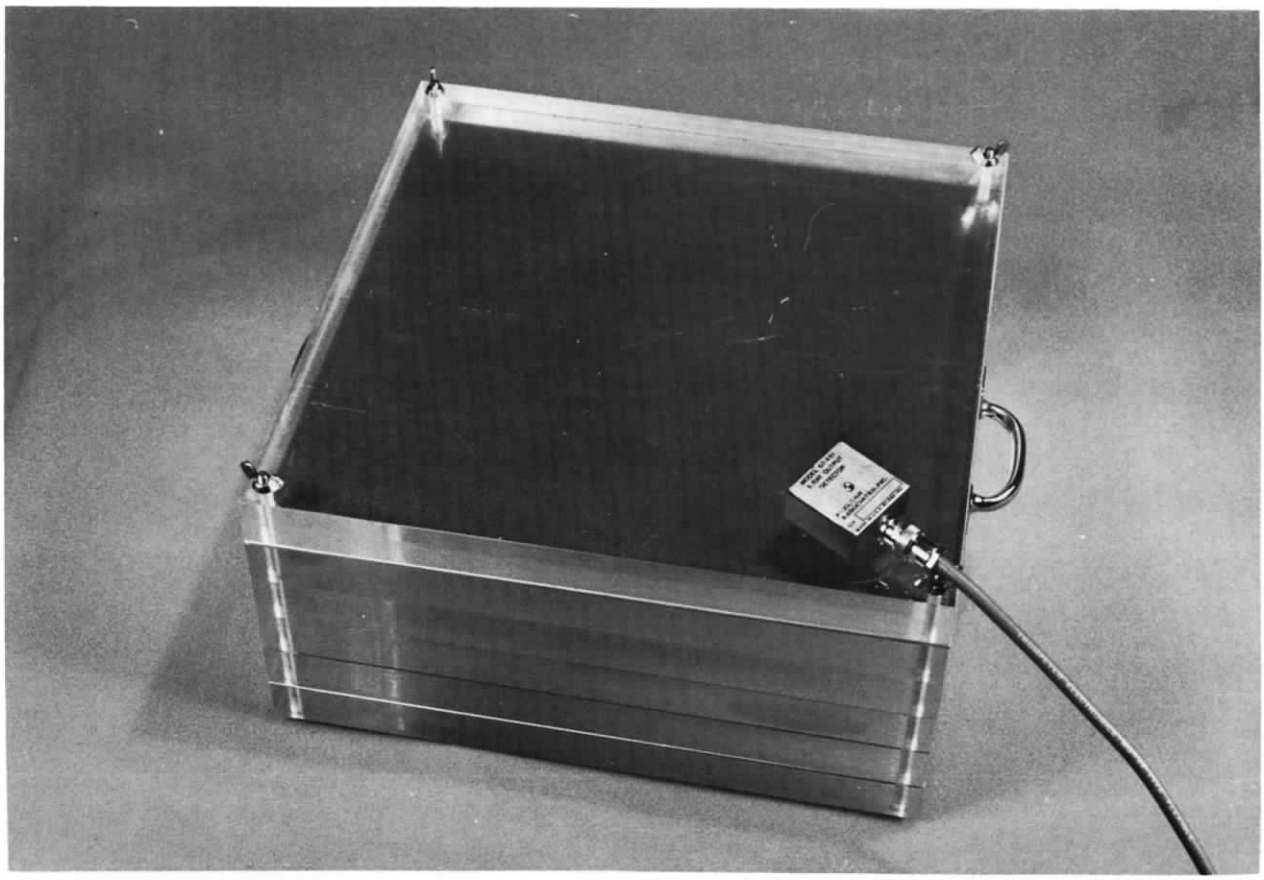


Figure 8.16b. The detector should be placed about 50 cm from the x-ray source to avoid saturation of the detector. We place the detector on top of the PEP and monitor waveforms during all exposures made with the PEP.

waveform from the baseline (the minimum height) and dividing by the average waveform height using the following formula:

$$\frac{\text{Maximum Height} - \text{Minimum Height}}{\left(\frac{\text{Maximum Height} + \text{Minimum Height}}{2}\right)} \times 100\% = \%\ \text{ripple}$$

For example, if we assume that the maximum height measured is 38 mm and the minimum height is 32 mm, then we obtain

$$\frac{38 - 32}{\left(\frac{38 + 32}{2}\right)} \times 100\% = 17\%$$

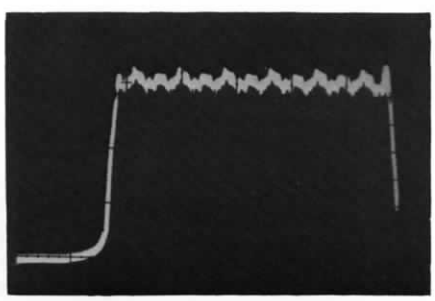


Figure 8.17a. Normal three-phase x-ray output waveform.

