

Quality Assurance Series
Diagnostic Radiology

Quality Assurance for
Radiographic X-Ray Units
and Associated Equipment

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FOREWORD

The Bureau of Radiological Health develops and carries out a national program to control unnecessary human exposure to potentially hazardous ionizing and nonionizing radiations and to ensure the safe, efficacious use of such radiations. The Bureau publishes the results of its work in scientific journals and in its own technical reports.

These reports provide a mechanism for disseminating results of Bureau and contractor projects. They are distributed to Federal, State, and local governments; industry; hospitals; the medical profession; educators; researchers; libraries; professional and trade organizations; the press; and others. The reports are sold by the Government Printing Office and/or the National Technical Information Service.

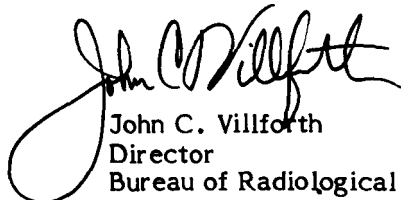
The Bureau also makes its technical reports available to the World Health Organization. Under a memorandum of agreement between WHO and the Department of Health, Education, and Welfare, three WHO Collaborating Centers have been established within the Bureau of Radiological Health, FDA:

WHO Collaborating Center for Standardization of Protection Against Nonionizing Radiations;

WHO Collaborating Center for Training and General Tasks in Radiation Medicine; and

WHO Collaborating Center for Nuclear Medicine.

Please report errors or omissions to the Bureau. Your comments and requests for further information are also encouraged.



John C. Villforth
Director
Bureau of Radiological Health

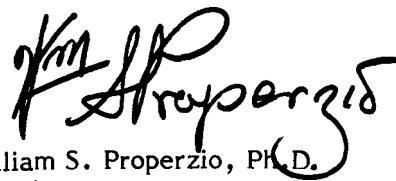
PREFACE

Production of radiologic images of acceptable diagnostic quality obtained with minimum radiation exposure to patients is a basic goal of the Bureau of Radiological Health (BRH). The efforts of the Division of Training and Medical Applications to meet this goal are diverse; one very promising approach is the development and dissemination of Quality Assurance (QA) information and methodology for medical uses of radiation. A Quality Assurance Recommendation for diagnostic radiology facilities is currently being developed for publication in the FEDERAL REGISTER. Concurrently, the Division is developing a series of quality assurance instruction manuals. These manuals describe in detail the establishment and operation of specific elements of a quality assurance program. They present proven QA techniques that can be adapted by individual radiology facilities according to their needs and resources. These manuals are part of the "BRH Quality Assurance Publications" series providing QA information for many uses of medical radiation including ultrasound, nuclear medicine and radiation therapy as well as diagnostic radiology. A listing of subjects and specific titles follows.

This volume, "Quality Assurance for Radiographic X-Ray Units and Associated Equipment," provides detailed QA procedures for general purpose radiographic equipment and ancillary equipment such as intensifying screens, cassettes and view boxes. Included is data analysis techniques and recommendations for taking corrective measures. The procedures described in this manual are based on the techniques and equipment used by the contractor. Comparable equipment from other manufacturers may serve equally well in performance of these tests. A variety of QA test equipment is described in the QUALITY ASSURANCE CATALOG (HEW publication (FDA) 77-8028) and its supplement (HEW publication (FDA) 78-8028).

This and related manuals provide the basis for a comprehensive QA program in diagnostic radiology. We hope that each facility will evaluate its own needs and adopt as much of this program as appropriate.

We welcome comments on your experience with this manual, as well as suggestions for the content, style and direction of future manuals.



William S. Properzio, Ph.D.
Director
Division of Training and
Medical Applications
Bureau of Radiological Health

BRH QUALITY ASSURANCE PUBLICATIONS

GENERAL

Gray, J.E. Photographic quality assurance in diagnostic radiology, nuclear medicine and radiation therapy, Volume 1: the basic principles of daily photographic quality assurance. HEW Publication (FDA) 76-8043 (June 1976).

Gray, J.E. Photographic quality assurance in diagnostic radiology, nuclear medicine and radiation therapy, Volume 2: photographic processing quality assurance and the evaluation of photographic materials. HEW Publication (FDA) 77-8018 (March 1977).

U.S. Department of Health, Education, and Welfare. Quality assurance catalog and quality assurance catalog supplement. HEW Publication (FDA) 77-8028 (July 1977), HEW Publication (FDA) 78-8028 (August 1978). Compiled by R.L. Burkhart.

DIAGNOSTIC RADIOLOGY

Hendee, W.R. and R.P. Rossi. Quality assurance for radiographic x-ray units and associated equipment. HEW Publication (FDA) 79-8094.

Hendee, W.R. and R.P. Rossi. Quality assurance for fluoroscopic x-ray units and associated equipment. HEW Publication (FDA) 80-8095.

Hendee, W.R. and R.P. Rossi. Quality assurance for conventional tomographic x-ray units. HEW Publication (FDA) 80-8096.

Goldman, L.W. and S. Beech. Analysis of retakes: understanding, managing and using an analysis of retakes program for quality assurance. HEW Publication (FDA) 79-8097.

ULTRASOUND

Lopez, H. and S.W. Smith. Implementation of a quality assurance program for ultrasound B-scanners. (To be published).

NUCLEAR MEDICINE

Department of Health, Education, and Welfare. Quality control for scintillation cameras. HEW Publication (FDA) 76-8046 (June 1976).

Department of Health, Education, and Welfare. Workshop manual for quality control of scintillation cameras in nuclear medicine. HEW Publication (FDA) 76-8039 (May 1976).

Hine, G., P. Paras and C. Warr. Measurements of the performance parameters of gama cameras, Part 1. HEW Publication (FDA) 78-8049 (December 1977).

Radionuclide handling and radiopharmaceutical quality control. (To be published).

DENTAL RADIOGRAPHY

Department of Health, Education, and Welfare. Exposure and processing guide for dental radiography. HEW Publication (FDA) 77-8039 (August 1977).

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The opinions and statements contained in this report are those of the authors and may not reflect the views of the Department of Health, Education, and Welfare (HEW), or necessarily represent the views or the stated policy of the World Health Organization (WHO). The mention of commercial products, their sources, or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products by the Department or the World Health Organization. Similarly, the Department has not verified manufacturers' values for accuracy and reproducibility of their instruments.

QUALITY ASSURANCE FOR RADIOGRAPHIC X-RAY UNITS AND ASSOCIATED EQUIPMENT

1. INTRODUCTION: WHAT A QUALITY ASSURANCE PROGRAM IS AND WHY IT IS NEEDED

A quality assurance program may be defined as an organized effort by a facility to ensure that the product produced by the facility is of consistently high quality. In diagnostic radiology, the product of the facility is roentgenographic images, and a quality assurance program maximizes the likelihood that the images will consistently provide adequate diagnostic information for the least possible radiation exposure and cost to the patient. In its most comprehensive form, the quality assurance program monitors each phase of operation of the diagnostic radiologic facility, beginning with the request for an examination and ending with the interpretation of the examination and the communication of this interpretation to the referring physician. Included within this program are actions to ensure that the radiologic equipment used for the examination will yield the information desired about the patient. It is these actions which are emphasized in this manual.

Quality assurance actions to ensure that radiologic equipment will yield the desired information include both quality control techniques and quality administrative procedures. Quality control techniques are directed to the routine testing and maintenance of components of the x-ray system to verify that the equipment is operating satisfactorily. Quality administration procedures encompass management actions designed to verify that the quality control monitoring techniques are performed regularly and properly, that the results of these techniques are evaluated promptly and accurately, and that the necessary corrective measures are taken in response to these results. Quality administration procedures also include the assignment of responsibility for quality assurance actions, the establishment of standards of quality expected for equipment in the facility, the provision of adequate training for quality assurance personnel, and the verification that equipment selected for each examination is appropriate for the examination.

The question of the appropriateness of the equipment used for an examination is addressed at the time the equipment is ordered and installed, and is answered by a variety of procedures including determination of the clinical imaging requirements for the equipment, the translation of these requirements into technical specifications for the equipment, the selection of equipment which satisfies the technical specifications, and the acceptance testing of the equipment after installation to confirm that the equipment actually performs at the level described in the technical specifications agreed upon by manufacturer and purchaser.

This approach to a quality assurance program for radiologic equipment is outlined in Figure 1. During the acceptance testing phase, performance data are compiled which serve as a comparative standard for similar data collected subsequently during quality assurance monitoring of the equipment as it is used to produce clinical images. It is this latter quality control phase of an equipment quality assurance program, namely the monitoring of the performance of the equipment during routine clinical use, that is addressed by the procedures outlined in this manual.

This quality control phase must be supported by quality administration procedures which include the assignment of responsibility for monitoring and corrective actions and for evaluation and review of the overall quality assurance program. These procedures are discussed further in Appendix A. Quality administration procedures specifically applicable

to each quality control technique are included with the description of the techniques in this manual.

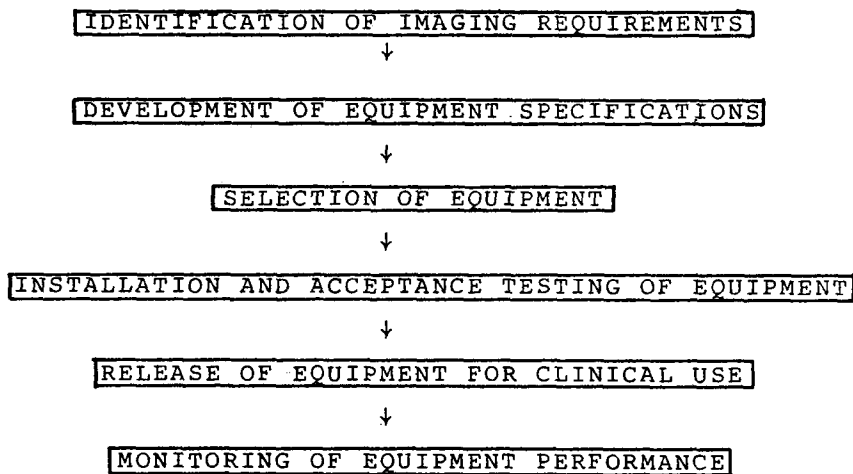


Figure 1. Quality assurance in diagnostic radiology

The fundamental responsibility for a quality assurance program for any radiologic facility is vested in the individual in charge of the facility. If the program is to be implemented successfully, however, the responsibility for the quality control equipment performance monitoring phase of the program must be delegated to the individuals responsible for use of the equipment in routine clinical practice. These individuals are the technologists who use the equipment day after day to produce clinical images, and the quality control techniques must be designed for use by these technologists. Because of the limited time which technologists have available for quality assurance testing of their equipment, the quality control techniques must be straightforward and must require little time for execution. These constraints were considered in the design of the monitoring techniques recommended in this manual. Other techniques which are mentioned in the manual are designated as alternative rather than as recommended techniques because they are more complex, require more time or more costly equipment, or furnish data related less directly to the proper functioning of the equipment.

In a properly conceived diagnostic radiology facility, each technologist is responsible for ensuring that images with adequate diagnostic information are obtained at minimal cost to the institution and patient and with the least possible exposure of the patient to radiation. This responsibility requires the implementation of an adequate quality assurance management program and the use of monitoring techniques to verify consistent and satisfactory operation of the equipment with which the images are produced. It is towards this objective that the techniques described in this manual are recommended.

2. PRINCIPLES OF A QUALITY ASSURANCE PROGRAM

In the application of a quality assurance management program to a diagnostic radiology facility, each technologist is held responsible for ensuring that the equipment which he uses is performing in a consistent and satisfactory manner. To fulfill this responsibility, the technologist needs straightforward and rapid techniques to confirm that the equipment is functioning in a satisfactory and reproducible manner. By utilizing these techniques according to a prescribed schedule, and by comparing the resulting data to those collected during acceptance testing of the equipment, the technologist can affirm that the equipment is satisfactory. For this affirmation, each test should be related to a tolerance range of

satisfactory results, with test data falling outside the tolerance range interpreted as indicative of unsatisfactory performance of the equipment. Before this interpretation is made, however, tests yielding unsatisfactory results should be repeated to verify that a problem exists, and data from tests on previous days should be consulted to determine if a trend toward unsatisfactory performance is detectable, or if the unsatisfactory results represent a sudden change in equipment performance. For this consultation, accurate and complete record keeping of quality control test results is essential.

If testing results indicate that the equipment's operation is unsatisfactory, the supervisor of the quality assurance program should be informed so that corrective measures may be implemented. Usually, the supervisor is a medical physicist, a chief technologist or a quality assurance technologist for the facility. In response to this information, the supervisor should initiate immediate corrective action by arranging for service of the equipment to restore it to satisfactory operation. Prior to clinical use of the serviced equipment, the quality control tests should be repeated to confirm that the equipment has been restored to a satisfactory level of performance.

3. VARIABLES ADDRESSED BY THE QUALITY ASSURANCE PROGRAM

In any x-ray imaging system, a number of variables can affect the availability of diagnostic information in the image and the exposure of the patient to radiation. Each of these variables should be monitored periodically if a quality assurance program is to be maximally effective in improving image quality and reducing the exposure of the patient to radiation. Results of these monitoring procedures should fall within acceptable tolerance limits of baseline data established when the unit was accepted for clinical use or otherwise judged to be operating properly. In the establishment of acceptable tolerance limits, judgments are required in the level of performance which can reasonably be expected for mass produced components of x-ray equipment, and in the variability which can be tolerated for the components without adverse effects on the clarity of diagnostic information. In each of the tests described below, these judgments have been made in establishing tolerance limits for test results.

Almost all x-ray units provide means to align the x-ray beam with the patient and image receptor and to confine the beam to only the region of interest in the patient. Misalignment introduces distortion into the image and may cause deletion of information essential to diagnosis of the patient's condition. Extension of the x-ray beam beyond the anatomical region of interest increases the radiation exposure of the patient and degrades image quality by introducing excessive scatter into the image. To verify the adequacy of the beam alignment and restriction systems, a special beam restriction cassette and beam alignment tool are used.

The density of the x-ray image varies directly with exposure time, and irreproducible exposure timers cause fluctuations in density from one image to the next which may obscure needed diagnostic information and increase the number of repeated examinations. Inaccurate exposure timers introduce difficulties in adjusting the radiographic technique for differences in body size and composition, by changing the exposure time. To evaluate the accuracy and reproducibility of an exposure timer, a digital x-ray timer with a radiation sensitive diode is employed.

Every x-ray tube has certain limits to the rate at which heat can be produced in the focal spot without structural damage to the x-ray target. These limits are described in the heat rating chart for the x-ray tube. In most modern x-ray generators, heat limits also are incorporated into protective circuitry in the generator console to prevent the operator from selecting a technique beyond the heat production capacity of the x-ray target. Since the operator often depends on this circuitry to prevent an improper exposure without consulting the heat rating chart, a malfunction of the circuitry could result in excessive heat generation and structural damage in the target, leading ultimately to replacement of the x-ray tube.

To confirm the proper functioning of the protective circuitry for an x-ray tube, techniques are selected from the heat rating chart and programmed into the generator console while the tube overload indicator is monitored.

For the same technique settings, consecutive exposures should yield identical amounts of radiation and identical film densities. If the consecutive exposures are not reproducible, films of varying density will be produced, leading to an increase in the rate of repeated examinations. Similarly, techniques at constant kVp and mAs should yield identical exposures and film densities irrespective of the combinations of mA and exposure time chosen to provide the constant mAs. Nonlinearity of the mA and timer settings (i.e. variations in exposure for constant mAs) also will yield varying film densities and an increase in retake rate. For any x-ray beam, filtration should be present to remove low energy photons from the x-ray beam so that these photons are not absorbed in the patient to produce excessive patient radiation dose. The presence of adequate filtration can be verified by measuring the half-value layer of the x-ray beam.

For these measurements, an ionization chamber and electrometer are required, together with aluminum attenuators for measurements of the half-value layer.

The x-ray tube focal spot is the region of the x-ray target where x rays appear to originate. The sharpness of the roentgenographic image is strongly dependent on the size of the x-ray tube focal spot, and tests should be performed periodically to ensure that the focal spot has not increased in size. These tests are conducted with a focal spot test tool and direct exposure x-ray film.

The density and contrast of the roentgenographic image vary with the kVp chosen for an examination, and an improperly calibrated kVp indicator can yield inadequate diagnostic information and overexposed or underexposed films, leading to an increase in the rate of repeated examinations. The kVp across an x-ray tube is affected by the tube current, and special circuits are employed in the x-ray generator to compensate for this effect so that the indicated kVp is independent of x-ray tube current. To verify the accuracy of the indicated kVp and the independence of indicated kVp on tube current, a special kVp test cassette is used in conjunction with an optical densitometer for evaluation of test images.

Alignment of the antiscatter grid with the x-ray tube and image receptor is essential to prevent grid cutoff which is reflected in a reduced and nonuniform film density which may obscure needed diagnostic information. To test an x-ray system for grid alignment, a special test tool is employed to yield roentgenographic images which can be analyzed for proper alignment.

Many x-ray units are equipped with an automatic exposure control device ("phototimer") which relieves the operator of the responsibility for selecting exposure times to yield satisfactory film densities. A malfunction of the automatic exposure control system produces overexposed or underexposed film, resulting in an increase in examination repeat rate and exposure of patients to unnecessary radiation. To evaluate an automatic exposure control system, a Plexiglas phantom and digital x-ray timer are used.

In the production of most x-ray images, x-ray film is sandwiched between intensifying screens. Any displacement of the film from either intensifying screen results in image blurring which dramatically reduces the clarity of diagnostic information in the image. To overcome this problem, screen-film cassettes should be evaluated periodically for adequate screen-film contact, and cassettes failing the test should be removed from clinical use.

To evaluate screen film contact, exposures are made with a test pattern on top of the cassette, and the resulting roentgenogram is examined for distortions which imply inadequate contact.

Variations in the sensitivity (speed) among a group of supposedly identical screen-film cassettes will produce variations in film density which can lead to loss of diagnostic information and increase in repeat examinations. A cassette with sensitivity outside the tolerance range from a group of similar cassettes should be replaced.

To test for the uniformity of screen sensitivity, films are exposed inside each of several similar cassettes, and the resultant optical densities are compared.

Uniformly illuminated viewing conditions are essential to the display of diagnostic information present in roentgenographic images. Consequently, the uniformity of radiographic illuminators should be evaluated periodically and whenever a light bulb is changed. For this evaluation, only an optical light meter and viewing mask are required.

4. QUALITY ASSURANCE TEST FOR GENERAL PURPOSE RADIOGRAPHIC SYSTEMS

This section of the manual presents specific detailed test procedures to be used in establishing a quality assurance program for general purpose radiographic systems. Each test procedure has been designed to be used on a "stand alone" basis. However, it is important to recognize that certain data gathered during one test may be useful in another or that certain aspects of equipment performance are interrelated. Thus when implementing a quality assurance program it is essential to recognize that an approach which allows for the phased implementation of the test procedures is likely to meet with the greatest success as it allows individuals to become familiar with the required procedures over a reasonable period of time instead of rushing headlong into it.