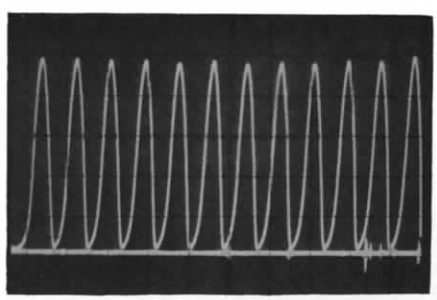


Figure 8.17b. Normal single-phase x-ray output waveform

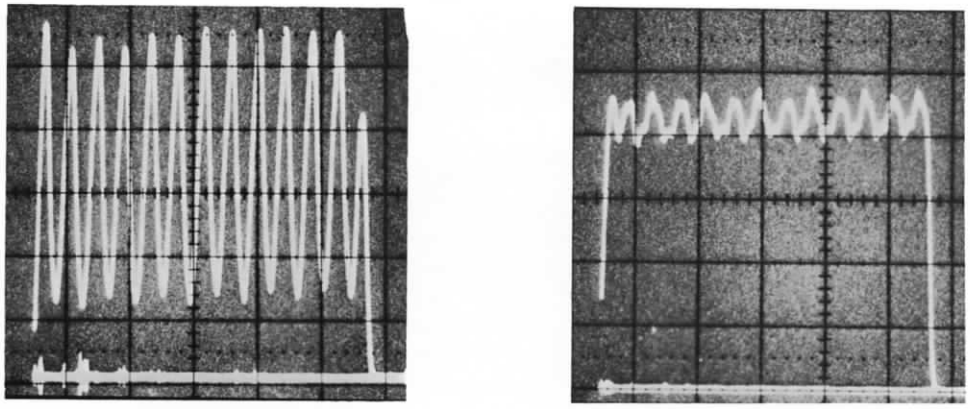


Figure 8.17c. Three-phase waveform with one phase missing *(left)* and after service *(right)*.

8. Mount the pictures of the baseline and aberrant waveforms in the QC room log along with all of the data concerning how they were produced.

Problems and Pitfalls

1. You may have difficulty in setting the trigger levels of the oscilloscope so that the scope triggers on the leading edge of the waveform. Ask the representative from the firm that you purchased the scope from to assist you or ask your x-ray equipment service engineer for assistance.
2. Most detectors that are available today are not sensitive enough to evaluate fluoroscopic equipment.

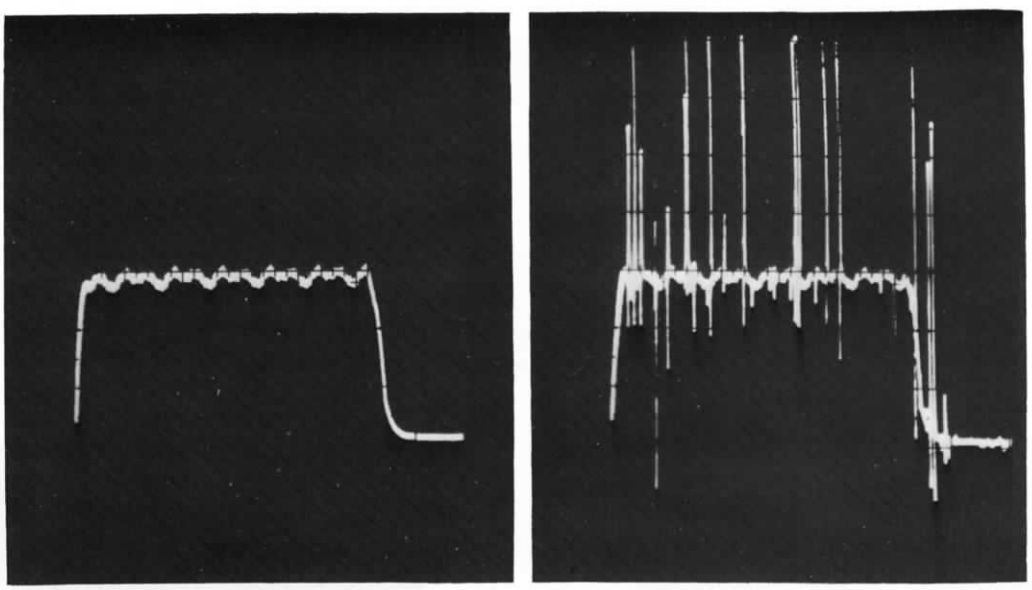


Figure 8.17d. The spikes on the waveform on the right were apparent on the output waveform but not on the kV waveform the service engineer produced *(left)*. However, after further investigation it was determined that the spikes were present on the mA waveform as measured by the service engineer. The output waveform measured with the solid-state detector includes both mA and kVp waveform information, whereas the service engineer normally only looks at the kV waveform. This is another case where you may be measuring something different than the service engineer measures. It is essential to work together to sort out such problems.

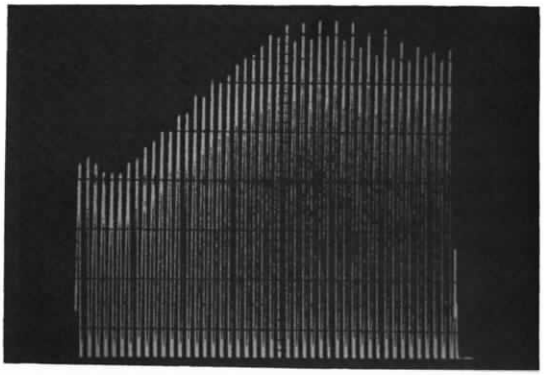


Figure 8.17e. This single-phase generator in a dental section required service to correct a problem with the filament stabilization circuit.

3. Don't photograph every waveform, just the unusual ones. (On new equipment, or the first time you check any room, record one waveform at each mA station for the QC room log.)
4. Don't try to verbally describe the appearance of an aberrant waveform to the service engineer. Either provide him with the original or a photocopy (Xerox copies are very good).
5. If the x-ray detector saturates, you will obtain a waveform with a very flat top. Saturation occurs when the detector receives too high a radiation flux level. To avoid this, move the detector further away from the x-ray source.