To assist those individuals who will be responsible for the implementation of a quality assurance program in their own facility Table 1 has been provided. This table lists the parameter being tested, the number of test procedures which address this parameter, the recommended testing frequency for quality assurance purposes, a suggested order of test implementation with 1 representing the first and the approximate time required to carry out the test. It is important to recognize that these time requirements assume that the person performing the test has become familiar with it. It is not unreasonable to anticipate that more time will be required by individuals to conduct the test during the early stages of program implementation.

It should be recognized that results of these QA tests, as with any measurement, are subject to error. The action limits provided represent a reasonable compromise between sensitivity of problem detection and accuracy of the testing method. To minimize the probability of a test result being in error, any test resulting in a value exceeding the action limits should first be repeated for confirmation.

Several of the action limits in this manual are more stringent than those used to determine compliance with applicable regulations. This allows early problem detection and subsequent correction before imaging is impaired. One should not assume, therefore, that exceeded action limits means non-compliance. What it does mean is possible sub-optimum performance which may or may not be a compliance problem. Several of these tests may be used to satisfy the manufacturer's maintenance schedule. The prime value of these tests, however, is to detect changes in equipment performance that may affect radiologic imaging, and not to measure absolute performance. More rigorous performance tests should be used to establish baseline equipment performance with these QA tests to indicate changes from that performance. In this context, initial comparisons between QA tests and baseline performance tests should be done with caution, since results may be due to differing test procedures.

Table 1. Parameters, testing frequency, implementation order and approximate time requirements for quality assurance procedures for general purpose radiographic systems

Parameter	Test no.	Routine testing frequency	Implementation mode	Time requirement
Source to image receptor distance indicator accuracy	4.1	N.A.	1	.5 h
Radiographic beam restriction system adequacy	4.1	Every 2 mos.	2	1 h
Exposure timer accuracy and reproducibility	4.2	Every 6 mos.	5	.75 h
Tube protection	4.3	6 mos.	13	1 h
Exposure reproducibility and linearity	4.4	3 mos.	6	1.5 h
Beam quality	4.4	3 mos.	7	.5 h
Focal spot size	4.5	3 mos.	12	.5 h
kVp	4.6	3 mos.	9	.75 h
Grid alignment	4.7	6 mos.	10	1 h
Automatic exposure control system performance	4.8	6 mos.	11	3 h
Film-screen contact	4.17	6 mos.	20	.25 h/ cassette
Screen speed uniformity	4.18	1 yr.	21	.25 h/ cassette
Radiographic illuminator uniformity	4.19	6 mos.	22	.25 h/ illuminator

4.1 SOURCE TO IMAGE RECEPTOR DISTANCE INDICATOR ACCURACY AND BEAM RESTRICTION SYSTEM ADEQUACY

4.1.1 **Objective of Test:** To verify the accuracy of the source-to-image receptor distance indicator, the centering alignment of the beam restriction system, the accuracy of the numerically indicated field size (collimator scale) and the congruence of the radiation and light field.

4.1.2 **Recommended Test Equipment:** Shown in Figure 2 is the equipment recommended for performing this test. In addition to the equipment shown, Data Form RF 1 is required.

4.1.3 Testing Frequency:

1. SID Indicator Accuracy - upon installation of equipment and/or implementation of the quality assurance program and following any service work which can affect the accuracy of the indicated SID such as x-ray tube replacement and/or service work on the x-ray tube suspension. An annual check is also recommended.
2. Beam Restriction System Adequacy - routinely at 2-month intervals and following any service work performed on the beam restriction system such as replacement of a light bulb.

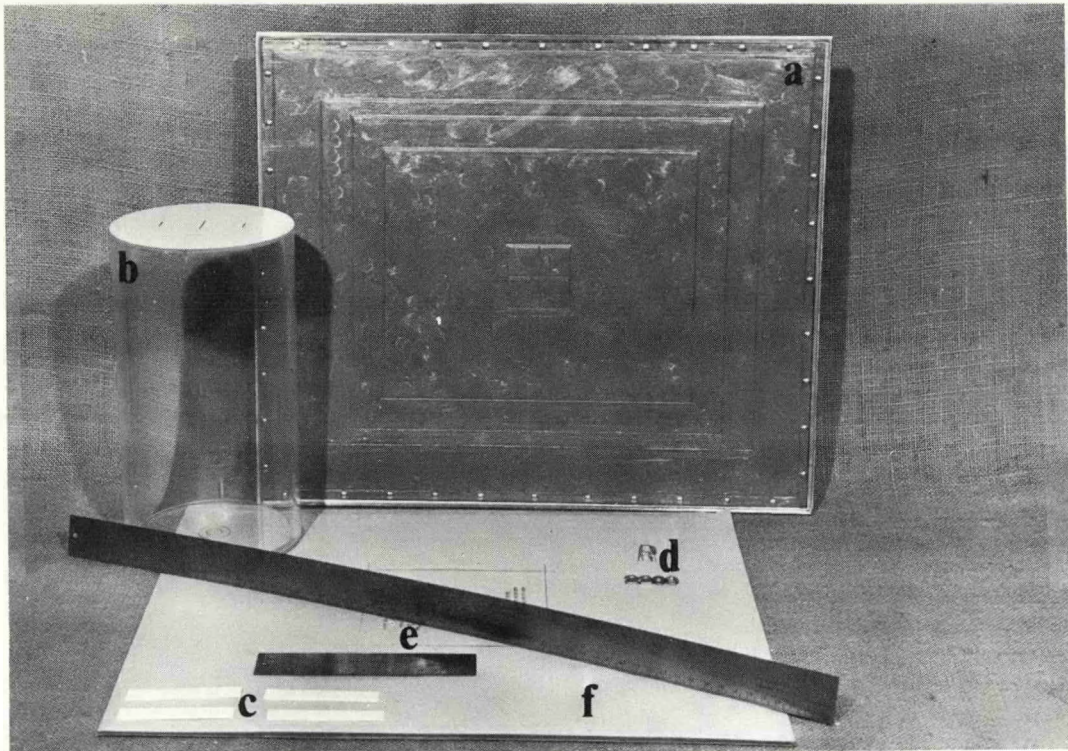


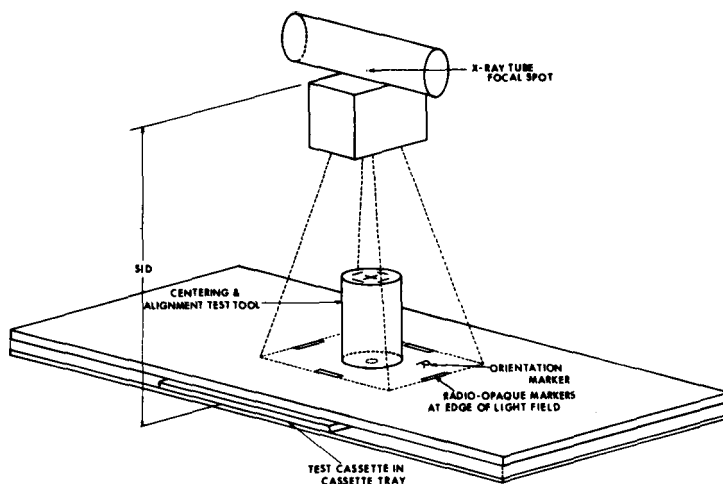
Figure 2. Recommended equipment for performing source to image receptor distance indicator accuracy and beam restriction system adequacy test: a. beam restriction system test cassette; b. centering and alignment test tool; c. radiopaque marker strips (.5- x 3- x .06-in); d. lead "R" marker and numbers for test film identification; e. 6 in and 24 in rulers; and f. direct exposure ready pack film (14- x 17-in).

4.1.4 Test Procedure:

Manual Collimation Systems or Automatic Collimation Systems Operated in the Manual Mode

1. Position the loaded test cassette in the cassette tray being careful to properly center the cassette with respect to the cassette tray. Orient the long dimension of the cassette parallel to the long axis of the table. Insert the cassette tray three-fourths of the way into the table (Fig. 3a and 3b).
2. Using the 6-inch ruler measure the distance from the top surface of the table to the top surface of the test cassette and record in the data form as dimension p. (It may be helpful to lay a straight edge on the surface of the table to serve as a measuring guide.)
3. Using the means provided on the equipment (e.g., electrical magnetic centering locks and measuring devices), set the source to image receptor distance (SID) to that normally used on the system (e.g., 40 in, 72 in) and lock the vertical travel of the x-ray tube suspension. Record this distance as SIDs in the data form,

a



b

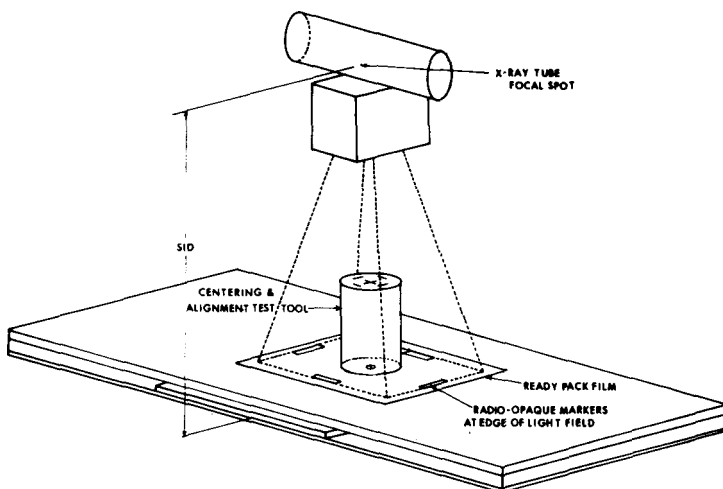


Figure 3. Illustration of equipment set up for performing test: a. source to image receptor distance accuracy and adequacy of manual collimation systems or automatic collimation systems operated in the manual mode; b. adequacy of positive beam limitation systems.

4. Using the means provided on the equipment, verify that the x-ray tube is perpendicular to the cassette and center the x-ray tube with respect to the cassette both longitudinally and transversely and lock the tube in place. Insert the cassette tray completely into the table.
5. Using the numerical indicators adjust the beam restriction system to provide an 11- x 14-in (or other size as might be desired) radiation field for the set SID. Record the length and width of the numerically indicated field size in the data form as L_S and W_S , respectively (e.g., $L_S = 14$ in, $W_S = 11$ in).
6. Activate the beam restriction light field and position the centering and alignment test tool so that the surface containing the central wire cross is facing the collimator and centered with respect to the center of the projected light field center (intersection of collimator cross hairs).
7. Position the four radiopaque markers at the sides of the light field as projected on the tabletop. The markers should be positioned under normal room illumination such that their outer edges coincide with the outer edges of the visual light field. Penumbra at the edges of the field require this to be carried out using the utmost of care.
8. Position a right marker in the upper right quadrant of the projected light field as you face the table. Below the right marker position lead numbers to identify the unit on which the test is being conducted.
9. On the x-ray generator control select 60 kVp, the small focal spot and make a radiographic exposure of approximately 3 to 5 mAs. (Technique may need to be altered depending on the unit under test.)
10. Open the beam restrictor system to provide a field size of 14x17 in and make a second exposure of approximately 0.5 mAs.
11. Remove the test cassette from the cassette tray and process the test film. Analyze the test film as described under interpretation of test results and record the information on the data form.
12. If desired, repeat the test for other field sizes and/or beam restriction system configurations (e.g. vertical cassette holder).

Positive Beam Limitation Systems

13. If so equipped, place the beam restriction system in positive beam limitation mode of operation.
14. Place an unloaded 11- x 14-in cassette in the cassette tray making sure to carefully center the cassette with respect to the cassette tray. In the data form record the length and width of the cassette size used as L_I and W_I , respectively (e.g., $L_I = 14$ in, $W_I = 11$ in).
15. Set the source to image receptor distance to that normally used on the system (e.g., 40 in, 72 in) and lock the vertical travel of the x-ray tube.
16. Using the means provided on the equipment, verify that the x-ray tube is perpendicular to the cassette and center the x-ray tube both longitudinally and transversely with respect to the cassette in the cassette tray.
17. Activate the beam restriction system localizing light and insert the cassette tray completely into the table. The field size should automatically adjust to

the size of the cassette or prevent an x-ray exposure until the beam restriction system is manually adjusted to provide a field size no greater than the size of the cassette. Automatic adjustment may be verified by noting a change in size of the projected light field on the tabletop and by the indication of the field size corresponding to the dimension of the cassette on the numerical field size indicators for the SID employed. For systems which prohibit exposure until manual adjustment is accomplished an indicator light may be provided to denote system status. Note and record whether one of these two functions is present and operable on the system.

18. Position a ready pack 14- x 17-in film on the tabletop so that it is approximately centered in the projected light field and tape the ready pack film in place to prevent it from shifting position.
19. Activate the localizing light on the beam restriction system and position the centering and alignment test tool so that the surface containing the central wire cross is facing the collimator and centered with respect to the center of the projected light field (intersection of collimator cross hairs).
20. Position the four radiopaque markers at the sides of the light field as projected on the tabletop. The markers should be positioned under normal room illumination such that their outer edges coincide with the outer edges of the visual light field.
21. Position a right marker in the upper right quadrant of the projected light field as you face the table. Below the right marker position lead numbers to identify the unit on which the test is being conducted.
22. On the x-ray generator control select 60 kVp, the small focal spot and make a radiographic exposure of approximately 60-80 mAs.
23. Override the positive beam limitation system and adjust to provide a 14- x 17-in field size. Make a second radiographic exposure of approximately 10 mAs.
24. Remove the test film from the tabletop and process the test film. Analyze the test film as explained under interpretation of test results and record the required information on the data form.
25. If desired, repeat the test for other cassette sizes and/or beam restriction configurations (e.g., vertical cassette holder).

4.1.5 Documentation of Test Results: Proper documentation of all measurements required to analyze the test films is essential to this test. Using the data form shown in Figure 4 as a guide and the discussion below make all required measurements and perform all required calculations and record on the data form.

4.1.6 Interpretation of Test Results: The analysis of the resultant test radiographs will require careful measurements of certain dimensions on the test film to determine the accuracy of the source-to-image receptor distance indicator, centering alignment of the radiation field with respect to the image receptor, accuracy of the numerical field size indicators and congruence of the radiation and light fields. To aid in keeping track of the measurements and in aiding in the required calculations certain symbolic notation will be introduced and defined as needed.

Shown in Figure 5 is an example of a typical test film for a system equipped with a manual beam restriction or a positive beam restriction system operated in the manual mode which indicates the needed reconstructions and measurements for test film analysis.

**SOURCE TO IMAGE RECEPTOR DISTANCE ACCURACY
AND BEAM RESTRICTION SYSTEM ADEQUACY**

DATA FORM RF 1								
Date: <u>10-25-78</u> Room No.: <u>CGH 1138h</u>								
Equipment Identification: <u>Orthopedic Radiology</u>								
Beam Restriction System <u>XII</u>								
Identification: Manufacturer: <u>Pickar</u> Model No. <u>Collimator</u> Serial No. <u>419</u>								
Beam Restriction System <u>x</u> Manual <u>x</u> Positive Beam <u>Manual</u>								
Operational Modes: <u>Table Bucky</u> Limitation: <u>x</u> Automatic								
Beam Restriction Configuration Tested: <u>Table Bucky</u>								
Source to Image Receptor Distance Used for Test: <u>4.00</u> (SID) "								
Tabletop to Cassette Surface Distance: <u>1.75</u> (p) "								
SID Indicator Accuracy								
SID _a	h	O	P	I _L	I _T	<I>	<SID>	ΔSID
40"	10	2.5	1.75	3.4	3.56	3.56	39.5	.5
MANUAL BEAM RESTRICTION SYSTEMS OR POSITIVE BEAM LIMITATION SYSTEM IN MANUAL MODE								
Numerically Indicated Field Size	8 x 10	RI	10 x 12	11 x 14				
L _S	10		12	14				
W _S	8		10	11				
L _R	9.88		11.88	13.61				
W _R	8.13		10	10.94				
ΔC _{RT}	.13		.13	.19				
ΔL _{RL}	0		.06	.09				
ΔL _{RL} ²	.13		.13	.09				
ΔW _{RL}	0		.06	.22				
ΔW _{RL} ²	.06		.06	0				
A _L	.12		.12	.37				
A _W	.13		0	.06				
A _T	.25		.12	.42				
M _L	.13		.19	.18				
M _W	.06		.12	.22				
M _T	.19		.31	.40				
Remarks/Comments								

**SOURCE TO IMAGE RECEPTOR DISTANCE ACCURACY
AND BEAM RESTRICTION SYSTEM ADEQUACY**

DATA FORM RF 1				
Does the system automatically adjust the field size to the size of the image receptor inserted in the cassette tray or prevent x-ray exposure until the field size is manually adjusted?				
<u>x</u> Yes				
<u> </u> No				
Image Receptor Size	8 x 10	10 x 12	11 x 14	14 x 17
L _I	10	12	14	17.5
W _I	7.5	9.5	10.5	13.75
ΔC _{RL}	.06	.13	.19	.13
L _R	9.44	11.25	13	16.41
W _R	7.31	9.28	10.09	13.06
Δ ¹ L _{RL}	.16	.13	.19	.31
Δ ² L _{RL}	.06	.09	.06	.13
Δ ¹ W _{RL}	.09	0	.06	.06
Δ ² W _{RL}	.09	0	.09	.06
L _R ^P	9.88	11.77	13.6	17.17
W _R ^P	7.65	9.71	10.56	13.67
RIC _L	.12	.23	.40	.33
RIC _W	.15	.22	.06	.08
RIC _T	.27	.45	.46	.41
M _L	.22	.22	.25	.44
M _W	.18	0	.15	.12
M _T	.40	.22	.40	.56
Remarks/Comments:				
Signature _____				

Figure 4. Example of data form used for recording test results illustrating representative data obtained.

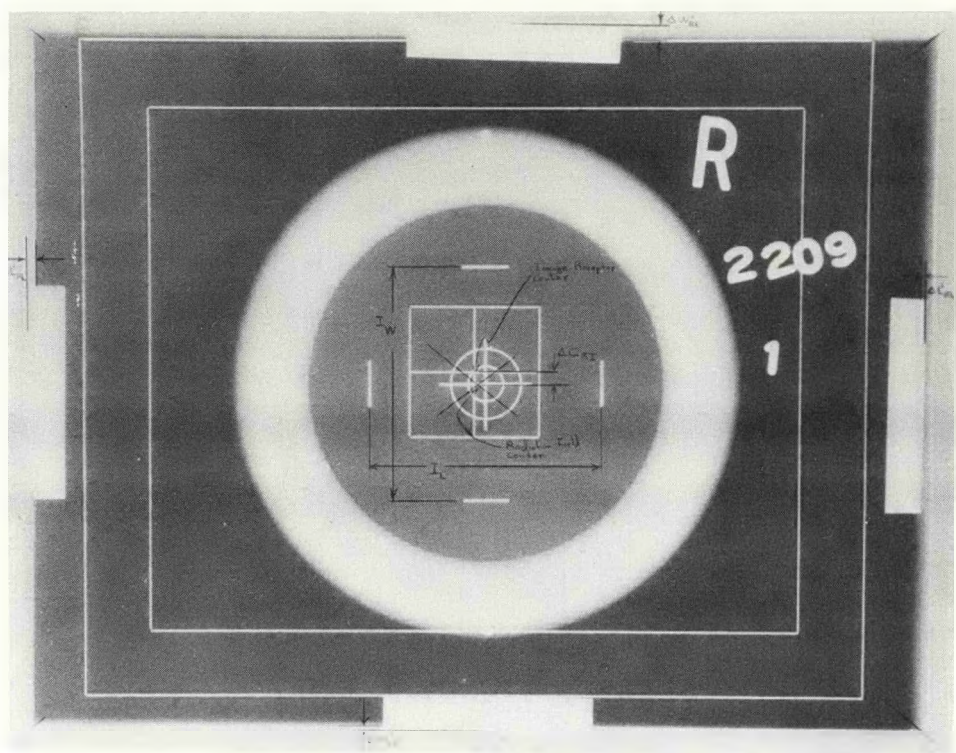


Figure 5. Typical test film from which source to image receptor distance and beam restriction system adequacy for manual systems of systems operated in the manual mode are determined. Required measurements are illustrated in this image.