Acceptance Limits

1. Any waveform that you think deviates from a normal waveform should be shown to the service engineer. With experience, you will be able to diagnose the possible problems from the waveforms, but work closely with the service engineer and rely on his diagnosis. You should point out any deviation from normal since small changes that occur infrequently may be indicative of a major problem that is in the process of developing and may have serious consequences if allowed to persist.
2. In theory three-phase, twelve-pulse waveforms should have about 5% ripple, but most of these will actually exhibit ripple of the order of 10–15%. Any three-phase, twelve-pulse system with ripple in excess of 20% should be further evaluated by a service engineer to determine the cause. Three-phase, six-pulse equipment will probably have ripple in excess of 15%, but ripple in excess of 25% indicates potential problems and a need for corrective action. Single-phase equipment has 100% ripple, but all of the peak heights should not vary by more than 10%, and ideally this variation should be much less.
3. In some cases of excessive ripple, the cause may be an inherent flaw in the design or construction of the high-tension transformer or generator that cannot be corrected. However, the knowledge of the percentage of ripple will help in troubleshooting other problems such as apparent problems in kVp calibration. The kVp cassette measures the effective or average kVp, so with a considerable amount of ripple the cassette measurement will be lower than that made by the service engineer using a voltage divider and reading the true peak kilovoltage. Also, high ripple will result in lower tube output, in terms of mR or mR/mAs, as compared to systems exhibiting less ripple.

Corrective Action

If you detect problems with x-ray output waveforms, it will be essential to call in the x-ray service engineer since the problems that affect these waveforms must be corrected internally in the x-ray generator and its associated components.

8.4. REPEATABILITY, LINEARITY, AND mR/mAs OUTPUT

Purpose

1. *Repeatability*—To assure that the exposure received for the same mA, time, and kVp is the same from exposure to exposure.
2. *Linearity*—To assure that similar exposures are obtained for the same mAs and kVp, regardless of the exposure time and mA used.

3. *mR/mAs Output Consistency*—To assure that the average radiation output of like systems is consistent from room to room.

Equipment Needed

1. Direct readout dosimeter
2. mAs/timer test tool (alternate procedure)
3. Screen-film cassette and film (alternate procedure)
4. Patient equivalent phantom (PEP) with base
5. Sheet of 12 × 12-inch (30 × 30-cm) lead

Procedure—Repeatability, Linearity, and mR/mAs Output Using the Direct Readout Dosimeter

1. Place the sheet of lead in the center of the x-ray table with the phantom and base directly on top of the lead.
2. Place the large chamber in the opening beneath the phantom, making sure the chamber is in the exact center of the phantom (Figure 8.18a).
3. Set the x-ray tube at a 36-inch (90-cm) source-to-tabletop distance, center the tube to the phantom, and collimate to the edges of the phantom (Figure 8.18b).
4. A complete set of measurements will be made in order to collect all of the data necessary for this test, as shown in Table 8.1.
5. Make radiation exposure measurements at 60 kVp and at four mA stations using the same mAs and record the data (use mA and time combinations typically used in this room). [***Note:*** Be sure to set the techniques carefully, dialing slowly *up* to the technique desired.]
6. Repeat Step 5 at 100 kVp, using the same mA and time combinations, and record the data.
7. Make measurements at 80 kVp. Since you will also use the data to determine the generator repeatability, three exposures will be needed at each mA and time combination. Record each individual reading (Table

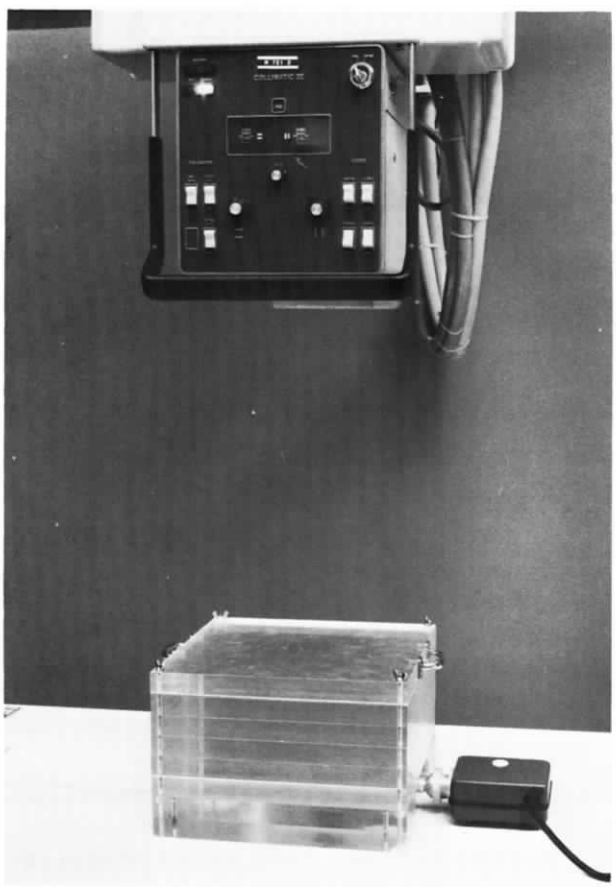


Figure 8.18a. Repeatability, linearity, and mR/mAs output test setup. PEP on the base with the dosimeter properly positioned. A sheet of lead must be placed under the phantom base.

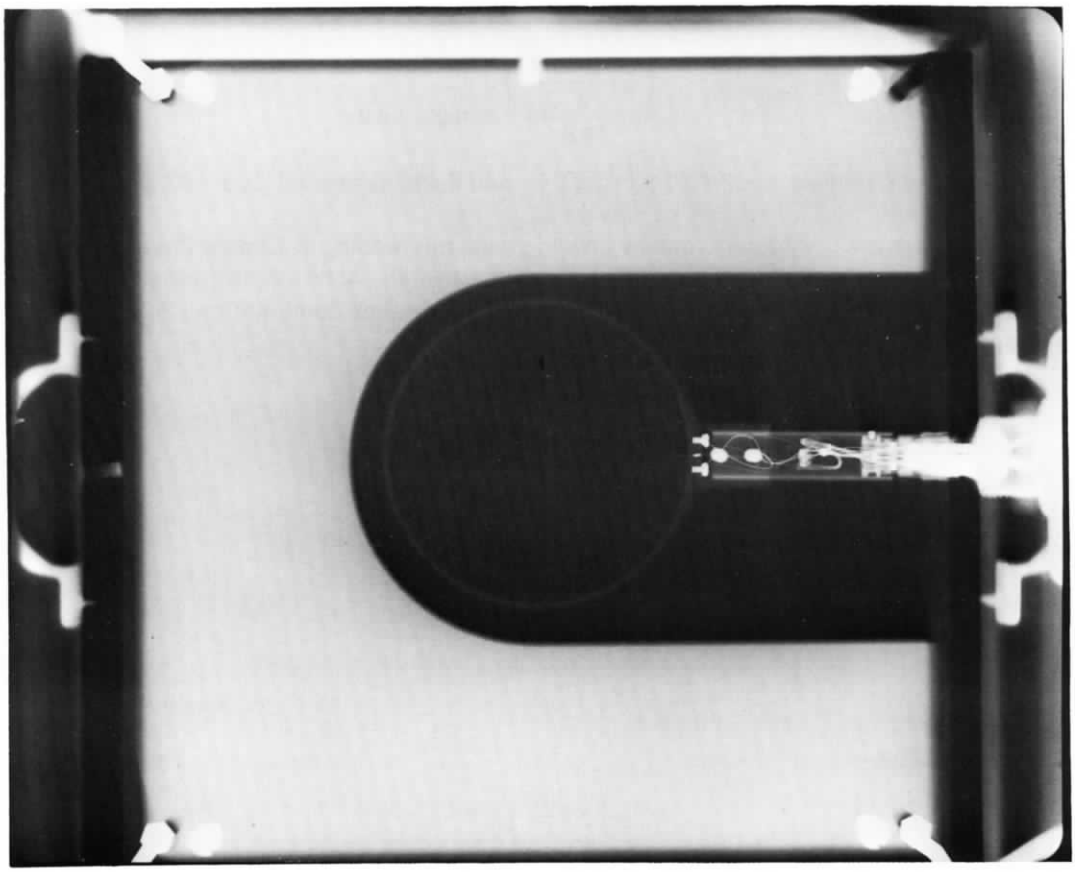


Figure 8.18b. Repeatability, linearity, and mR/mAs output test setup. It is essential to cone to the edge of the phantom and to assure that the ionization chamber is centered to the x-ray beam and the phantom.

8.1). [***Note:*** Do *not* set the techniques as you did for the above measurements. Before each exposure, change the technique and then go back to the desired technique, but do *not* dial the technique in the same way, i.e., dial up one time, dial down the next. The reason for this is to determine how repeatable the generator is when used under normal operating conditions.]

8. Determine the average of the three measurements made at each mA and time setting at 80 kVp and enter the data in the table (Table 8.1).
9. The repeatability is then calculated for each of the mA-time combinations at 80 kVp using the formula

$$\frac{\left(\frac{\text{Maximum mR} - \text{Minimum mR}}{2}\right)}{\text{Average mR}} \times 100\% = \%\ \text{Repeatability}$$

Table 8.1. mR measurements for repeatability, linearity, and mR/mAs output

(40 mAs)		60	80 kVp				100
mA	Time	kVp	1st exposure	2nd exposure	3rd exposure	Average	kVp
100	0.40	7.98	30.0	30.2	28.9	29.7	67
200	0.20	6.86	31.1	31.5	31.8	31.6	65
400	0.10	7.23	27.2	32.0	30.6	29.9	60
800	0.05	6.95	34.0	34.1	34.3	34.1	62

For example, at 400 mA and 0.10 seconds,

$$\frac{\left(\frac{32.0 - 27.2}{2}\right)}{29.9} \times 100\% = 8.0\%$$

The resulting repeatabilities are 2.1%, 1.1%, 8.0%, and 0.4% at the 100, 200, 400, and 800 mA stations, respectively.

10. The mR/mAs values are next determined by dividing each mR reading in Table 8.1 by the mAs (in this case 40 mAs). Record the mR/mAs in a table such as Table 8.2. [***Note:*** At 80 kVp the mR/mAs is determined using the *average* mR value from the three readings for each mA-time combination.] For example, at 80 kVp, 100 mA, and 0.40 seconds,

$$\frac{29.7 \text{ mR}}{40 \text{ mAs}} = 0.74 \text{ mR/mAs}$$

11. Determine the average mR/mAs value at 80 kVp (Table 8.2). For example,

$$\frac{0.74 + 0.79 + 0.75 + 0.85}{4} = 0.78 \text{ mR/mAs}$$

12. Determine the linearity for each kVp station using the formula

$$\frac{\left(\frac{\text{Maximum mR/mAs} - \text{Minimum mR/mAs}}{2}\right)}{\text{Average mR/mAs}} \times 100\% = \%\ \text{Linearity}$$

For example, at 80 kVp

$$\frac{\left(\frac{0.85 - 0.74}{2}\right)}{0.78} \times 100\% = 7.1\%$$

The resulting linearities are 8.3%, 7.1%, and 5.7% at 60, 80, and 100 kVp, respectively.