Before proceeding with the actual analysis of the test film, let us consider for a moment the information contained within this image. The darkest (greatest density) region of the test film delineates the actual radiation field in the plane of the image receptor and the intersection of diagonal lines drawn between opposite corners of the radiation field defines its center. As the center of the image receptor is defined by the image of the wire cross within a square box on the cassette the alignment of the radiation field center with respect to the image receptor center can be rapidly evaluated.

The borders of the light field are delineated by the images of the four radiopaque markers and a quick visual analysis of their relationship to the edges of the radiation field allows determination of the radiation light field congruence.

The adequacy of the numerical field size indicators can be evaluated by comparing the size of the radiation field with respect to the proper field size as indicated by images of the field size wire inlays in the test cassette.

The test film will also contain the image of the centering and alignment test tool. The structure of the test tool will be visualized as a circle with a central dot (at the bottom of the test tool) and a cross and four outlying lines. The separation distance between the lines will be used to calculate the SID. The relationship of the image of the cross and circle with central dot can be used to diagnose the location of beam restriction malfunction in certain cases. For example, since the cross and circle are

physically aligned with each other in the test tool, the intersection of the wires in the cross and central dot in the circle should coincide with each other and with the center of the image receptor if the test tool was properly aligned and the tube perpendicular to the image receptor. If the test tool cross and dot align with each other but not with cassette center, it is probably indicative of a malfunction in the cassette centering means (e.g. centering light). If, however, the cross and dot do not align with each other, it is possible the x-ray tube is not truly perpendicular to the plane of the image receptor.

As a general rule, if the test film shows the image of the cross in the top of the test tool and the cross on the test cassette inlay both contained within the image of the circle the centering means on the equipment and tube angulation indicator are adequate and any deficiencies in the test film are probably due to other causes.

We now proceed with the analysis of the test films. Refer to Figure 5 as required to determine the measurements to be made.

To determine the accuracy of the SID indicator, measure the separation of the images of the outlying wires of the test tool in the test film image and record in the data form as I_L and I_T where

I_L = separation of wire images in longitudinal direction.

I_T = separation of wire images in transverse dimension.

Referring to Figure 6 which illustrates the geometry required to determine the SID we define:

- p: The distance between the top of the table and the surface of the cassette in the cassette tray
- h: The height of the centering and alignment test tool (h = 10 in for test tool described)
- 0: The separation of the outlying wires in the top surface of the test tool (0 = 2.5 in for test tool described)

then from similar triangles it follows that:

$$SID = I(h+p)/(I-0)$$

or for the dimensions of the test tool described:

$$SID = I(10+p)/(I-2.5) \quad (SID \text{ in inches})$$

Using the above equation, calculate the SID using the average value of I defined as $\langle I \rangle = (I_L + I_T)/2$. Record the calculated value of SID as $\langle SID \rangle$ in the data form. Finally, calculate the difference between the set SID and calculated SID as

$$\Delta SID = SIDs - \langle SID \rangle$$

and record on the data form.

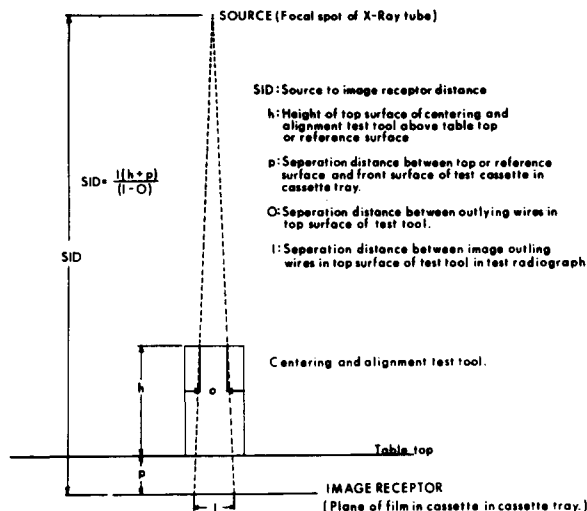


Figure 6. Geometrical relationships required to all calculation of the source to image receptor distance from the image illustrated in Figure 5.

Again refer to Figure 5 as needed and proceed as follows

Using the 24-in ruler as a straight edge and a film marking pencil, draw diagonal lines between the opposite corners of the radiation field in the test image to define the radiation field center. Measure and record in the data form as ΔC_{RI} the distance between the intersection of lines and the center of the image receptor as defined by the image of the wire cross inlay of the cassette.

Using the ruler and film marking pencil reconstruct the edges of the light field defined by the outside edges of the images of the four radiopaque markers strips in the test film. Measure and record on the data form the following dimensions:

L_R = the length of the radiation field

W_R = the width of the radiation field

ΔL^1_{RL} = the distance between the edges of the light and radiation fields at the side of the test film corresponding to the orientation of a patient's head

ΔL^2_{RL} = the distance between the edges of the light and radiation fields on the side of the test film corresponding to the orientation of patient's feet

ΔW^1_{RL} = the distance between the edges of the light and radiation fields on the side of the test film corresponding to the orientation of a patient's right side

ΔW^2_{RL} = the distance between the edges of the light and radiation field on the side of the test film corresponding to the orientation of a patient's left side

Now calculate and record on the data from the following:

Numerical Field Size Accuracy, Length: $A_L = L_S - L_R$

Numerical Field Size Accuracy, Width: $A_W = W_S - W_R$

Numerical Field Size Accuracy, Total: $A = |A_L| + |A_W|$ (See Note 1)

Radiation/Light Field Misalignment, Length: $M_L = \Delta L_{RL} + \Delta L_{RL}$

Radiation/Light Field Misalignment, Width: $M_W = \Delta W^1_{RL} + \Delta W^2_{RL}$

Radiation/Light Field Misalignment, Total: $M_T = |M_L| + |M_W|$ (See Note 1)

Illustrated in Figure 7 is an example of a test film obtained with the ready pack film at tabletop indicating the required measurements for analysis. As described previously, determine the center of radiation field and reconstruct the outer edges of the visual light field. Now measure on the test film and record on the data form the following values:

ΔC_{RL} = the distance between the center of the radiation field and center of the optically projected light field defined as the image of the wire cross on the top of the centering and alignment test tool.

L'_R = the length of the radiation field as measured in the test film.

W'_R = the width of the radiation field as measured in the test film.

ΔL^1_{RL} = the distance between the edges of the light and radiation fields at the side of the test film corresponding to the orientation of a patient's head

ΔL^2_{RL} = the distance between the edges of the lighted radiation fields on the side of the test film corresponding to the orientation of a patient's feet

ΔW^1_{RL} = the distance between the edges of the light and radiation fields on the side of the test film corresponding to the orientation of a patient's right side

ΔW^2_{RL} = the distance between the edges of the light and radiation field on the side of the test film corresponding to the orientation of a patient's left side

Now in order to determine if the beam restriction system provides a radiation field no larger than the image receptor it is necessary to calculate the size of the radiation field in the plane of the image receptor from the size measured at tabletop. Letting L^P_R and W^P_R be the length and width of the radiation field projected into the plane of the image receptor we have

$$L^P_R = L'_R \times \langle \text{SID} \rangle / (\langle \text{SID} \rangle - p)$$

an

$$W^P_R = W'_R \times \langle \text{SID} \rangle / (\langle \text{SID} \rangle - p)$$

where $\langle \text{SID} \rangle$ has been determined from a test of the beam restriction system in the manual mode and p is the distance from the tabletop surface to the cassette surface in the cassette tray. Perform the above calculation and record in the data form.

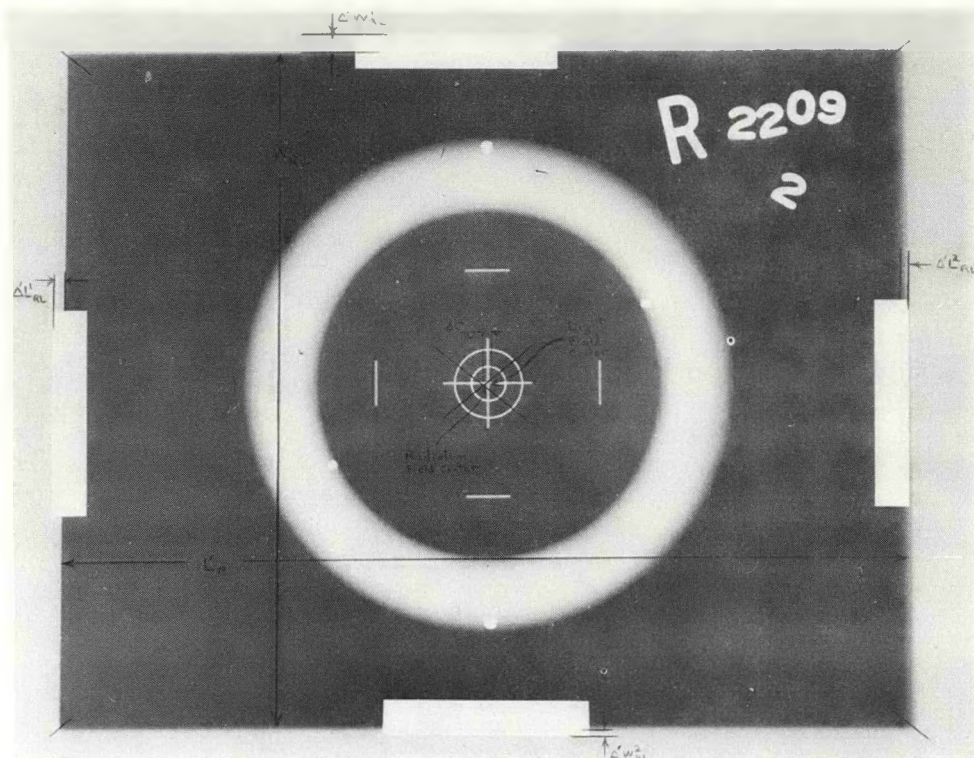


Figure 7. Typical test film from which adequacy of positive beam limitation systems is determined. Required measurements are illustrated in this image.

Now calculate the following and record on the data form:

Radiation Field/Image Receptor Size Congruence, Length

$$RIC_L = L_I - L_R^P$$

Radiation Field Size/Image Receptor Size Congruence, Width

$$RIC_W = W_I - W_R^P$$

Radiation Field Size/Image Receptor Size Congruence, Total

$$RIC_T = |RIC_L| + |RIC_W| \quad (\text{See Note 1})$$

Radiation Field/Light Field Misalignment, Length

$$M'_L = \Delta L_{RL}^1 + \Delta L_{RL}^2$$

Radiation Field/Light Field Misalignment, Width

$$M'_W = \Delta W_{RL}^1 + \Delta W_{RL}^2$$

Radiation Field/Light Field Misalignment, Total

$$M'_T = |M'_L| + |M'_W| \quad (\text{See Note 1})$$

This completes the required calculations and data recording.

Now compare the results of your test analysis with the acceptable limits for beam restriction system performance outlined below.

Note 1: The symbol " $|$ " when placed about a numerical value indicates that the absolute value of the numerical value is to be used in the indicated calculation (that is, disregard a minus sign). For example: $|-a| = a$.

- 4.1.7 **Action Limits and Corrective Action:** (These limits are indications for action only, and do not necessarily indicate non-compliance with applicable standards. A test result exceeding these action levels should be verified by retesting prior to the further action.) In reviewing the results of the beam restriction test the following general guides may be used. In a properly functioning system the centering means provided should allow centering of the radiation field with respect to the image receptor to within .5 in. The same criteria is applicable to the centering of the visual light field with respect to the radiation field. The numerical indicators should provide an indication of the size of the radiation field which corresponds to the actual size of the radiation field to within .5 in along either the length and width dimension and to within .8 in for the sum of both dimensions. The radiation and light field edges should coincide to within .3 in along any of the four edges of the field; the sum of the misalignments along the length and width dimensions should be less than or equal to .5 in and the sum of the misalignments along all four edges should be less than 1.0 in.

When the beam restriction system is operated in the positive beam limitation mode the size of the projected radiation field should correspond to the size of the image receptor to within .8 in along either the length or width dimension and to within 1.2 in with respect to the sum of the length and width dimensions. The SID indicator employed on the unit should provide an SID indication which is accurate to within $\pm .8$ in.

To assist in the evaluation results of the test above, performance criteria are summarized in Table 2. After evaluating the results of the test, determine if the system is performing in an acceptable manner. Should any deficiencies be found, the manufacturer's service representative should be contacted to determine the exact nature of the problem and take the necessary corrective action.

- 4.1.8 **Test Procedure Limitations:** In carrying out the analysis of the test film a considerable number of measurements are necessary to be used in the required calculations. The care with which these measurements are carried out can greatly influence the test results as even a small error in measurement can result in a considerable error in a calculated result. When making the measurements, try to measure and record all dimensions to the nearest 1/32 of an inch. The careful centering of the cassette in the cassette tray with respect to the x-ray tube and positioning of the centering and alignment test tool are all critical to obtain meaningful results from this test.

For radiographic systems equipped with curved tabletops it is necessary to make certain modifications to the test procedures to overcome difficulties which would be associated with trying to position the centering and alignment test tool on the curved surface of the table. When dealing with such systems, obtain a piece of plywood $\frac{1}{2}$ in thick and approximately 20 x 24 in. When carrying out the test the plywood is placed on the table providing a level surface for the test stand. The value of p is then taken as that from the plywood surface to the cassette in the cassette tray. All other aspects of the test procedure remain the same.

Table 2. Acceptable performance for beam restriction systems

<u>Manual beam restriction systems or positive beam limitation systems operated in the manual mode</u>		
Parameter	Symbol	Acceptable performance level (inches)
SID indicator accuracy	Δ_{SID}	$\pm .8$
Radiation field-image receptor centering	ΔC_{RI}	$\pm .5$
Numerical indicator accuracy, length	A_L	.5
Numerical indicator accuracy, width	A_W	.5
Numerical indicator accuracy, total	A_T	.8
	$\Delta L_{RL}^1 \quad \Delta W_{RL}^2$	
	$\Delta W_{RL}^1 \quad \Delta W_{RL}^2$	.3
Radiation field/light field misalignment, length	M_L	.5
Radiation field/light field misalignment, width	M_W	.5
Radiation field/light field misalignment, total	M_T	1.0
<u>Positive beam limitation systems</u>		
SID indicator accuracy	Δ_{SID}	$\pm .8$
Radiation/light field centering alignment	ΔC_{RL}	$\pm .5$
Radiation field/light field misalignment, any edge	$\Delta' L_{RL}^1 \quad \Delta' L_{RL}^2$	.3
	$\Delta' W_{RL}^1 \quad \Delta' W_{RL}^2$	.3
Radiation field/light field misalignment, length	M_L'	.5
Radiation field/light field misalignment, width	M_W'	.5
Radiation field/light field misalignment, total	M_T'	1.0
Radiation field/image receptor size congruence, length	RIC_L	.8
Radiation field/image receptor size congruence, width	RIC_W	.8
Radiation field/image receptor size congruence, total	RIC_T	1.2

- 4.1.9 Alternate Test Procedures:** Over the years, a large number of test procedures have been developed and used for checking the adequacy of beam restriction systems. Several of these test procedures are cited in the reference section of the manual and the interested reader may consult these works for further details. One test procedure which is very useful for rapid checks of light/radiation field congruence employs a fluorescent screen to observe the image of the radiation field during exposure. To carry out this test a section of fluorescent screen of the type used in non-image intensified fluoroscopic systems is placed on the tabletop. The x-ray tube is then centered over the screen and the light localizer turned on and four radiopaque marker strips placed at the edges of the visual light field. Then, under subdued room illumination the screen is observed while a low kVp, mA and long time (approximately 1-2 seconds) exposure is made. The radiation field is visualized by the area of the screen which fluoresces and can be compared to the light field as indicated by the marker position. While providing a rapid check in case of beam restriction system problem, this procedure does not yield a permanent record and does not allow evaluation of the equipment centering means.

4.2 ACCURACY AND REPRODUCIBILITY OF EXPOSURE TIME

4.2.1 Objective of Test: To determine the accuracy of indicated exposure time and the reproducibility of exposure time.

4.2.2 Recommended Test Equipment: Shown in Figure 8 is the equipment recommended for performing this test. In addition to the equipment shown, Data Form RF 2 is required.

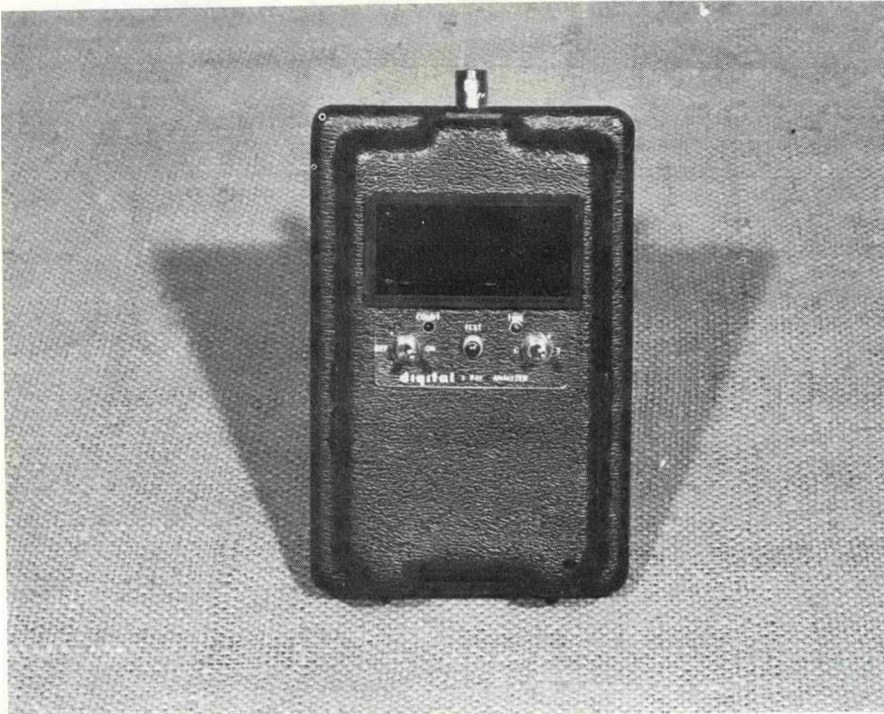


Figure 8. Recommended equipment for performing accuracy and reproducibility of exposure time tests: digital x-ray generator timer.

4.2.3 Testing Frequency: Routinely performed at 6-month intervals and following any service work which could affect the calibration of the x-ray generator timing circuit.