13. Enter the repeatability, linearity, and mR/mAs data in the QC room log.

Problems and Pitfalls

1. The x-ray tube should be checked for overheating since a large number of exposures are being made in a short period of time. (You should be familiar with the tube loading and cooling charts for the rooms, so overheating the tube should never occur during a QC check.)
2. The sheet of lead is placed under the phantom and dosimeter to obtain standard backscatter conditions. Tabletops made by different manufacturers may have different backscatter characteristics, thus altering the dosimeter readings. Standard backscatter conditions assure more accurate mR/mAs output comparisons of all radiographic rooms in the department.
3. The mR/mAs measurements should be made using the focal spot or spots that are used in the room.
4. Follow a strict procedure with regard to the phantom position and the x-ray tube, the chamber position within the phantom, and the distance from the x-ray source to the tabletop. This will produce more consistent and accurate results.

Table 8.2. mR/mAs (calculated from data in Table 8.1)

mA	Time	60 kVp	80 kVp	100 kVp
100	0.40	0.20	0.74	1.68
200	0.20	0.17	0.79	1.63
400	0.10	0.18	0.75	1.50
800	0.05	0.17	0.85	1.55
Average		0.18	0.78	1.59

5. Never use the overhead distance indicator. Always measure the distance accurately, using a *tape measure*. The overhead distance indicator can be incorrect.
6. Always approach the technique setting slowly, dialing up to the desired setting (except for the repeatability measurements). This assures consistency in the results.
7. Always evaluate the generators closely following the test protocol.
8. The use of pen-type dosimeters is not recommended for this test of generator performance. Pen-type dosimeters are not accurate and cannot reliably be used for QC purposes.
9. It is essential that kVp measurements be done before initially performing this test to establish baseline values. If the kVp calibration exceeds acceptance limits, the mR/mAs data will be inaccurate.

Acceptance Limits

1. The repeatability should be maintained within ± 5% and the linearity should be less than or equal to ± 10%.
2. The average mR/mAs output at 80 kVp from each room should be within ± 10% for all rooms. However, the output from different generators does vary somewhat. For example, only single-phase generators (full-wave rectified) should be compared, only three-phase, six-pulse generators should be compared, and only three-phase, twelve-pulse generators should be compared. In addition, generators made by different manufacturers may exhibit different output. If the output can be maintained to within ± 10% for like rooms, then the same technique charts will produce diagnostic-quality films from those rooms.
3. The individual mR/mAs values, as recorded in the QC room log, will provide valuable data in troubleshooting problems. For example, if a room is said to be "shooting light," a check of the mR/mAs values at the present time with those recorded in the log book will indicate if the generator output is lower than acceptable, and what mA and time stations are at fault.
4. It is also important to review all of the resultant data from this test since changes can occur in the repeatability, linearity, or individual mR/mAs values, independent of each other. In other words, the repeatability may exceed acceptance limits while the linearity is still acceptable, or the individual mR/mAs values may exceed acceptable limits while the repeatability and linearity are acceptable.

Corrective Action

A service engineer should be called to recalibrate the generator if these tests indicate that it is outside of acceptance limits.

Alternate Procedure for Linearity Using the Motorized Synchronous Top

1. If the timing has already been checked using the motorized synchronous top and found to be acceptable, the mA calibration can be interpreted from the wedge pattern that is also imaged on the film.
2. Check the step wedges from the various mA stations and determine if the steps on each pattern are the same density (Figure 8.19). For the most accurate results, read the densities with a densitometer. If the generator is properly calibrated, the densities should be within ± 0.1 in density.
3. Record the results in the QC room log.

Problems and Pitfalls

1. Variability in film batches and processing conditions can increase the error between checks.
2. Numerical values and percentage variations cannot be obtained from this test.
3. It is difficult to check the generator at high kVp and mAs techniques because the test tool will be overpenetrated. However, a sheet of aluminum can be placed over the test tool to obtain proper film density.

Acceptance Limits

The density should not vary by more than one step on the wedge or ± 0.10 if read with a densitometer.

Corrective Action

If the linearity is found to be outside of the above limits, a service engineer should be called to correct the problem.

8.5. PHOTOTIMER EVALUATION

Purpose

To assure that the exposure is being terminated at the proper time after a predetermined quantity of radiation has been detected.

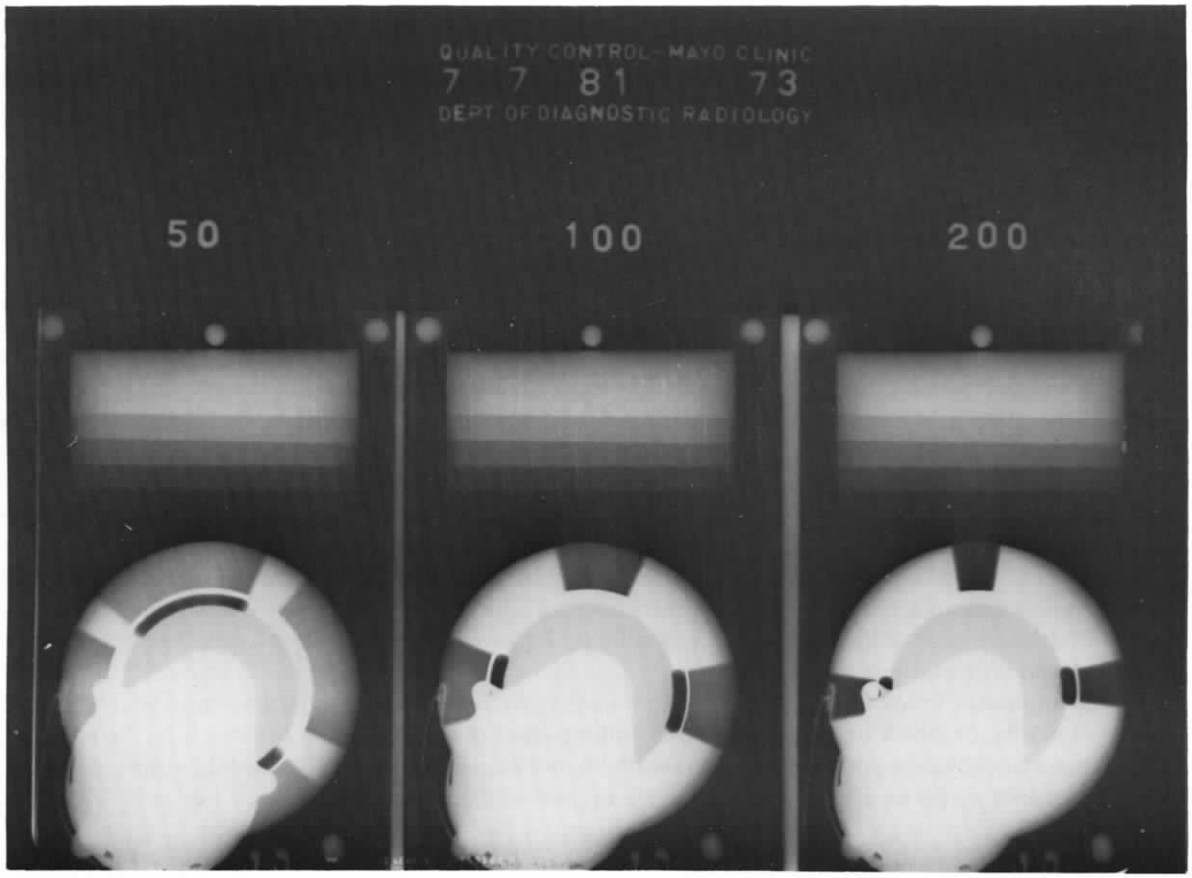


Figure 8.19a. Acceptable density variation in generator linearity test results using the motorized synchronous timer.

Equipment Needed

1. Homogeneous patient equivalent phantom (PEP), plus two additional 1 × 12 × 12-inch (2.5 × 30 × 30-cm) sheets of Plexiglas
2. Densitometer
3. Single cassette to be used for all exposures and film from the same batch
4. Direct readout dosimeter
5. Two sheets of 1/8-inch (3-mm) lead, 12 × 12-inch (30 × 30-cm)

Procedure—Conventional Phototimed Systems

1. Set the x-ray tube at the normal working distance and center the tube to the table and cassette.
2. Place four sheets of Plexiglas from the PEP in the light field and cone slightly inside the dimensions of the phantom (Figure 8.20). (The phantom must be centered to the phototiming sensors.)
3. Use the center sensing area and make three exposures on three different films using the same cassette at 60, 80, and 100 kVp, keeping the mA constant. (Use the mA that is typically used in the room.) Remember to use the *same cassette* for all exposures. This will entail processing the film after each exposure.
4. Place four more sheets of Plexiglas on top of the original four and repeat the exposures at the same three kVp values and at the same technique using the same cassette and film from the same emulsion batch.
5. After the sixth film has been processed, read the densities of the films (in the same area) with the densitometer. [***Note:*** You should also check the system at different mA stations and with the different sensing areas to assure that the entire system is working properly.]
6. Record the results in the QC room log.