4.2.4 Test Procedure:

1. Position the digital x-ray timer on the tabletop so that the display can be viewed from the control booth window (Fig. 9).
2. Turn the digital x-ray timer on and select the time mode for 3-phase equipment or the count mode for single-phase equipment.
3. Using the light localizing beam restriction system, adjust the position of the x-ray tube so that the center of the light field is incident upon the detector area of the digital x-ray timer. Adjust the vertical height of the x-ray tube to provide a focal spot to detector distance of approximately 30 in.
4. On the x-ray generator control select 80 kVp and 300 mA for testing exposure times of .5 sec or less and 100 mA for testing exposure times of greater than .5 sec.

5. Select the most commonly used exposure times (e.g. .005 sec, .015 sec, .035 sec, .1 sec, .25 sec) employed for routine radiographic work on the system being tested and record in the data form. Consult the x-ray tube rating charts to make sure that none of the selected exposure times exceed the maximum allowable exposure time for the kVp, mA, focal spot size combination employed.
6. In sequence, select each timer station to be tested and make an exposure. Note the reading on the digital x-ray timer display and record on the data form. Allow sufficient time between exposures to allow the display of the digital x-ray timer to turn off.
7. Repeat Step 6 to obtain three readings for each timer station to be tested.

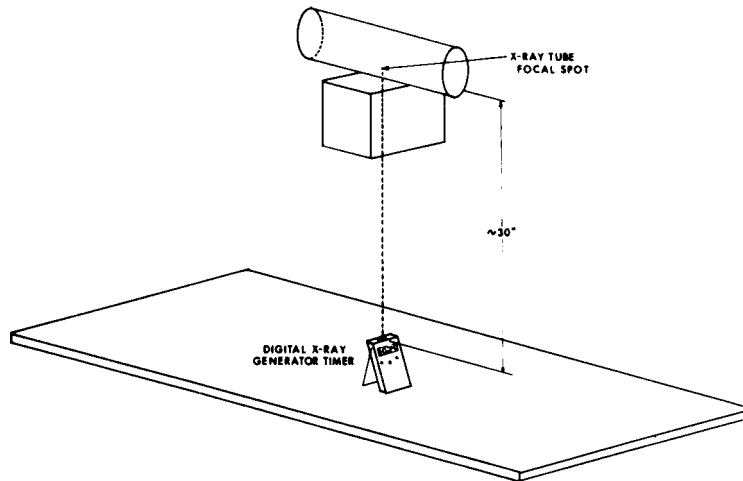


Figure 9. Illustration of equipment set up for performing test.

- 4.2.5 **Documentation of Test Results:** Record all measured exposure times for each timer station tested on the data form along with the other required information as shown in the example data form, Figure 10.
- 4.2.6 **Interpretation of Test Results:** For each timer station tested determine the average value of the measured exposure time defined as $\bar{t}_m = (t_1 + t_2 + t_3)/3$. Then calculate the ratio of each measured exposure time to the average exposure time. This ratio should fall within the range of .95-1.05. Now calculate the percent difference between the measured exposure time and exposure time indicated on the timer station selected as follows:

$$\% \Delta t = \frac{\bar{t}_m - t_{in}}{t_{in}} \times 100$$

where $\bar{t}_m$ is the average value of the measured exposure timer, and t_{in} is the indicated exposure time. Record these values on the data form.

For single phase equipment the measured exposure time is defined as the number of pulses indicated on the digital x-ray timer display divided by 1/120 sec.

ACCURACY AND REPRODUCIBILITY OF EXPOSURE TIMER

[illegible]

Figure 10. Example of data form used for recording test results illustrating representative data obtained.

4.2.7 **Action Limits and Corrective Action:** (These limits are indications for action only, and do not necessarily indicate non-compliance with any applicable standards. A test result exceeding these action levels should be verified by retesting prior to further action.) In reviewing the test data a given exposure time station should be reproducible to within 5 percent or better. Similarly, the accuracy of the indicated exposure time should be 5 percent or better for timer settings of 10 milliseconds or greater. For times of less than 10 milliseconds an accuracy of 20 percent is considered acceptable using this type of test procedure. For single phase equipment the actual number of exposure pulses must be equal to the expected number of exposure pulses for exposure times of .1 sec or less. For exposure times of greater than .1 sec an accuracy of ± 1 pulse is acceptable. Should either the reproducibility of exposure time or accuracy of exposure time fall outside of these limits a service representative should be contacted to recalibrate the timing circuit of the x-ray generator.

4.2.8 Test Procedure Limitations: The major limitation of the test procedure is associated with the definition of exposure time as applied to 3-phase equipment. The majority of x-ray equipment manufacturers define exposure time as the width of the high-voltage waveform during exposure at 75 percent of peak level. This definition is not necessarily consistent with what the digital x-ray timer measures. In general, the agreement is quite good for exposure times of 10 msec or longer but is not very good in the 1-6 msec range. This limitation can only be overcome by use of very sophisticated measurement techniques which are not suitable to a routine quality assurance program.

4.2.9 Alternate Test Procedures: A variety of test methods has been developed to test timer accuracy. These methods in general employ some form of spinning top. For single phase equipment a radiopaque disk with a hole in it is placed on a film and spun by hand. An exposure is made and the film processed. The number of visible dots is counted and exposure time determined as the ratio of number of visible dots to a theoretical number of 120 dots in 1 second for a single-phase full-wave rectified equipment or 60 dots in 1 second for single phase half-wave rectified equipment.

For three-phase equipment a form of synchronous spin top is used of which a radiograph is taken with the top rotating at a known speed. In the radiographic image of the top an exposed area in the form of an arc is swept out and the exposure time may be determined from a knowledge of the angle swept out by the arc and the top's rotational speed. Additional information may be found in the cited reference.

4.3 X-RAY TUBE PROTECTIVE CIRCUITRY

4.3.1 Objective of Test: To verify the function of the x-ray tube protective circuitry.

4.3.2 Recommended Test Equipment: In order to carry out the x-ray tube protective circuitry test it is necessary to have the tube rating chart for the tube to be tested and Data Form RF 3 for recording of test results.

4.3.3 Testing Frequency: Routinely at 6-month intervals and following installation of a new x-ray tube.

4.3.4 Test Procedure:

1. Select 90 kVp on the x-ray generator control.
2. From the appropriate tube rating chart determine the maximum allowable mA for the small focal spot at this kVp at the highest anode rotation speed.
3. On the generator control, select the available mA station which most closely equals the mA determined from the tube rating chart in Step 2 but does not exceed it.
4. From the tube rating chart for the kVp waveform and anode rotational speed for the focal spot employed, determine the maximum allowable exposure time for the kVp/mA combination selected and record on the data form. Select this time on the x-ray generator control or the time station which most closely equals but does not exceed it. (An example of this procedure is shown in Figure 11).
5. If the x-ray control does not automatically activate the high speed rotational circuit, manually select high speed if available.

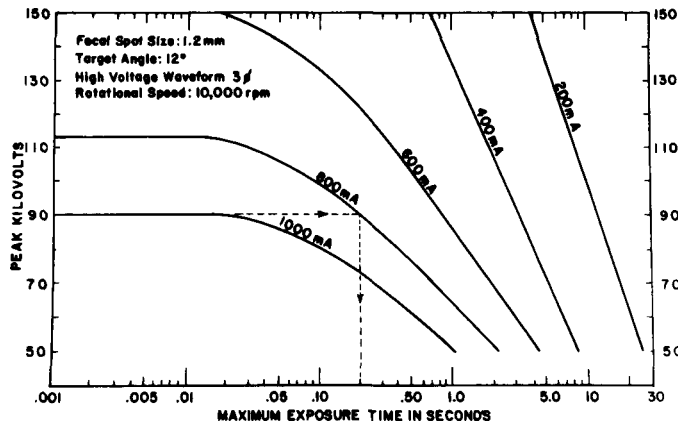


Figure 11. An example of an x-ray tube rating chart illustrating its use in performing the x-ray tube protective circuitry test.

6. Activate the x-ray tube rotor control but do not make an exposure. Note whether or not the technique overload indicator(s) is activated and record on the data form.
7. If the overload indicator(s) is not activated, increase the selected time by one step and repeat the above. Note whether it does come on or not. Repeat as necessary until the indicator(s) activates and record the time at which the indicator activates.
8. If the overload indicator activates at the first time station selected, decrease the selected time until the overload indicator(s) de-activates and record this time in the data form.
9. Repeat Steps 2 - 8 for the large focal spot.
10. Repeat Steps 2 - 8 for the large and small focal spot at 60 and 120 kVp.

4.3.5 Documentation of Test Results: For each combination of kVp and mA tested, the timer station at which the technique overload indicator(s) activates should be recorded on the data forms. The maximum allowable time as determined from the tube rating chart for the selected kVp/mA combination should also be recorded on the data form. An example of the data form and information to be recorded is shown in Figure 12.

4.3.6 Interpretation of Test Results: For all kVp/mA combinations tested compare the exposure time setting at which the technique overload indicator activates with the maximum allowable exposure time as determined from the tube rating charts and calculate what fraction of the maximum this is and record. In all cases, the exposure time at which the overload indicator activates should not exceed the maximum allowable exposure time as determined from the tube rating chart. For general radiographic equipment the tube protector may be set somewhere between 85 to 100 percent of the maximum single exposure rating. For angiographic equipment where rapid filming is carried out, the tube protector may generally be adjusted to 60 to 70 percent of the maximum single radiographic exposure ratings.

X-RAY TUBE PROTECTIVE CIRCUITRY

DATA FORM RF 3						
Date: <u>1-12-78</u>		Room No.: <u>CGH 2209</u>				
Equipment Identification: <u>Pediatric Radiology-Radiographic/Fluoroscopic</u>						
Generator Identification:		Manufacturer: <u>GE</u>		Model: <u>MSI 850II</u>		
X-Ray Tube Identification: Serial No.: <u>038309</u>		Manufacturer: <u>GE</u>		Model: <u>Maxiray 100</u>		
Anode Thermal Capacity: <u>200,000 HU</u>		Nominal Focal Spot: <u>Small .6 mm</u>		Spot Sizes: Large <u>1.5 mm</u>		
High Voltage Waveform: <u>3 phase, 12 pulse</u> X-Ray Tube Application: <u>Radiography</u>						
Focal Spot Size	kVp	mA	Anode Rotational Speed	Maximum Allowed Exposure Time As Determined From Tube Rating Chart (t_{max})	Set Exposure Time At Which Overload Indicator Is Activated (t_{OL})	Fraction of Maximum Exposure Time Allowed By Tube Protector (t_{OL}/t_{max})
.6	60	100	High	6	None	1.0
.6	90	100	High	6	None	1.0
.6	120	100	High	2	None	1.0
.6	60	300	High	2	2	1.0
.6	90	300	High	.2	.35	1.3
.6	120	300	High	TL	TL	-
1.5	60	400	High	NA	NA	NA
1.5	90	400	High	6	4	.66
1.5	120	400	High	2	2	1.00
1.5	60	800	High	4	2	.50
1.5	90	800	High	1	2	2.00
1.5	120	800	High	.5	.35	.80
Remarks/Comments: ① Maximum available exposure time on generator is 6 sec. Misadjust appears to be problem at several stations. Requires a service call. Signature _____						

Figure 12. Example of data form used for recording test results illustrating representative data obtained.

- 4.3.7 **Action Limits and Corrective Action:** Should this test reveal that the tube protector will allow an exposure in excess of the allowable maximum as determined from the tube rating charts, a service representative should be contacted immediately to readjust the unit. Likewise, if the tube protector greatly understates the x-ray tube and limits the system's capability, readjustment of the tube protective circuitry is indicated.
- 4.3.8 **Test Procedure Limitations:** Even the best tube protective circuitry can only approximate the actual rating chart of an x-ray tube. Additionally, only certain discrete timer stations are available on the x-ray control so it is not uncommon to find that the x-ray tube must be derated slightly from the allowable maximums in a practical situation. As maximum tube ratings are strongly dependent on high

voltage waveforms and anode rotational speed it is essential that the proper tube rating chart be referred to for comparison of test results to avoid incorrect conclusions. It is also very important to determine the rotational speed of the anode as some systems automatically select the proper speed based on selected technique while others do not.

This test procedure is generally limited to fixed current/time x-ray controls and is not applicable to falling load type generators where the actual tube current during a given exposure may vary continuously or in a step fashion and is not known.

- 4.3.9 Alternative Test Procedures:** The test procedure described above or a minor variation of it is the only simple way to check the functional capability of the tube protector. The interested reader will find in the reference section a listing of useful articles which deal with the practical considerations of x-ray tube ratings and their applications.

4.4 REPRODUCIBILITY OF EXPOSURE, EXPOSURE LINEARITY AND BEAM QUALITY OF RADIOGRAPHIC UNITS

- 4.4.1 Objective of Test:** To determine the reproducibility of exposure, linearity of exposure (i.e., same exposure for a given mAs regardless of the mA/time station combination employed) and beam quality for radiographic systems.
- 4.4.2 Recommended Test Equipment:** Shown in Figure 13 is the equipment recommended for performing this test. In addition to the equipment shown, Data Form RF 4 is required.

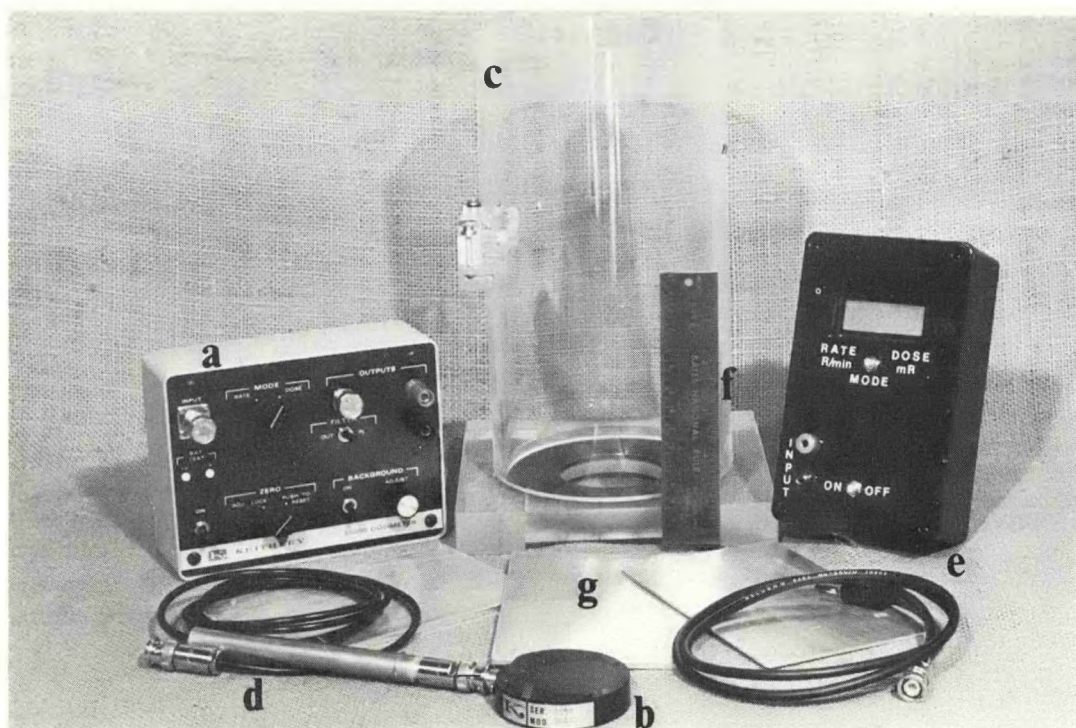


Figure 13. Recommended equipment for performing reproducibility of exposure, exposure linearity and beam quality of radiographic units test: a. Keithley Model 35050 dosimeter; b. Keithley Model 96030 ionization chamber; c. ionization chamber test stand; d. Keithley Model 86204 ionization chamber triax cable with 5 in aluminum stem - 4 ft. cable length; e. dosimeter digital readout with interconnecting cable; f. 6 in spacer, and; g. aluminum attenuators (Type 1100) 1.3, 2.5, and 3.2 mm thick.

4.4.3 Testing Frequency: Routinely at 3-month intervals, following replacement of the x-ray tube and following service and/or repair work on the x-ray generator which could affect the calibration of the x-ray system.

4.4.4 Test Procedure:

1. Center the x-ray tube to be tested over the approximate center of the radiographic table (Fig. 14).

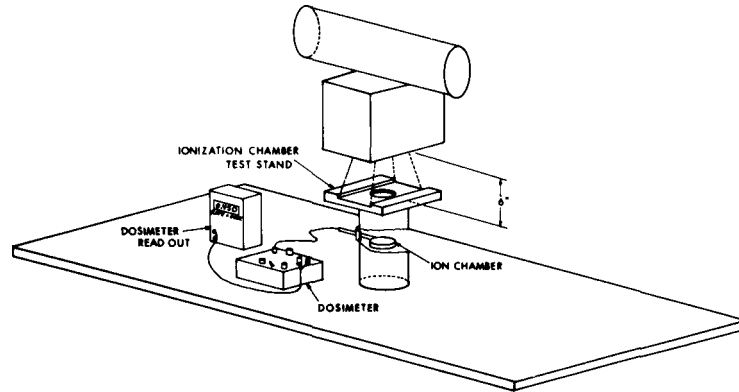


Figure 14. Illustration of equipment set up for performing test.

2. Position the ion chamber test stand on the tabletop so the lead aperture is toward the x-ray tube.
3. Using the spacer adjust the x-ray tube vertically until the face of the beam restriction system is 6 in above the top of the test stand and center the test stand with respect to the indicated center of the radiation field.
4. Connect the stemmed end of the triax cable to the ion chamber and carefully position the ion chamber in test stand and lock in place. The surface of the ion chamber having the etched surface (if present) should be facing toward the x-ray tube.
5. Connect the other end of the triax cable to the dosimeter "INPUT" and then turn the dosimeter "ON".
6. Connect the dosimeter "OUTPUT" binding posts to the "INPUT" of the digital readout and turn "ON". Orient the digital readout so that it is visible from the control booth window.
7. Set the dosimeter and readout controls as follows:

Dosimeter	Readout
Mode: Dose	Mode: mR
Background: Off	
Filter: Out	
Zero: Lock	

8. Allow 10 minutes for the system to stabilize, and check battery power adequacy if not performed in last 6 months.

9. Note the reading on the readout. It should be 0 ± 2 mR. If necessary, adjust the "ZERO ADJUST" control to obtain the proper zero. Now place the "ZERO" control to the "PUSH TO RESET" position and momentarily depress this control. The dosimeter is now prepared for making measurements. (Note: To ensure reliable operation of the dosimeter, be sure to press the "RESET" button prior to each exposure.)
10. On the x-ray generator control select 90 kVp and the most commonly used mA station for the particular equipment being tested. Select an exposure time such that the mAs product of the mA and time chosen is approximately 20 mAs. Record the values on the data form.
11. Momentarily depress the "PUSH TO RESET" zero control on the dosimeter.
12. Make an exposure and note the reading on the digital readout. This reading should fall between 200 mR and 600 mR. If it does not, modify the mAs value chosen to bring it in this range and change the test values recorded in the data form.
13. At the chosen mA and time values, make three exposures and record the readout reading on the data form as X_0^1 , X_0^2 , and X_0^3 respectively. Make sure to momentarily depress the "PUSH TO RESET" zero control on the dosimeter between each exposure.
14. Insert the 2.5 mm aluminum filter into the top of the test stand and make an additional exposure at the same technique factors. Record the reading on the data form as X_f . Remove the filter from the top of the test stand.
15. While maintaining 90 kVp on the x-ray generator control, select other commonly used mA stations and at each mA station select the exposure time to yield approximately the same mAs as was used for the initial measurements.
16. For each mA station/time station tested, make three exposures as before and record the readings on the data form. Do not repeat the measurement with the aluminum filter in place.
17. Return the x-ray generator control to the mA station used initially for the 90 kVp measurement (step 10).
18. Adjust the x-ray generator control for 60 kVp.
19. Select a time to yield an mAs product of approximately 50 mAs or an mAs sufficient to yield a measured exposure in the range of 200-600 mR. Record the mA and time values used on the data form.
20. At the chosen mA and time value make three exposures and record the reading of the display on the data form. Make sure to momentarily depress the "PUSH TO RESET" zero control on the dosimeter between each exposure.
21. Insert the 1.3 mm aluminum filter into the top of the test stand and make an additional exposure at the same technique factors. Record the reading on the data form. Remove the filter from the test stand.
22. Maintaining the same mA station, adjust the x-ray control for 120 kVp and select a time station such that the mA time product is 5 mAs or an mAs sufficient to yield a measured exposure in the range of 300-600 mR. Record these values on the data form.

23. At the chosen mA and time values, make three exposure and record the reading on the display for each exposure on the data form. Make sure to momentarily depress the "PUSH TO RESET" zero control on the dosimeter between exposures.
24. Insert the 3.2 mm aluminum attenuator into the top of the test stand and make an additional exposure at the same technique factors and record the display reading on the data form.

4.4.5 Documentation of Test Results: On the data form, record the information required for the test including the date, room, generator and x-ray tube identification technique factors employed and all measured exposure values. After analyzing the data as explained under interpretation of test results, record the final test results on the data form. An example of the data form with required information is shown in Figure 15.

Date: 9-12-78 Room No.: CGH 2220											DATA FORM RF 4	
Equipment Identification: Picker General Purpose Radiographic												
Generator Identification: Manufacturer: Picker Model: PH 70												
X-Ray Tube Identification: Manufacturer: Eureka Model: Sapphire Serial No.: F9325												
Nominal Focal Spot Sizes: Small .6 mm, Large 1.2 mm 150 TH												
	60 kVp		90 kVp								120 kVp	
mA	300 (L)	15 (S)	50 (S)	100 (S)	200 (L)	300 (L)	400 (L)	500 (L)	700 (L)		300 (L)	
time (secs.)	3/10	1	2/5	1/5	1/10	1/15	1/20	1/24	1/30		1/15	
mAs	90	15	20	20	20	20	20	21	23		20	
X_O^1	479	189	210	252	239	209	204	219	233		372	
X_O^2	471	190	209	252	237	207	208	212	232		375	
X_O^3	498	193	209	253	235	207	205	214	234		372	
X_f	290	-	-	-	-	135	-	-	-		255	
$\bar{X}_O$	483	191	209	252	237	209	206	215	233		373	
$0.95\bar{X}_O - 1.05\bar{X}_O$	459/508	181/201	199/219	239/263	225/248	199/219	196/216	204/225	221/244		354/391	
$R(\bar{X}_O/X_f)$	1.67	-	-	-	-	1.55	-	-	-		1.46	
mR/mAs	5.4	9.6	10.5	12.6	11.9	10.5	10.3	10.2	10.1		18.7	
L		-	-.04	-.09	.03	.06	.01	.00	.00			
Remarks/Comments: New x-ray tube install 9/11/78												
											Signature _____	

EXPOSURE REPRODUCIBILITY, EXPOSURE LINEARITY AND BEAM QUALITY

Figure 15. Example of data form used for recording test results illustrating representative data obtained.

4.4.6 Interpretation of Test Results: In order to properly interpret the data and results of this test it will be necessary to carry out certain calculations. They are simple and straightforward to do, but will be assisted greatly by the use of a small electronic calculator. If we let X_O^1 be the reading of the display in milliroentgens (mR) for a given exposure measurement, then for the three exposure measurements made at each kVp, mA and time combination when no added filter was in the beam, we calculate the average exposure as

$$\bar{X}_0 = (X_0^1 + X_0^2 + X_0^3)/3$$

Carry out this calculation for all recorded data and record in the appropriate space on the data form. Next determine if the exposure is reproducible. Calculate and record on the data form $.95 \bar{X}_0$ and $1.05 \bar{X}_0$. Compare the individual exposure measurements to this range about the average exposure. Each measurement should be in this range.

To determine the linearity of exposure calculate for the 90 kVp data for each mA and time station tested the average exposure per indicated mAs as:

$$\text{mR/mAs} = \bar{X}_0 / (\text{mA} \cdot t)$$

where $\bar{X}_0$ is the average value of the recorded exposures at each mA-time station combination, mA is the mA station selected on the control and t is the value of the time station selected on the control. Carry out the required calculations for all mA/time combinations tested and record the calculated mR/mAs values in the data form.

From the calculated mR/mAs values determine the linearity of exposure defined as

$$\text{Lin} = [(\text{mR/mAs})_{\text{max}} - (\text{mR/mAs})_{\text{min}}] / [(\text{mR/mAs})_{\text{max}} + (\text{mR/mAs})_{\text{min}}]$$

where $(\text{mR/mAs})_{\text{max}}$ and $(\text{mR/mAs})_{\text{min}}$ are the maximum and minimum values of the calculated mR/mAs as recorded on the data form. Record the calculated value of exposure linearity on the data form.

The final calculations to be carried out are used to determine the beam quality. The values of attenuators chosen for use in this test are equal to the minimum acceptable beam quality at the three kVp test values. Thus, if we take the ratio of the exposure with no attenuator in the beam to the exposure with the attenuator in the beam, and the beam quality was just equal to the minimum required, the ratio would be 2.0. If the beam quality is greater than the minimum required value, the ratio will be less than 2.0 and if the beam quality is less than the minimum required value the ratio will be greater than 2.0. If we let X_f be the measured exposure with the appropriate attenuator in placed (f = 1.3 mm at 60 kVp, 2.5 mm at 90 kVp and 3.2 mm at 120 kVp) the desired ratio is given by

$$R = \bar{X}_0 / X_f$$

Calculate the above ratio for each kVp value tested at the common mA station and record in the data form.

- 4.4.7 Action Limits and Corrective Action:** (These limits are indications for action only, and do not necessarily indicate non-compliance with any applicable standards. A test result exceeding these action levels should be verified by retesting prior to further action.) Some general guide may be given concerning the inferred performance of the x-ray equipment from the test results. A well calibrated and properly performing x-ray generator system should provide reproducible exposure to 5 percent or better at a fixed set of technique factors. Thus, at a given kVp, mA and t combination, the individual exposure measurements should fall within 5 percent of the average (i.e., $.95 \bar{X}_0 \leq \bar{X}_0^1 \leq 1.05 \bar{X}_0$). If this is not the case for the unit tested, the equipment manufacturer's service representative should be contacted to determine the cause. By using the timer reproducibility test described elsewhere in this manual you can rapidly determine if time errors are the cause of nonreproducibility.

The calculated value of exposure linearity must not exceed 0.1. Should the system test not be able to meet this criteria, a service representative should be contacted immediately to perform a recalibration of the system as it is highly likely that serious miscalibrations exist.

For the beam quality test the calculated ratio must always be less than 2.0. If the ratio exceeds 2.0 it is very likely that insufficient filtration exists in the beam and this should be checked immediately by either departmental personnel or the equipment manufacturer's service representative.

The actual exposure per mAs should fall within a given range at a given kVp and mAs at a certain distance from the focal spot. If one assumes that the distance from the focal spot to the face of the beam restriction system is 12 in which is somewhat typical of many x-ray systems, then the ionization chamber is approximately 22 in from the focal spot when positioned in the test stand for this test. Under these conditions Table 3 gives typical expected mR/mAs values for a properly calibrated system with normal filtration. Unfortunately a number of factors influence the mR/mAs for a given system. One of the more common is filtration. Thus, if the exposure of a system is to be found to be lower than expected it is likely that the beam quality ratio will be low (much less than 2). This could be due to too much added filter in the beam, improper mA or kVp calibration or age of the x-ray tube. If a given unit under test agrees with these values to within ± 30 percent and other tests indicate proper performance, it may be considered acceptable.

When comparing the output on a given unit over a long period of time it is likely that the exposure will decrease. If you have verified the kVp calibration of the unit and if the beam quality ratio is decreasing, the most likely cause is aging of the tube and is a result of roughening of the tube anode and possibly tungsten deposit on the x-ray tube. Should this phenomena result in a reduction in exposure output in excess of 30 percent of the initial value it is probably advisable to replace the x-ray tube.

Table 3. Typical exposure values in mR/mAs at 22 in from the focal spot for well calibrated and properly filtered radiographic x-ray generators

kVp	Single-phase units	Three-phase units
50	4.8	6.5
60	8.3	11.2
70	13.1	17.7
80	16.7	22.6
90	22.6	30.6
100	27.4	37.1
125	45.2	61.2

- 4.4.8 Test Procedure Limitations:** One factor which can seriously limit the usefulness of the test procedure when comparing the performance of a given unit over time is the care in which the test stand is positioned. As the measurement is relative it is very important to make sure that the geometry of the test procedure set up remains constant to allow accurate comparisons. If reasonable care is taken this should be no problem and the test procedure should provide excellent relative results.

If the test is used in an attempt to intercompare the exposure from a number of different units within the department, other factors are important to consider. For example, the measurements are essentially referenced to the front surface of the beam restriction system. If, for different x-ray units, the distance from the focal spot to the front surface of the beam restriction system is different, then the ion chamber will be located at different distances from the focal spot and the outputs will not be directly comparable. If it is possible to determine the distance between the focal spot and front of the collimator, the measured exposure outputs can be adjusted to a common distance using the inverse square law and thus directly compared. The equipment manufacturer's representative should be able to provide this information.

For x-ray systems with curved tabletop it may be somewhat difficult to position the test stand but with a little effort this should be able to be overcome. For some systems which employ fixed x-ray tubes or tubes which may not be directed vertically downward you will need to modify the position arrangement to achieve the desired geometry.

- 4.4.9 Alternate Test Procedures:** A number of alternate test procedures are available to carry out the above test. These usually employ some form of ionization chamber device to measure exposure at some reference point with respect to the x-ray tube. The exposure measuring systems range from the simple (pocket ionization chamber) to exceedingly complex. Except for the measuring system used, the test procedure is not different than that described above. The particular equipment used for this test was chosen because of its relative ease of operation and precision of test results.

Another test procedure which might be considered to determine the reproducibility of exposure and relative mA calibration of an x-ray generator is the use of a calibrated step wedge. These devices, usually constructed of aluminum, provide a known differential change in exposure per step when radiographed under a specific set of conditions. To check an x-ray unit with such a wedge, the wedge is placed on top of a standard cassette and radiographed at a specific kVp and mAs sufficient to yield an optical density of approximately 1.0 at a mid-range step. This test radiographic is maintained for reference and the test repeated at periodic intervals and the resultant images compared to the reference standard. A shift in the step at which the reference density occurs indicates a possible calibration problem with the unit. The relative calibration of the generator mA can be checked by producing several test images of the wedge on the same cassette at a fixed kVp and mAs but at different mA values. The density of the reference step should remain constant to within better than 1 step. The major problem associated with this test is that it is highly dependent on processing conditions and is thus unsuitable for detecting long-term drift unless the processing conditions are comparable each time the test is conducted.

For certain units the amount of filtration in the beam is not fixed. For such units the beam quality test described in this test should be carried out with the minimum permanent filtration in place. Filter interlock systems (i.e., an electric circuit which prevents exposure when the filter is not in position) are used and the function of such systems should be checked.

Exposure reproducibility may also be evaluated under conditions of heavy filtration (i.e., conditions which simulate the attenuation in the patient. The procedure would be identical except a .5 in to 1 in aluminum attenuator would be positioned in the beam. Occasionally systems which exhibit a non-reproducibility exposure when the unattenuated beam is evaluated will be found acceptable using this test.

4.5 FOCAL SPOT SIZE AND CONSISTENCY

- 4.5.1 **Objective of Test:** To determine the approximate size of the x-ray tube focal spot and monitor this size with time.
- 4.5.2 **Recommended Test Equipment:** Shown in Figure 16 is the equipment recommended for performing this test. In addition to the equipment shown, Data Form RF 5 is required.

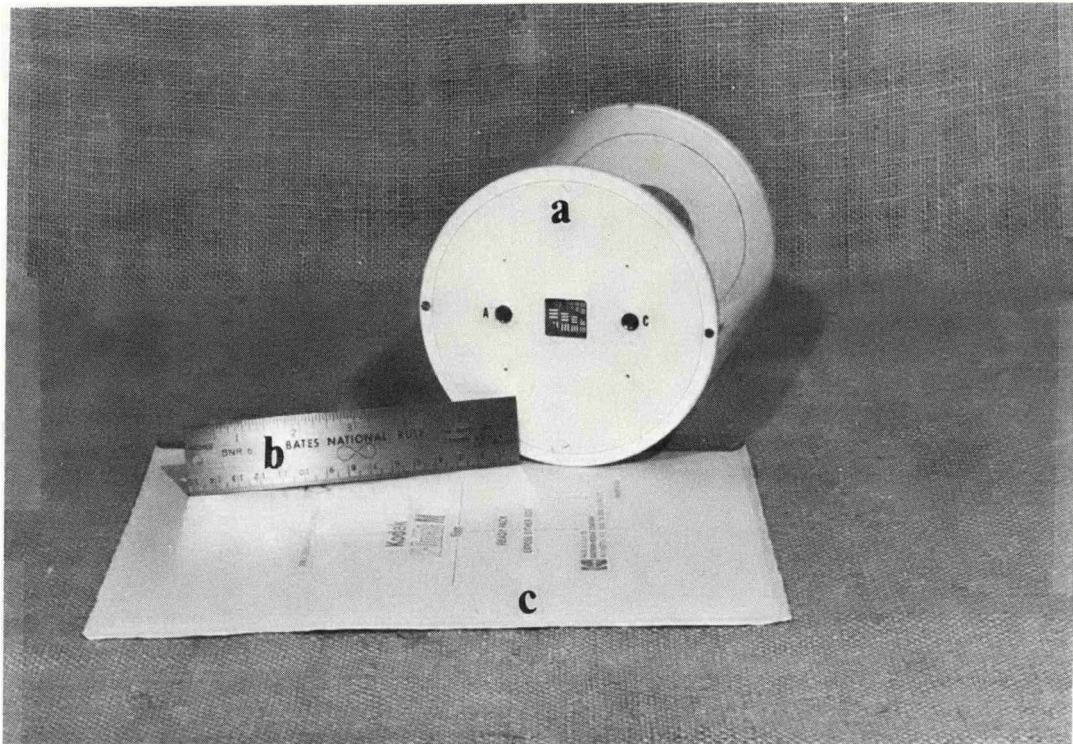


Figure 16. Recommended equipment for performing focal spot size and consistency test: a. focal spot test tool; b. 6-in spacer and; c. ready pack direct exposure x-ray film (8 x 10 in).

- 4.5.3 **Testing Frequency:** Routinely performed at 3-month intervals or upon installation of new x-ray tube.
- 4.5.4 **Test Procedure:**
1. Position the ready pack film on the top of the x-ray table (Fig. 17).
 2. Position the focal spot test tool on top of the film so that it is located on one-half of the film. Orient the focal spot test tool so that the anode-cathode markers on the test tool are parallel to and aligned with the anode-cathode axis of the x-ray tube.
 3. Turn on the x-ray field light localizer and reduce the size of the field to the size of the top of the test tool. Center the x-ray tube with respect to the test pattern in the test tool.
 4. Using the spacer, position the face of the x-ray tube collimator 6 in above the top surface of the test tool. Re-center the x-ray tube if necessary.

5. With the light field on, verify that the images of the four holes in the top of the test tool are projected onto the base of the test tool so as to coincide with the black circle. Adjust the vertical travel of the x-ray tube if necessary to achieve this alignment.
6. On the x-ray generator, select 80 kVp, small focal spot and the mA station which represents a mid-range value of the allowed mA values for the small focal spot.
7. Adjust the exposure time to yield approximately 50-60 mAs and make an exposure.
8. Reposition the film and test device to the second half of the film, and repeat the procedure for the large focal spot.
9. For both the small and large focal spot, record kVp, mA and time used on the data form as well as tube identifying data.
10. Process the exposed film.

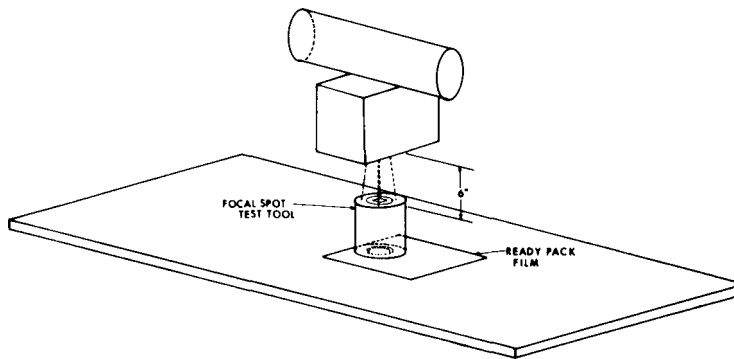


Figure 17. Illustration of equipment set up for performing test.

- 4.5.5 Documentation of Test Results:** On the processed film and data form, record the test date, x-ray tube identifying information, nominal size of the focal spots and technical factors used as illustrated in the example data form shown in Figure 18. View the images on a viewbox and starting with the largest group of bar patterns as number 1, count the number of groups of bar patterns which are clearly resolved. A group is said to be resolved if the pattern of bars in the image shows three dark bars separated by two light spaces in both directions. Record this group number on the data form. An example of typical test images are shown in Figure 19.
- 4.5.6 Interpretation of Test Results:** The approximate size of the focal spot can be determined from the test pattern image by reference to Table 4. Using this table, record on the data form the size of the focal spot which corresponds to the resolved number of groups. Compare this focal spot size with the nominal focal spot size of the x-ray tube.
- 4.5.7 Action Limits and Corrective Action:** (These limits are indications for action only, and do not necessarily indicate non-compliance with any applicable standards. A test result exceeding these action levels should be verified by retesting prior to further action.) A given nominal size focal spot should be able to resolve the group

number listed in Table 4 to within ± 1 group. Should this not be the case for the x-ray tube tested, it is advisable to recheck your test procedure to verify that the correct focal spot was selected and/or that the geometry was correct. If a given focal spot still does not pass the test it is advisable to retest using a more precise test methodology. When this test is performed on a routine basis it is expected that a given nominal size focal spot would be able to resolve the same number of groups over its useful life to within ± 1 group.

FOCAL SPOT SIZE AND CONSISTENCY		
Date: <u>6-26-78</u>	Room No.: <u>CGH 2332</u>	DATA FORM RF 5
Equipment Identification: <u>Neuroangiographic-Lateral</u>		
Generator: Manufacturer: <u>Picker</u>	Model: <u>PH 700</u>	
X-Ray Tube: Manufacturer: <u>Dunlee</u>	Model: <u>PX-414-ES/DU 300</u>	
Serial No.: <u>124822E1/9311-C</u>	Nominal Focal Spot Sizes: Small <u>.3</u> mm	Large <u>1.2</u> mm
	SMALL FOCAL SPOT	LARGE FOCAL SPOT
kVp	80	80
mA	100	400
Exposure Time	1/10 sec	1/40 sec
Number of Smallest Group Resolved	11 (A11)	8
Implied Focal Spot Size	.3 mm or less	1.0 mm or less
Remarks/Comments:		
_____ Signature		

Figure 18. Example of data form used for recording test results illustrating representative data obtained.