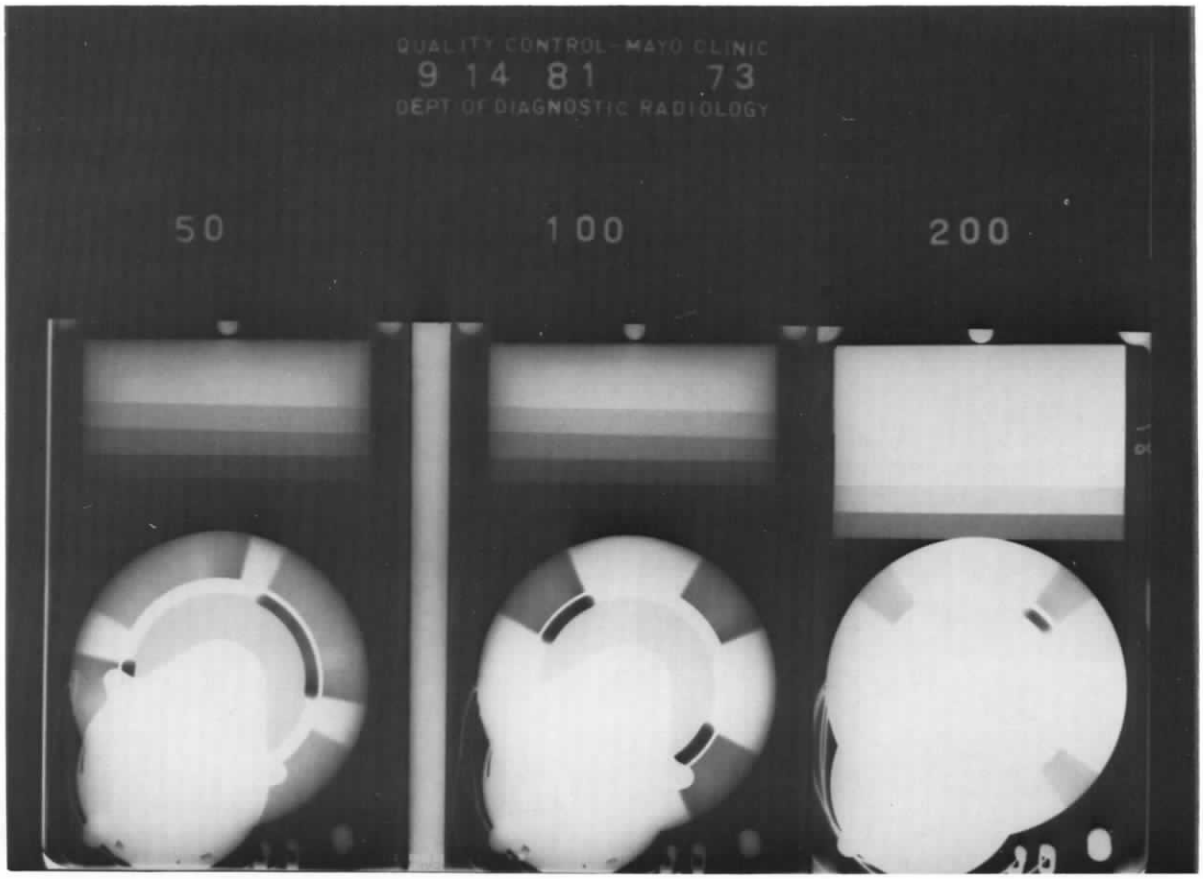


Figure 8.19b. Generator linearity test results using the motorized synchronous timer. Density variation for the various mA stations exceeds acceptable limits.

Procedure—Photofluorospot (PFS) Film Units and Automatic Chest Units

1. The procedure described above is used to check these units using the same thicknesses of Plexiglas and three different kVp values.
2. On fluoroscopic systems that vary the PFS kVp, the kVp should be set to the manual mode.
3. On automatic chest units, three and then six layers of Plexiglas should be used to better simulate the chest.

Problems and Pitfalls

1. Assure that the Plexiglas is covering the phototimer sensors and that the radiation field is coned to the Plexiglas.
2. Care must be taken to use only the screen-film system for which the unit has been calibrated.
3. The exposure time required may be shorter than the minimum response time of the system if high kVp and/or mA techniques are used.
4. On PFS film and chest systems, make sure the systems are being checked in the typically used kVp and mA ranges.
5. This test of the phototiming system may not entirely reveal calibration problems. Consequently, all the tests described in this chapter should be done to ensure optimal calibration and operation of the system.

Acceptance Limits

The densities of the six radiographs from a given system should be within ± 0.10 of each other. The average densities of the six radiographs from one check to another should be within ± 0.20 of each other. The larger variation accepted in this latter case is to allow for processor and film batch variations.

Corrective Action

If the densities exceed the above limits, a service engineer should be called to calibrate the system.

Figure 8.20. Phototimer evaluation test setup. Center the first four sheets under the x-ray tube and directly over the phototimer detectors. Be sure to include date, room, and technique information on each film.

Procedure—Backup Timer Check

It is important to assure that the backup timer is functioning and the backup time does not exceed that specified in federal regulations. If the phototimer should fail, the backup timer must terminate the exposure.

1. Remove the Plexiglas and place at least two sheets of 1/8-inch (3-mm) lead over the detector field so that *no radiation reaches the detectors.*
2. Place the small chamber on the dosimeter and place the dosimeter (or electronic timer) in the center of the x-ray beam in front of the lead sheets (Figure 8.21). Set the dosimeter to the time-measuring mode.
3. Make an exposure at a standard technique with the system in the phototiming mode.
4. The exposure should terminate after the preset backup time is reached.
5. Read the backup time on the dosimeter.

Problems and Pitfalls

Be sure that the phototimer sensors are completely covered by the lead.

Acceptance Limits

The backup timer should terminate the exposure so that a total exposure of 600 mAs is not exceeded.

Corrective Action

If the backup time can be exceeded, the equipment should not be used in the phototiming mode until a service engineer has corrected the problem.

Procedure—Minimum Exposure Time Check

The minimum exposure time is checked to record the shortest time at which the phototiming circuit will function. There are no minimum limits for exposure time; however, it is of value to know and record the minimum time so that techniques are selected using at least twice the minimum, even for thin patients.

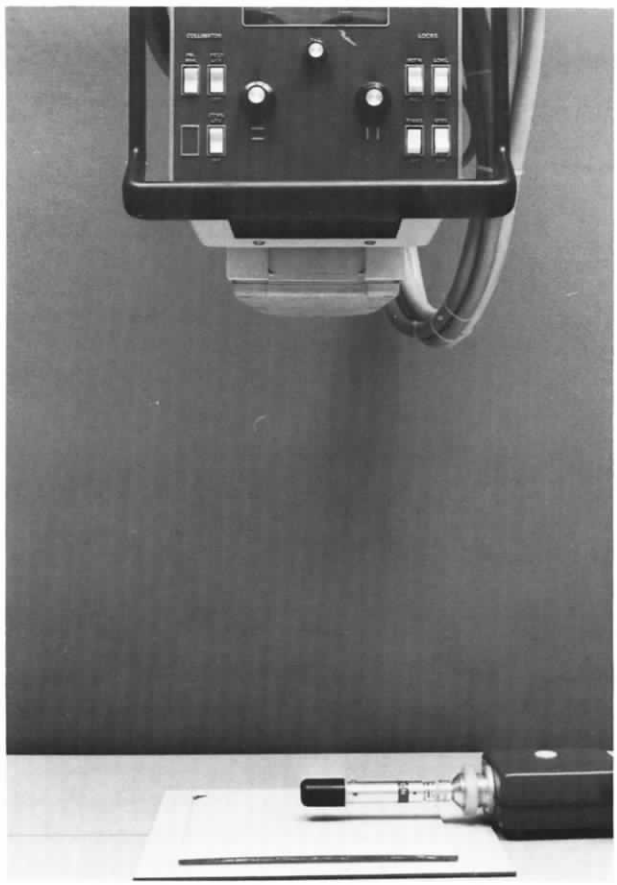


Figure 8.21. Backup timer check test setup. At least two sheets of 1/8-inch (3-mm) lead should be used to cover the phototimer detectors completely.