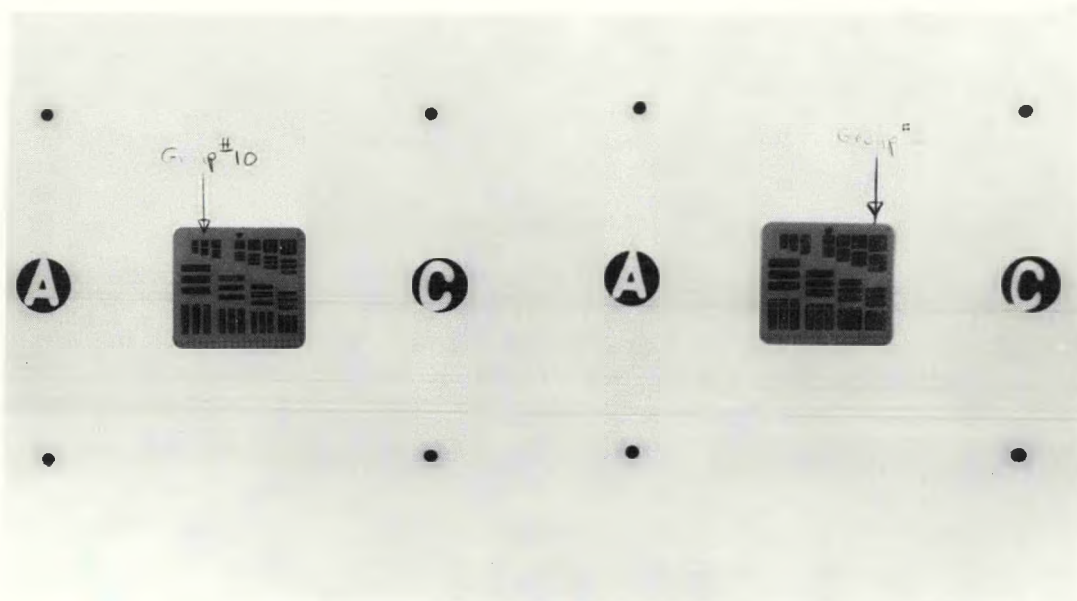


Figure 19. Typical test film from which focal spot size and consistency is determined.

Table 4. Relationship between nominal focal spot size and number of group resolved in focal spot test tool*

Nominal focal spot size	Number of group resolved	Line pair per millimeter equivalent for group
.3 mm	All	3.35
.6 mm	10	2.8
1.0 mm	7	1.7
1.2 mm	6	1.4
1.5 mm	5	1.15
2.0 mm	3	.85
2.5 mm	2	.71

*Relationship holds only for magnification of 1.3

- 4.5.8 **Test Procedure Limitations:** The focal spot test tool and relationship between nominal focal spot size and resolved number of groups is based on the test pattern being radiographed at a magnification of approximately 1.3 and will remain reasonably valid for magnifications from 1.25-11.35. To verify that the proper magnification has been achieved measure the separation between either of the diagonally opposite hole pairs in the image. It should be between 3.75 in and 4.05 in. If it is not, the relationship between resolved group number and nominal focal spot size is not valid. Likewise, the usefulness of the test as a measure of focal spot size consistency depends on the magnification being the same at every test.

4.5.9 Alternate Test Procedures: A large variety of test procedures are available for the measurement of focal spot size. The classical method involves the use of a pinhole camera to produce a magnified image of the actual focal spot. This image is then measured and the focal spot size calculated. A number of methods employing resolution patterns have also been developed. These tests relate the size of the focal spot to a given resolving capability in line pairs/mm in the image of the test object. The interested reader is referred to the reference section on focal spot measurements for more detailed descriptions of these tests.

4.6 kVp ACCURACY

4.6.1 Objective of Test: To determine the accuracy of the kVp indicators of the x-ray generator and to determine the consistency of kVp at different mA stations.

4.6.2 Recommended Test Equipment: Shown in Figure 20 is the equipment recommended for performing this test. In addition to the equipment shown, Data Form RF 6 and a suitable densitometer for the evaluation of test films is required.

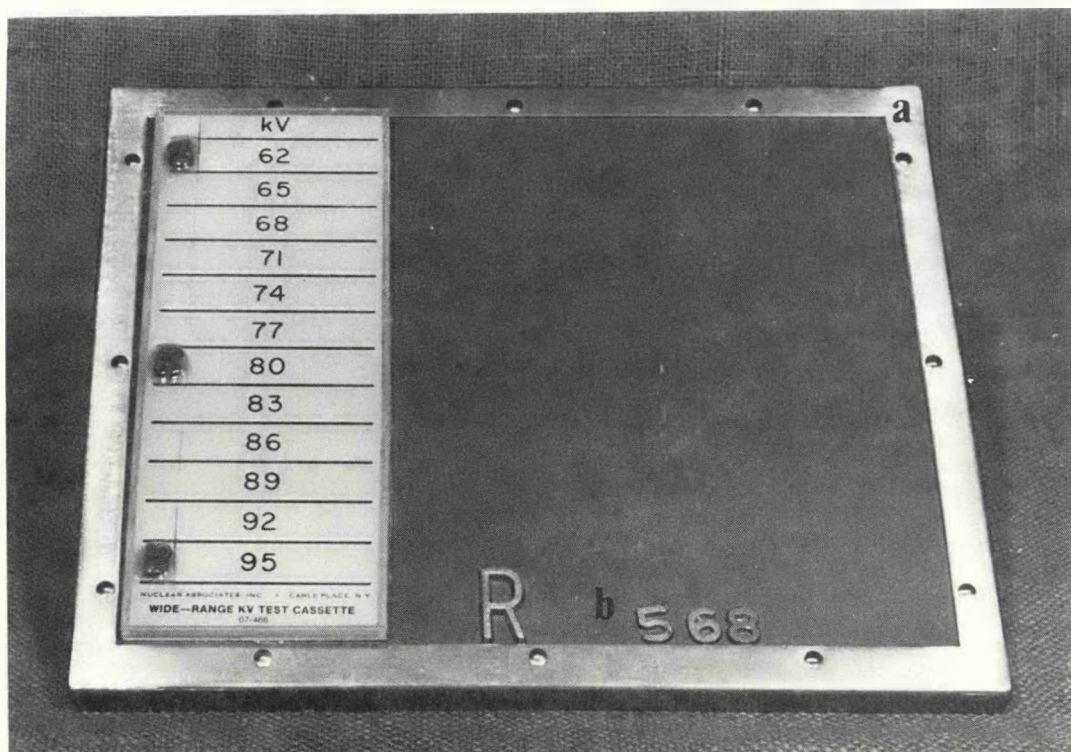


Figure 20. Recommended equipment for performing kVp accuracy test: a. kVp test cassette; and c. lead numbers and letters for test film.

4.6.3 Testing Frequency: Routinely at 3-month intervals and following any service work which can affect the calibration of the x-ray system such as replacement of the x-ray tube.

4.6.4 Test Procedure:

1. Position the radiographic tube to be tested approximately 40 in above the surface of the tabletop (Fig. 21).
2. Position the test cassette on the x-ray tabletop oriented so that the long axis of the kVp test wedge is perpendicular to the anode-cathode axis of the x-ray tube.
3. Using the x-ray tube light localizer, center the kVp test region in the x-ray field and restrict the field size to a size slightly larger than the test region of the cassette.
4. On the x-ray generator control, select 80 kVp and a commonly used mid-range mA station.
5. Using lead numbers on the surface of the test cassette next to the test wedge region, identify the test film and record the identifying information on the data form.
6. Select an exposure time sufficient to yield approximately 45 mAs and record.
7. Make an exposure and process the test film.
8. On the processed test film using a densitometer, measure the density of the reference wedge image. This density must be between 0.9-1.9 to provide accurate test results. If the first test film does not exhibit proper density adjust the mAs to obtain a density in the required range.
9. On the final test film record the technique factors used and the identification of the unit under test.
10. Repeat the test for other commonly used mA stations (low and high range).

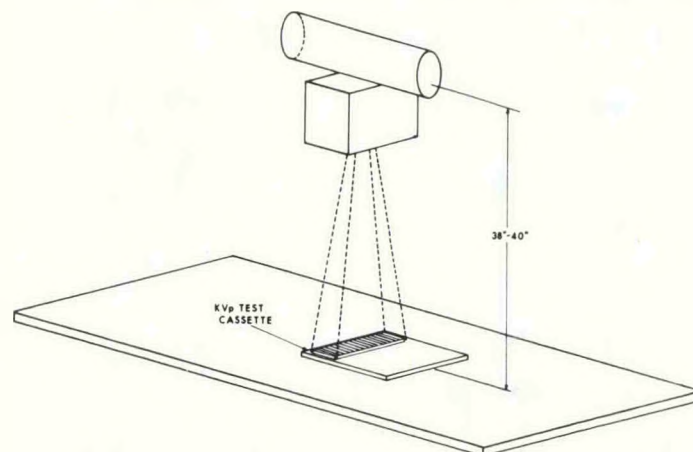


Figure 21. Illustration of equipment set up for performing test.

- 4.6.5 **Documentation of Test Results:** The processed test film will appear similar to that shown in Figure 22. On each test film record the kVp and mA used for the test and measure and record the optical density of each step in the reference wedge and attenuator wedge. This data should also be recorded on the data form as illustrated in Figure 23.

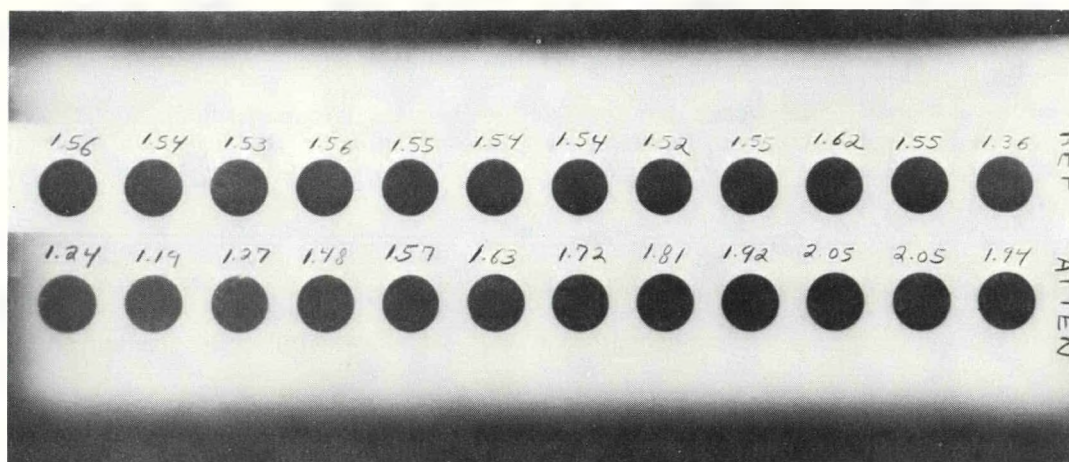


Figure 22. Typical test film from which kVp accuracy is determined.

- 4.6.6 **Interpretation of Test Results:** For each mA station tested, determine the number of the attenuator wedge step whose density most closely matches the density of the reference wedge step. Use linear interpretation between wedge steps if necessary. Record this step on the data form as the match step number. Refer to the calibration table or curve for the particular cassette used and determine the correspondence between match step number and kVp for the high voltage waveform of the equipment tested. An example of such a calibration table is shown in Table 5. Record the determined kVp on the data form. The kVp value as measured by the test cassette should correspond to that set on the x-ray generator control to within ± 4 kVp. Likewise, the measured kVp should remain constant regardless of the mA station selected to within the same tolerance.
- 4.6.7 **Action Limits and Corrective Action:** (These limits are indications for action only, and do not necessarily indicate non-compliance with any applicable standards. A test result exceeding these action levels should be verified by retesting prior to further action.) Should the measured kVp differ from the indicated kVp by greater than ± 4 kVp or the kVp difference as a function of mA exceed ± 4 kVp a service representative should be contacted to perform a complete calibration check of the generator. The most frequent cause of kVp miscalibration is mA drift as the tube ages and thus the need for periodic recalibration is to be expected.
- 4.6.8 **Test Procedure Limitations:** A number of techniques have been developed to measure the kVp applied to an x-ray tube by a non-invasive method. The majority of these techniques, including the one described above, rely on some form of attenuation measurement of a heavily filtered x-ray beam through some metallic attenuator. These techniques are secondary in nature and thus rely on calibration against a primary standard. The accuracy with which the initial calibration was performed will obviously influence the results. The calibration of the devices must be checked periodically and an annual calibration of the device is recommended.

Any form of penetrameter technique is dependent on the kVp waveform. Thus, it is necessary to always refer to the proper calibration curves and/or tables when interpreting test data. The proper density of the reference wedge is exceedingly important as too low or high a density may cause as much as a 10 kVp error.

The test outline above is designed to be performed at one kVp. While it is possible that the kVp may be correct at this point and off at higher and lower kVps, experience has shown that this is highly unlikely. Should the question of kVp calibration arise, it is advisable to have it checked out by a more precise method.

- 4.6.9 **Alternate Test Procedures:** A second form of kVp test cassette is commercially available at this time. The major difference as compared to the wide-range kVp cassette described here is that four separate kVp regions are provided which are optimized at 60, 80, 100 and 120 kVp. The use of the devices is identical. For details of other test methods, the interested reader is referred to the reference section of this manual.

kVp ACCURACY

DATA FORM RF 6								
Date: 1-11-78		Room No.: CGH 2208						
Equipment Identification:		Special Procedures/General Angio-Lat						
Generator Identification:		Manufacturer: Siemens		Model: Triodoros (T3-150)				
X-Ray Tube Identification:		Manufacturer: Siemens		Model:				
High Voltage Waveform:		Serial No.:		Single Phase:		Three Phase: ☒		
Test kVp: 80								
mA	200 (L1)		400 (L1)					
Exposure Time	.23		.13					
Test Film Identification	A1		A4					
Step Number	Optical Density Readings							
	Refer.	Atten.	Refer.	Atten.	Refer.	Atten.	Refer.	Atten.
1	1.24	1.01	1.21	.80				
2	1.24	0.96	1.16	.73				
3	1.24	1.04	1.14	.79				
4	1.24	1.23	1.15	.94				
5	1.24	1.30	1.15	1.00				
6	1.25	1.36	1.16	1.03				
7	1.23	1.49	1.16	1.15				
8	1.24	1.55	1.16	1.20				
9	1.27	1.88	1.15	1.30				
10	1.30	1.89	1.18	1.42				
11	1.30	1.89	1.20	1.54				
12	1.33	2.04	1.27	1.72				
Match Step	4		7					
Implied kVp	71		80					
Remarks/Comments: Apparent kVp miscalibration. Manufacturer's service representative needs to be contacted.								
Signature _____								

Figure 23. Example of data form used for recording test results illustrating representative data obtained.

4.7 GRID ALIGNMENT

- 4.7.1 **Objective of Test:** To determine that the radiographic grid is aligned properly with respect to the center of the image receptor and the central ray of the x-ray tube.
- 4.7.2 **Recommended Test Equipment:** Shown in Figure 24 is the equipment recommended for performing this test. In addition to the equipment shown, Data Form RF 7 and a suitable densitometer for the evaluation of test films is required.

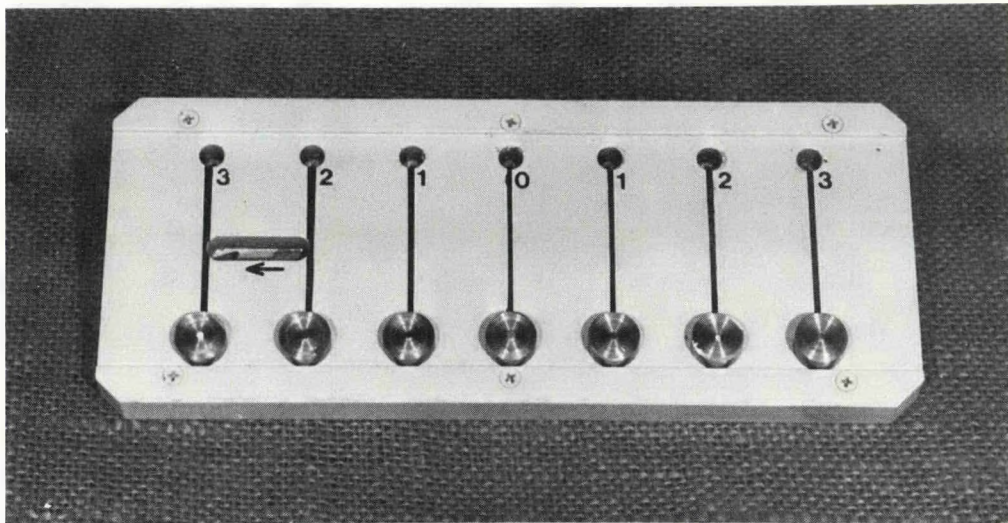


Figure 24. Recommended equipment for performing grid alignment test: grid alignment test tool.

- 4.7.3 **Testing Frequency:** Routinely performed at 6-month intervals and following any service on the x-ray system which could affect alignment between the x-ray tube, image receptor and grid (e.g., the repair of the cassette tray or grid mechanism).
- 4.7.4 **Test Procedure:**
1. Using the means provided on the equipment, center the x-ray tube with respect to the image receptor both longitudinally and transversely and adjust the system vertically to the proper source to image receptor distance for the grid employed on the system. Lock the travel of the tube in place.
 2. Position an 8- x 10-in cassette in the cassette tray so that the long dimension of the cassette is oriented perpendicular to the long dimension of the table and completely insert the cassette tray (Fig. 25).
 3. Position the grid alignment test tool on the tabletop perpendicular to the long dimension of the tube and center the zero position of the test tool with respect to the optical crosshairs of the beam restriction system. The orientation arrow of the test tool should be pointed towards the front of the table.
 4. Restrict the radiation field to a size that is approximately the width of the test tool and so that only the central hole will be irradiated. To avoid cross irradiation, insert the brass plugs into the other holes.
 5. In this configuration, make an exposure at 60 kVp and approximately 5 mAs.

6. After making the exposure at the central position, laterally decenter the tube over each of the other holes on the two sides of the central hole and make the same exposure at each position. Make sure to plug the holes not being irradiated.
7. Process the test film.

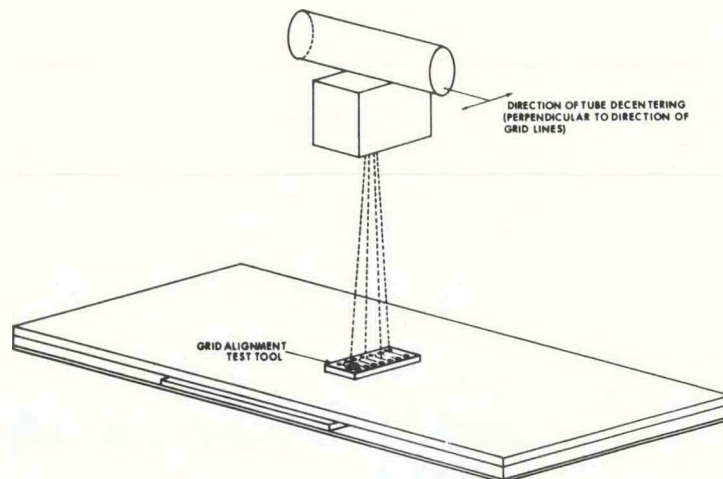


Figure 25. Illustration of equipment set up for performing test.