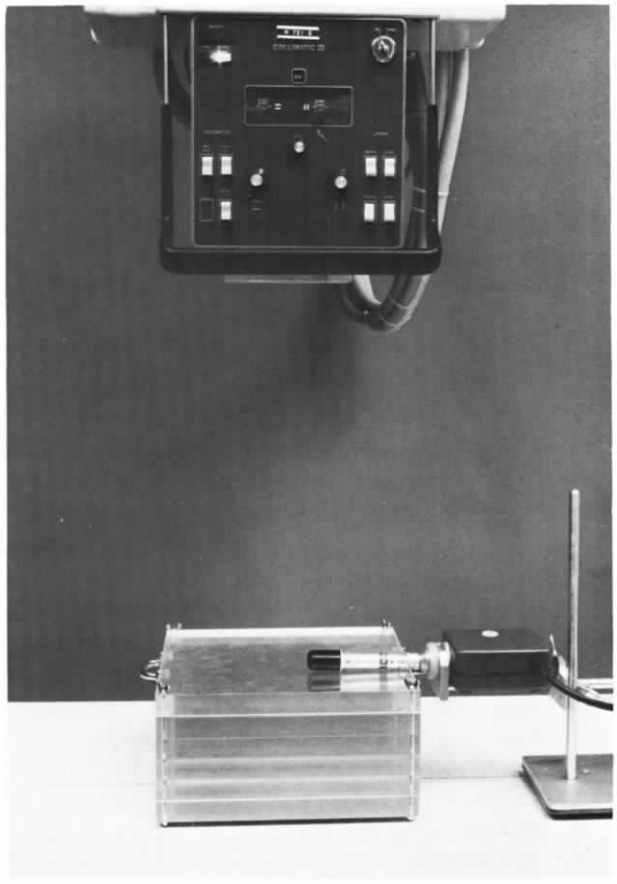


Figure 8.22. Minimum exposure time check test setup.

1. Place six sheets of Plexiglas over the detectors.
2. Place the dosimeter chamber (or electronic timing device) in the beam with the dosimeter set to the exposure time reading mode (Figure 8.22).
3. Make an exposure at a standard technique and note the exposure time.
4. Remove one sheet of material and make another exposure, again noting the exposure time.
5. The exposure time should be reduced for each sheet of material that is removed.
6. Keep removing the sheets of material until the minimum time is reached, i.e., when the time no longer changes as sheets of material are removed.
7. Record this value in your QC room log.

Problems and Pitfalls

1. In some cases, the minimum time may not be reached with just one layer of Plexiglas in the beam. In this case, leave the last sheet of Plexiglas in the beam and make additional exposures increasing the kVp by increments of 5 until the minimum time is reached. Record both the minimum time and kVp used in the QC room log.
2. It is necessary to use the 1 × 12 × 12-inch (2.5 × 30 × 30-cm) sheets of Plexiglas in this and the previous phototimer tests to assure that sufficient scattered radiation is introduced to simulate patient scatter conditions.

Acceptance Limits

There are no established limits for this test. However, make sure that the system will produce the minimum time as described in the manufacturer's specifications.

Corrective Action

A service engineer should check the system if the phototiming circuit cannot produce the minimum exposure time as described in the manufacturer's specifications.

8.6. MAMMOGRAPHY AND XERORADIOGRAPHY

Purpose

To provide consistent, high-quality mammograms and xeroradiographs with minimum exposure to the patient.

Equipment Needed

1. Full set of QC test tools
2. Low-kVp cassette (30–50 kVp)
3. Number 50 or 60 copper mesh for screen contact
4. Direct readout dosimeter with low-energy ionization chamber
5. Mammographic phantom

Procedures

1. All the components of a mammographic system should be checked exactly as in any other radiographic system and the same acceptance limits apply.
2. Check the half-value layer (HVL) at a kVp typically used for mammography and xeroradiography. Place 0.25, 0.50, and 1.0 mm of aluminum in the beam since the HVL will be much lower than in a conventional radiographic system. In addition, be sure the compression device, and any other devices that are normally in the x-ray beam, are in position while the HVL is checked.
3. Measure the kVp with the low-kVp cassette (sometimes referred to as the mammography cassette).
4. Check the screen contact of cassettes or vacuum bags regularly using a number 50 or 60 copper mesh.
5. Establish and outline an easily reproduced procedure controlling the mA, kVp, and target-to-film distance for radiographs of a mammographic phantom. Make radiographs of the phantom on a regular basis and observe the test objects in the phantom to ensure optimal resolution. Record the film density and resolution information in the QC room log.
6. Make sure the xeroradiographic cassettes are checked and cleaned at least once each week and that the proper maintenance is performed regularly on the charger and processor units.

Problems and Pitfalls

1. Because of the complexity and potential radiation hazard of mammography, it is wise to work closely with a qualified diagnostic radiologic physicist to establish a QC program on mammographic or xeroradiographic systems.
2. Because of the low-energy x-ray beam used for mammography, conventional ionization chambers will not provide accurate readings. Special thin-window, low-energy mammographic chambers can be obtained for most dosimeters. All measurements made on mammographic and xeroradiographic equipment should be made with the mammographic chamber.
3. Since the standard phantom cannot be used to check the linearity, repeatability, and mR/mAs output on mammographic and xeroradiographic systems, these measurements should be made in air. Be sure to closely follow your procedure with regard to such things as the chamber position in the beam for each subsequent QC check.

Acceptance Limits

The acceptance limits for conventional generators apply. Phantom procedures should consistently reproduce the test objects in the phantom. The film density from the phantom should remain within ± 0.15 on each QC check if the processor is in control.

Corrective Action

1. Consult a diagnostic radiologic physicist if questions arise regarding the use of the equipment.
2. Call a qualified service engineer for equipment problems.