- 4.7.5 **Documentation of Test Results:** An example of a typical test film is shown in Figure 26. On the processed film, measure the density of the central region. It should be approximately 1.0 to 1.8; if it is not, it will be necessary to repeat the test film and adjust technique to obtain this density. Measure and record on the film and data form the density of each of the hole images and other required information as shown in the example data form of Figure 27.
- 4.7.6 **Interpretation of Test Results:** Review the measured density of the hole images. If the grid is properly aligned the central hole should display the maximum density. For a properly aligned grid system the density fall off should be symmetrical about the central hole as the x-ray tube is laterally decentered to either side of the grid center.
- 4.7.7 **Action Limits and Corrective Action:** (These limits are indications for action only, and do not necessarily indicate non-compliance with any applicable standards. A test result exceeding these action levels should be verified by retesting prior to further action.) Should the density pattern displayed on the test film indicate that maximum density is obtained at 1 in or greater from the central hole grid alignment is unacceptable. A density pattern exhibiting maximum density occurring between the central hole and those immediately adjacent to it is acceptable. The density fall off pattern on either side of the hole should be reasonably symmetrical. Strong asymmetrical patterns suggest that some form of misalignment exists, possibly in the x-ray tube detent mechanism and/or the reciprocating action of the grid or the construction of the grid itself. Should the test indicate that a possible grid alignment problem exists a service representative should be contacted for corrective action.

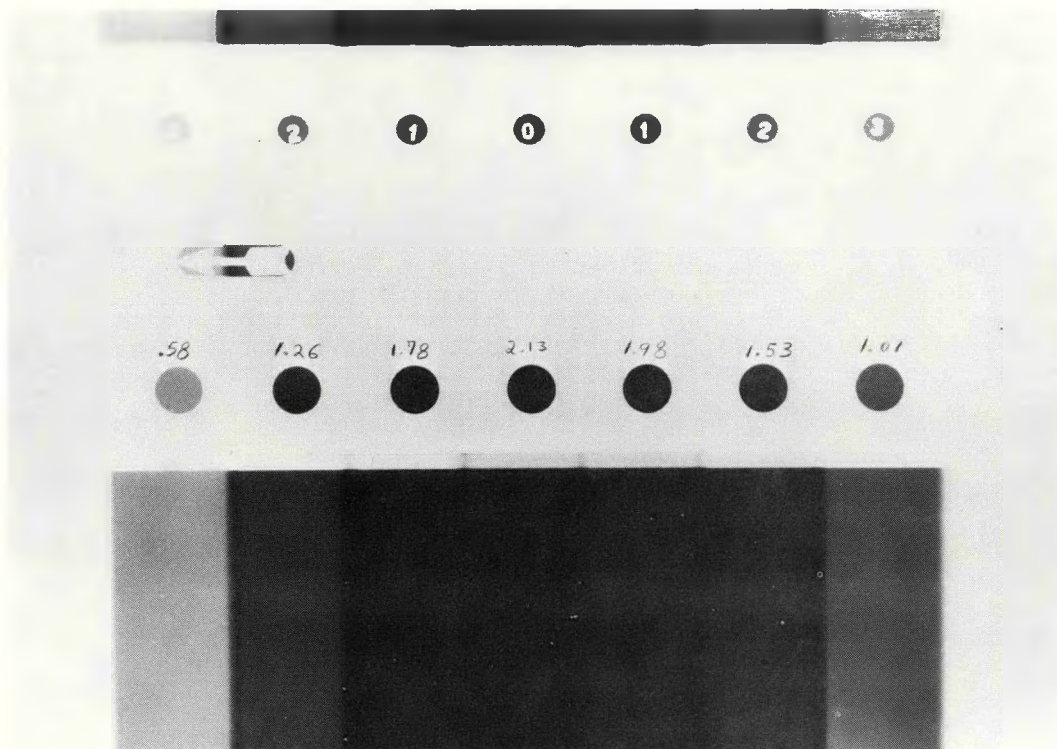


Figure 26. Typical test film from which adequacy of grid alignment is determined.

- 4.7.8 Test Procedure Limitations:** The test procedure outline above is very dependent on one's ability to accurately position the x-ray tube with respect to the test tool. Also the hole spacing of 1 in in the test tool limits the resolution of the test. Since small field sizes are employed it is possible to interpret a non-alignment of the radiation field and light field for a grid alignment problem. Overall, the test is capable of detecting gross grid alignment problems, which are frequently most troublesome. You should be able to tell from this test, if a centering and alignment test on the collimator system was performed previously, if the grid alignment is adequate to within .5 in which is an acceptable tolerance for most routinely used radiographic grids.
- 4.7.9 Alternate Test Procedures:** A number of alternate methods are available to verify grid alignment. If the system allows access to the grid so that its surface is visible one only need center the x-ray tube with respect to the grid with the means provided on the equipment and note the alignment between the optically projected field and grid center line. If light-radiation field center congruence has been previously tested and found to be adequate this is an adequate test. However, many systems employing reciprocating grid mechanisms place the grid as much as 1.3 in off center in the grid resting position and this must be compensated for. On systems with stationary grids any technique which can verify alignment of the x-ray tube central ray with the center line of the grid is acceptable. Details of additional test procedures may be found in the cited references.

GRID ALIGNMENT							
DATA FORM RF 7							
Date: <u>10-12-77</u>		Room No.: <u>CGH 2212</u>					
Equipment Identification: <u>Philips General Radiographic Fluoroscopic System</u>							
Grid Tested: <u>Radiographic Table</u>							
Grid Ratio: <u>12:1</u>		Line Number: <u>103 1/in</u>		Focal Distance: <u>40"</u>			
SID Used for Test: <u>40"</u>							
kVp: <u>60</u>		mA: <u>8 mAs</u>		Exposure Time: <u>NA</u>			
Measured Optical Density							
Reference Location	←						
	3	2	1	0	1	2	3
	.27	.55	.91	1.08	.77	.46	.22
Remarks/Comments: Alignment okay. *← Indicates orientation arrow on test device. Always orient arrow towards front of table. _____ Signature							

Figure 27. Example of data form used for recording test results indicating typical data obtained.

4.8. AUTOMATIC EXPOSURE CONTROL SYSTEM EVALUATION

- 4.8.1 **Objective of Test:** To evaluate the performance of automatic exposure control systems used in conjunction with radiographic units.
- 4.8.2 **Recommended Test Equipment:** Shown in Figure 28 is the equipment recommended for performing this test. In addition to the equipment shown, Data Form RF 8 and a suitable densitometer for the evaluation of test films is required.
- 4.8.3 **Testing Frequency:** Routinely performed at 6-month intervals, following any service of repair work carried out on the automatic exposure control system or when a suspected problem exists with the automatic exposure control system.

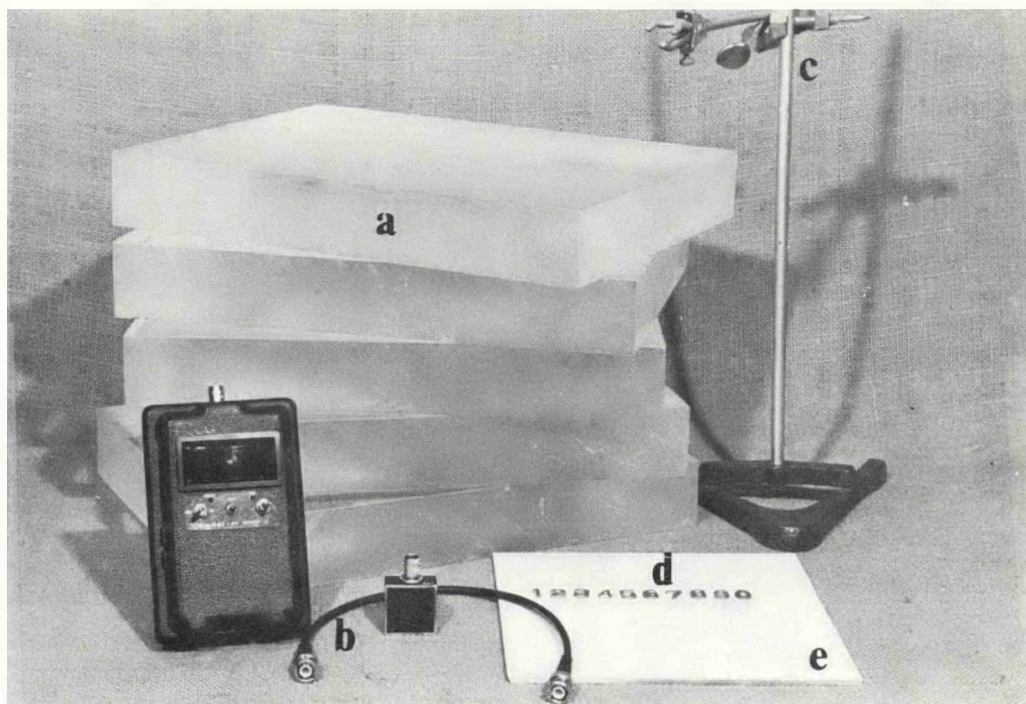


Figure 28. Recommended equipment for performing automatic exposure control system evaluation test: a. automatic exposure control system evaluation phantom (5-2 in thick blocks of Plexiglas 11 x 14 in); b. digital x-ray generator timer with remote detector and interconnecting cable; c. ringstand and clamp; d. lead numbers for test film identification; and e. lead beam stop.

4.8.4 Test Procedure:

1. Prepare the radiographic system to be tested for operation in the automatic exposure control mode.
2. Using the means provided on the equipment, center the x-ray tube longitudinally and transversely with respect to the cassette tray and image receptor of the system. Set the x-ray tube vertically for the source to image receptor distance normally employed on the equipment.
3. Position the base section of the phantom on the tabletop centered with respect to the center of the projected light field and so the orientation marker in the phantom is located in the upper right quadrant as you face the table (Fig. 29).
4. Using the beam restriction system adjust the field size to provide an 11- x 14-in field for the SID employed.
5. Using a ring stand and clamp position the remote detector of the digital x-ray timer approximately 11 in above the top of the table and orient so that it is contained within the projected light field. Connect the remote detector to the display unit and turn the display unit "ON". Orient the display so it is visible from the control booth window and select the proper mode of operation for the unit (pulse for single phase equipment, time for three phase equipment).

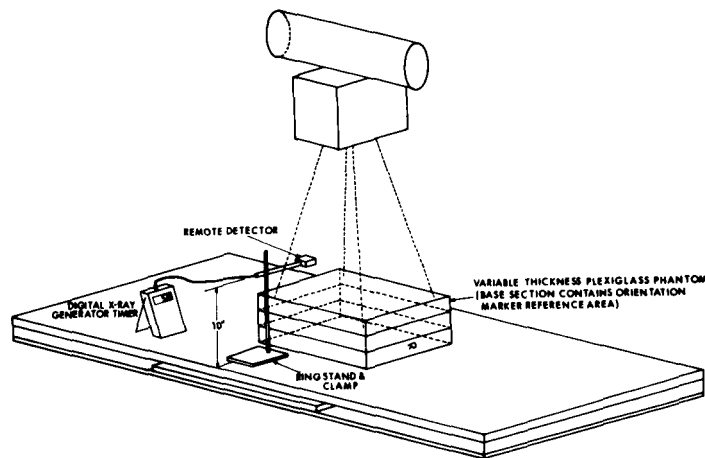


Figure 29. Illustration of equipment set up for performing test.

The above steps are common to all of the subsequent tests to be performed. The following steps outline each individual procedure:

Reproducibility

6. Add an additional 2 sections of phantom on top of the base phantom section for a total thickness of 6 in.
7. Insert an 11- x 14-in cassette into the cassette tray and completely insert the cassette tray.
8. On the x-ray generator control select 80 kVp and the mA station most commonly used for automatically controlled exposures.
9. Select the normal density control.
10. For systems equipped with multiple sensitive fields select the pick-up fields which provide the largest averaging area over the phantom (i.e., in dual field systems select the largest field; in tri-field systems, select all three fields in combination, if possible).
11. Record on the data form under "Reproducibility" the technical factors used for the test. Place lead identifying numbers on the top surface of the phantom.
12. In succession, make three automatically controlled exposures changing the films between each exposure. Note and record the exposure time of each exposure on the data form.
13. Process the three test films and measure the film density at the point of the reference marker in the image of the phantom and record on the data form.

kVp Compensation

14. Maintain the same test geometry as used under "Reproducibility" and maintain the same phantom thickness, density station, sensing field(s) and mA station.
15. On the x-ray generator control, select 60 kVp.

16. Place lead numbers "60" on the top surface of the phantom so that their image will be visible on the test radiograph.
17. Insert an 11- x 14-in cassette into the cassette tray and make an automatically controlled exposure. Note and record on the data form the displayed exposure time.
18. Repeat the above at 80, 100 and 120 kVp making sure to change the cassette and lead identifying numbers between each exposure (i.e., use lead numbers corresponding to the test kVp's).
19. Process the four test films, measuring the density of each at the reference point and record on the data form.

Field Sensitivity Matching (Applicable only to systems with multiple sensing fields)

20. Maintain the same test geometry, phantom thickness, density control station and mA station as used for the "Reproducibility" test.
21. Select 80 kVp on the x-ray generator control.
22. In succession, select each sensing field and/or combination of sensing fields available on the system and insert an 11- x 14 in cassette, place lead numbers on top of the phantom for identification purposes and make an automatically controlled exposure. In the data form, record the technical factors used, the lead number identification for each field combination tested and the measured exposure time. Make sure to change the cassette and identifying lead numbers between exposures.
23. Process the series of test films, measuring the density of each at the reference point in the image and record the measured density on the data form.

Density Control Function

24. Maintain the 6 in phantom thickness, test mA, 80 kVp and geometry as used above.
25. Select the sensing fields as used under the "Reproducibility" test.
26. In succession for each available density control station on the equipment, insert an 11- x 14-in cassette, placing lead identifying numbers on top of the phantom and make an automatically controlled exposure. In the data form record the measured exposure time at each station and the film identification designation used. Make sure to change the cassette and film identification between exposures.
27. Process the series of test films and measure the density of each in the reference area of each film and record on the data form.

Response Capability

28. Maintain the same basic test geometry as used in the preceding sections of the test, but remove two sections of the phantom so that the initial phantom thickness is 2 in (base section only).
29. On the x-ray generator control, select the mA used for the reproducibility test as well as the normal density control and sensitive fields providing the largest area averaging.

30. Select 60 kVp on the x-ray generator control.
31. Insert an 11- x 14-in cassette into the cassette tray and place lead identifying numbers on the top surface of the phantom to identify the kVp and phantom thickness. Record identifying numbers used on the data form.
32. Make an automatically controlled exposure and note and record the exposure indicated on the display of the digital x-ray timer.
33. Repeat above procedure for total phantom thickness of 4 in, 6 in, 8 in and 10 in at 60 kVp and then repeat the entire procedure at 80, 100 and 120 kVp. Make sure to insert a new cassette between each exposure to verify that the proper phantom thickness is in place and the identifying lead numbers are changed.
34. Process the series of test films, measure the density of each in the reference area of the phantom and record in the proper place on the data form.

Backup Timer:

35. Reset the technique factors, automatic exposure system controls and phantom thickness as used for the reproducibility test.
36. Position the 8- x 8- x 1/8-in lead beam stop on top of the phantom so as to block the sensitive area of the automatic exposure control system sensing field(s).
37. Make an automatically controlled exposure and record the measured exposure time in the data form.

4.8.5 Documentation of Test Results: Because this test involves the accumulation of a relatively large amount of data, it is very important that the test results be recorded on the data form as you proceed with the test. Make sure to record all technical factors used in each section of the test, as well as to properly identify the test films so the final density readings can be accurately recorded in the data form. An example of the data form to be used is shown in Figure 30.

4.8.6 Interpretation of Test Results: Each section of this test requires certain calculations in order to properly interpret the test results. For the reproducibility data calculate and record the average exposure time and film density obtained. Compare the individual recorded measurements with the average values. A properly functioning automatic exposure control system may be expected to provide reproducibility to within 5 percent or better.

The kVp compensation data should be reviewed with respect to exposure time and film density. The measured exposure time should be expected to decrease with increasing kVp and the film density should be expected to remain constant with kVp to within + .4 optical density units. Should the exposure time fail to decrease and/or the film density increase dramatically, it is possible that the system is malfunctioning and possibly being asked to operate in a region outside of its capabilities. This can be further evaluated by testing at a different mA station of lower value.

For automatic exposure control systems equipped with multiple sensitive fields, calculate the average exposure time and film density for each field and/or combinations of fields tested. Record in the data form and compare the results of the individual field measurements to the average. The individual measurements should compare to the average to within 10 percent.

RADIOGRAPHIC AUTOMATIC EXPOSURE CONTROL SYSTEM EVALUATION

Date: <u>1-12-78</u>		Room No.: <u>CGH 2212</u>		DATA FORM RF 8	
Equipment Identification: <u>General Purpose Radiographic/Fluoroscopic - Philips</u>					
Automatic Exposure Control System Tested: <u>Table</u>					
Cassette/Screen/Film					
Combination Used for Test: <u>Philips/DuPont Hi Plus/Kodak XRPI</u>					
Processor Used for Processing Test Films: <u>Diplomat #1</u>					
Processing Parameters: Speed: <u>1.08</u>		Contrast: <u>2.34</u>		Base/Fog: <u>.16</u>	
SID Employed for Test: <u>40"</u>					
 REPRODUCIBILITY					
Test Conditions:		80 kVp	Falling load	mA Large	1 2
		Normal Density			3
		6" Phantom Thickness	<u>1+2+3</u>	Selected Sensitive Field(s)	
Test Film Identification	Measured Exposure Time (milliseconds)	Measured Film Density			
5	31.4	1.14			
28	31.4	1.11			
6	31.4	1.16			
Average Exposure Time	31.4				
Average Film Density		1.14			
Maximum Exposure Time Variation	0				
Maximum Film Density Variation		0.05			
 kVp COMPENSATION					
Test Conditions:		6" Phantom Thickness	Falling load	mA Large	
		Normal Density	<u>1+2+3</u>	Selected Sensitive Field(s)	
kVp	Test Film Identification	Measured Exposure Time	Measured Film Density		
60	5	91.5	1.06		
80	6	33.5	1.07		
100	7	18.0	1.33		
120	28	17.0	1.57		
Maximum Film Density Variation			.51		
Appears generator has minimum response time of ~20 msec.					

Figure 30. Example of data form used for recording test results illustrating representative data obtained.

RADIOGRAPHIC AUTOMATIC EXPOSURE CONTROL SYSTEM EVALUATION

DATA FORM RF 3

FIELD SENSITIVITY MATCHING

Test Conditions: 80 kVp Falling load mA Large
Normal Density
6" Phantom Thickness

Selected Sensitive Field	Test Film Identification	Measured Exposure Time	Measured Film Density
3	7	31.4	1.02
1	28	34.4	1.23
2	5	31.5	1.18
1 + 3	6	31.5	1.10
2 + 3	13	31.4	1.00
1 + 2	37	31.9	1.22
1 + 2 + 3	37B	31.9	
Average Exposure Time		32.0	
Average Film Density			1.12
Maximum Exposure Time Variation		3	
Maximum Film Density Variation			.23

DENSITY CONTROL FUNCTION

Test Conditions: 80 kVp Falling load mA Large
6" Phantom Thickness 1+2+3 Selected Sensitive Field(s)

Density Control Setting	-A	A	A+	B-	B	B+	C-	C	C+
Test Film Identification	37	13	6	6B	5	28	28B	7	7B
Measured Exposure Time (milliseconds)	20	23	25.9	26.4	31.5	36.4	36.9	45	51
Measured Film Density	.5	.74	.97	1.00	1.31	1.51	1.56	1.86	2.27
Fractional Change in Exposure Time*	.63	.63	.82	.84	1.00	1.16	1.17	1.43	1.64
Fractional Change in Film Density*	.38	.56	.74	.76	1.00	1.15	1.19	1.42	1.77

*Relative to that obtained at Normal density control setting.

Density controls are Min(A) Norm(B) Max(C) and anatomical figures representing thin(-) and thick (+)

Figure 30 continued

RADIOGRAPHIC AUTOMATIC EXPOSURE CONTROL SYSTEM EVALUATION

DATA FORM RF 8												
RESPONSE CAPABILITY Test Conditions: Normal Density Falling load mA 600 mAs Selected Back-Up Time Large 1+2+3 Selected Sensitive Field(s)												
Phantom Thickness	60 kVp			80 kVp			100 kVp			120 kVp		
	Test Film Identification	Measured Exposure Time (milliseconds)	Measured Film Density	Test Film Identification	Measured Exposure Time (milliseconds)	Measured Film Density	Test Film Identification	Measured Exposure Time (milliseconds)	Measured Film Density	Test Film Identification	Measured Exposure Time (milliseconds)	Measured Film Density
2"	28	10.7	1.08	6	11.8	2.70	7	13.3	3.40	5	14.1	3.6
4"	6	30.4	1.31	28	14.3	1.15	37	13.5	2.29	13	14.4	2.98
6"	7	89.9	1.23	5	31.5	1.30	37A	19.0	1.52	13C	16.9	1.84
8"	7A	233.0	1.17	6	78.8	1.27	28	35.9	1.52	5A	25.4	1.64
10"	13	1352.0	0.38	37	245.8	1.23	28B	85.7	1.43	5B	50.4	1.52
Maximum Variation in Film Density at Constant kVp			0.23	1.47			1.97			2.08		
Maximum Variation in Film Density at Constant Phantom Thickness			2"	4"	6"	8"	10"					
			2.52	1.83	0.61	0.47	1.14					
BACK-UP TIMER Test Conditions: 80 kVp Falling load mA Large 6" Phantom Thickness 1+2+3 Selected Sensitive Field(s) plus lead beam stop Selected Back-up Time Measured Exposure Time: .16 sec. mA-time produce: mAs - starting mA is not known Remarks/Comments: ① 10" phantom resulted in back up timer being hit-exclude. Using falling load large is driving system into region it cannot operate well. Required exposure time is less than minimum response time of system. Signature												

Figure 30 continued

If the system is equipped with a density control function, calculate the fractional change in exposure time and film density with respect to the normal density control value and record in the data form. As the relationship between exposure received by the film and resultant film density is not a simple linear one, do not expect the fractional change in film density to necessarily correspond to the fractional change in exposure time. The majority of density controls on automatic exposure control systems are calibrated on a relative scale and thus the purpose of this section of the test is only to provide information concerning the capabilities of the given density control system in conjunction with the film screen combination employed for use with the system. The general statement may be made, however, that as the density station tested is increased above or decreased below the normal setting, the exposure time and film density should increase or decrease, respectively.

In evaluating the response capability of the system several general trends should be noted. First, at a given kVp level the exposure time should increase with increasing phantom thickness. Second, at a given phantom thickness the exposure time should decrease with increasing kVp. Third, and perhaps most important, the test film density should remain constant within $\pm .4$ optical density units regardless of the kVp or phantom thickness. In interpreting this data there are several factors which must be considered, however. It may be noted for example, that for thin thicknesses of phantoms the test film density is higher than would be expected. While this may indicate an automatic exposure control system malfunction, it is also possible that this may be due to the system being unable to terminate the exposure rapidly enough. As a general rule, in high quality automatic exposure control systems, the minimum controllable exposure time for the system is on the order of 5 milliseconds. Thus, as long as the measured exposure time exceeds this value, this would probably not be the cause of excessive density variations. However, for an older system the minimum response time of the system may be on the order of 15 milliseconds and this should be considered.

To evaluate the adequacy and functional integrity of the backup timer determine the product of the mA used for the test and the measured exposure time. This product should not exceed 600 mAs.

One last comment concerning the overall performance of an automatic exposure control system. In a system which has been properly set up and calibrated, the absolute density of a standard test film such as those taken during the reproducibility section of the test should be in the range of 1.1-1.3 if clinical useable films are to be obtained.

- 4.8.7 Action Limits and Corrective Action:** (These limits are indications for action only, and do not necessarily indicate non-compliance with any applicable standards. A test result exceeding these action levels should be verified by retesting prior to further action.) Summarizing the above we may state that an automatic exposure control system which provides 5 percent or better reproducibility, 10 percent or better matching for the sensitivity of multiple fields, can maintain constant film density to within $\pm .4$ density units over the kVp range used for phantom thickness of 4 in and greater and limits the maximum automatically controlled exposure to 600 mAs is functioning properly. Should one or more of the above criteria not be met, the equipment manufacturer's service representative should be contacted to determine the cause of system malfunction and correct it.
- 4.8.8 Test Procedure Limitations:** In carrying out the above test a certain number of implicit assumptions are being made which can influence the results of the test. Since a number of cassettes are to be used in the test we are relying on the uniformity of the radiographic cassette/screen/film employed. These components in themselves exhibit normal variations which must be considered. The effect could be minimized by using only one cassette throughout the test, but this would greatly

lengthen the time required for the test to be completed. Also, except for the reproducibility test only one test film is being taken at each measurement condition. Again, due to normal variations it is possible that the degree of consistency indicated by the test is less than that which the system is actually capable of. The only way to overcome this would be to take multiple test films for each measurement and take the average. These problems have been compensated for to some extent in the limits chosen.

Processing can seriously affect this test. It goes without saying that for the utmost consistency all test films must be processed through the same film processor and in a relatively short period of time. When comparing system performance over long periods of time the influence of processing can be extremely large and the test can only be used for long-term comparisons in conjunction with a processor monitoring program to verify that processing conditions are identical at the time the tests were carried out.

Two other factors can also influence the results of the test. As the kVp is varied the response of the screen film system itself may change and introduce density variations. At a fixed kVp as the phantom thickness is varied the exposure times may range widely. Under these conditions it is possible that the reciprocity characteristics of the film itself can cause density variations.

For the most part, these latter two factors are compensated for to some extent in quality AEC systems and in the tolerance limits of the test but the reader should be aware of their potential impact.

The test described is intended for general purpose radiographic systems. In those systems which tend to operate over a very narrow kVp range (e.g., GI systems as dedicated chest units) the test need only be performed at the most commonly used kVp).

- 4.8.9 Alternate Test Procedures:** Tests similar to the one described above have been used for evaluation of AEC system performance. For the most part they do not differ in concept from the above with one major variation being the type of phantom material used. Extensive evaluations of different phantoms have shown that the Plexiglas phantom method described above correlates most closely with clinical performance of the system. For the interested reader these tests as well as more detailed discussion of automatic exposure control systems may be found in the cited references.

4.9 FILM-SCREEN CONTACT

- 4.9.1 Objective of Test:** To determine the adequacy of film-screen contact of radiographic cassettes.
- 4.9.2 Recommended Test Equipment:** Shown in Figure 31 is the equipment recommended for performing this test. In addition to the equipment shown, Data Form RF 17 is required.
- 4.9.3 Testing Frequency:** Routinely performed at 6-month intervals, upon acquisition of new cassettes prior to clinical use and following any possible damage and/or repair involving a given cassette.

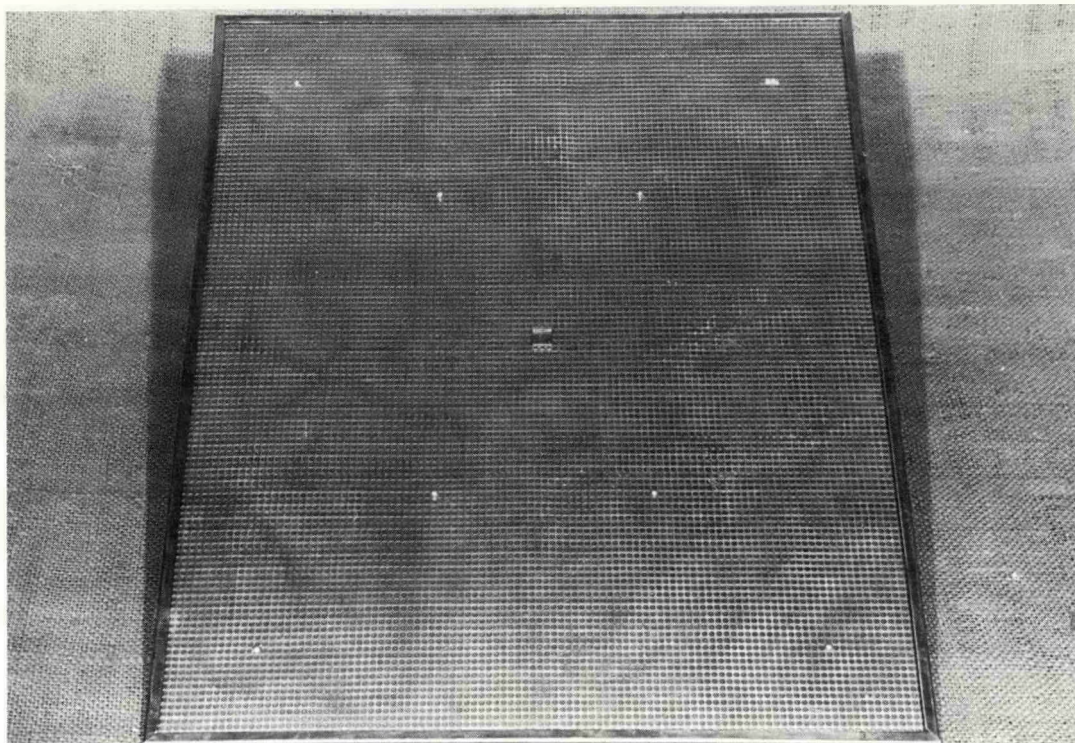


Figure 31. Recommended test equipment for performing film-screen contact test: film screen contact test pattern.

4.9.4 Test Procedure

1. Position the radiographic cassette to be tested on the x-ray table surface. Orient the long axis of the cassette perpendicular to the anode-cathode axis of the x-ray tube (Fig.32).

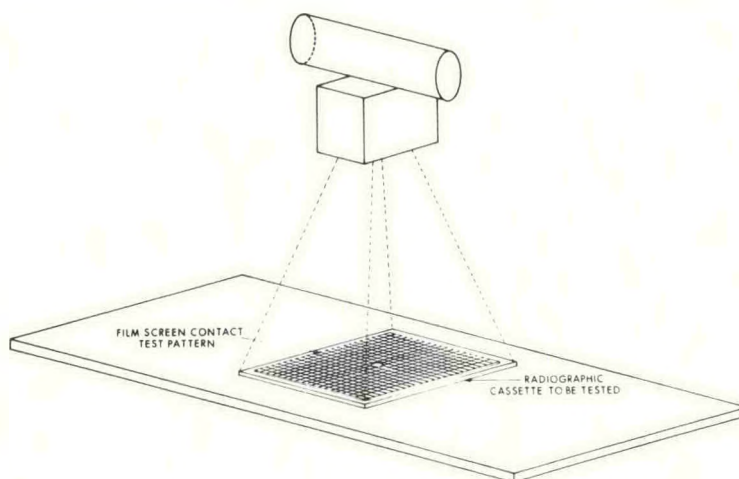


Figure 32. Illustration of equipment set up for performing test.

- 4.9.5 Documentation of Test Results:** After analyzing a given test film for proper film-screen contact as described below, it is necessary to maintain an accurate record of the results. To this end it is advisable to permanently identify all cassettes/screens within the department as they are acquired. This makes the tracking down of a cassette with a suspected contact problem considerably easier. After analyzing the test films, record the results in the data form such as that shown in Figure 33 and note the action taken regarding defective cassettes.

Figure 33. Example of data form to be used for recording test results illustrating typical data obtained.

- 4.9.6 Interpretation of Test Results:** Place the processed test film on a radiographic illuminator and view the test image from a distance of approximately 9 feet. Areas of poor contact will be demonstrated by reduced sharpness in the image or non-uniformity of density in the image. As the test films are viewed, note the identification of any cassette exhibiting poor contact.
- 4.9.7 Action Limits and Corrective Action:** Any radiographic cassette exhibiting poor film-screen contact should not be returned to clinical service. Areas of poor contact which exist around the perimeter of the cassette may be considered acceptable provided they do not extend more than 1 in into the film. Areas of poor contact in the center of the image are completely unacceptable. Any cassette exhibiting poor contact should be examined for physical damage which may be repairable. To determine whether a cassette may be repaired, it is best to contact the cassette manufacturer's representative. If the cassette cannot be repaired it should be destroyed and replaced. For new cassettes the above criteria should be tightened whereas that for older cassettes may be loosened slightly.
- 4.9.8 Test Procedure Limitations:** The only significant limitations of this test procedure is over or underexposing the test film. As a general rule, as long as the background density of the film is between 1.8 and 3.5 no problem will be experienced determining adequate film-screen contact. With new cassettes and screens it is advisable to clean the screens prior to testing.
- 4.9.9 Alternate Test Procedures:** All practical tests for film-screen contact are essentially variations of the test just described employing a radiographic image of some form of mesh pattern in contact with the test pattern. The interested reader is referred to the reference section for a list of publications which provide further details.
- 4.10 UNIFORMITY OF SCREEN SPEED**
- 4.10.1 Objective of Test:** To determine the uniformity of radiographic speed of cassette/screen combinations as routinely used within the department.
- 4.10.2 Recommended Test Equipment:** To perform the uniformity of screen speed test a master radiographic cassette/screen combination (required for each class of cassette/screen combination as used in the department), radiographic film, lead markers for test film identification and Data Form RF 18 will be required. The availability of a densitometer for measurement of test film densities is also required.
- 4.10.3 Testing Frequency:** Routinely performed on an annual basis and upon acquisition of any new cassette/screen combinations.
- 4.10.4 Test Procedure**
1. Select a radiographic room for carrying out the test. A system in which a target to tabletop distance of 50 in can be obtained is to be preferred.
 2. Center the x-ray tube longitudinally and transversely with respect to the tabletop.
 3. Adjust the light localizing collimator to provide a radiation field of approximately 10- x 10 in at the tabletop (Fig. 34).
 4. Select one cassette/screen combination of a given speed range as the "master" cassette for the group of cassette/screen combinations to be tested and identify as such.

5. Place the master cassette on the tabletop centered on the projected light field.
6. On the x-ray generator select 60 kVp and an mAs of approximately 2 to 5 mAs.
7. Make a radiographic exposure and process the film.
8. Measure the central density of the processed film. From the density of the processed film and the mAs used, determine the mAs which will yield a film density in the range of 1.3 to 1.8.
9. Set this mAs in the x-ray generator.
10. Reposition the master cassette/screen combination on the tabletop so that a portion of the cassette is in the upper right quadrant of the light field as you face the table. Place a lead marker "R" in the center of the quadrant on top of the cassette. On the data form, record the identifying number of the master cassette.
11. Select three additional cassettes from the group to be tested and position on the tabletop so that corner of each cassette is contained within the remaining light field quadrants. On the surface of each cassette place a sequential lead number and record this number as test film number in the data form along with cassette/screen identity number.
12. Make a radiographic exposure and process the test films.
13. Measure the central density on each test film and record on the data form.
14. Repeat the test for all other cassette/screens in the group under test. In each group of four test films, make sure to include the master cassette/screen for reference purposes.

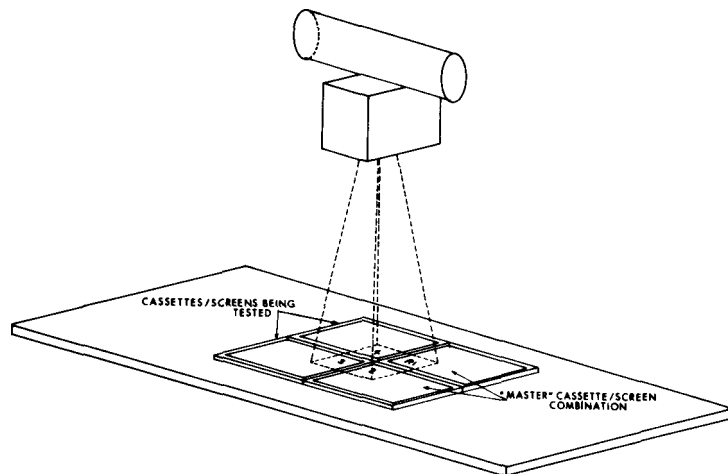


Figure 34. Illustration of equipment set up for performing uniformity of screen speed test.

- 4.10.5 **Documentation of Test Results:** On the data form as illustrated in Figure 35, record the measured central film density for each test film series next to the cassette/screen identification number and test film identification number.

UNIFORMITY OF SCREEN SPEED

DATA FORM RF 18

Date: 6-3-78

X-ray Equipment Used for Test: General Radiographic CGH 2209

Technique Factors: 60 kVp 100 mA .010 Time

Processor Used for Processing Test Films: Pako XR

Processing Parameters: 1.14 Speed 2.25 Contrast .17 Base/Fog

Screen Type: X-omatic Reg. Film Type Used for Test: XRP-1

Cassette Type: X-omatic ~~xMasterxScreens/x~~

Master Cassette/Screen Identification: R-1

Cassette Identification	Test Film Identification	Measured Optical Density (D_i)	$D_i/\bar{D}_R$
B-12	R-1	1.51	1.02
G-18	2	1.37	.93
G-16	3	1.32	.89
G-17	4	1.15	.78
B-2	R-2	1.47	.99
G-20	5	1.42	.96
G-19	6	1.36	.92
G-13	7	1.29	.87
B-2	R-3	1.46	.99
G-1	8	1.51	1.02
G-7	9	1.45	.98
G-6	10	1.43	.97
B-2	R-4	1.53	1.03
G-4	11	1.50	1.01
G-10	12	1.47	.99
G-2	13	1.41	.95
B-2	R-5	1.46	.99
G-11	14	1.54	1.04
G-3	15	1.39	.94
G-12	16	1.37	.93
B-2	R-6	1.46	.99
F-24	17	1.49	1.01
G-8	18	1.45	.98
G-5	19	1.40	.95
B-2	R-7	1.46	.99
G-14	20	1.52	1.03
G-13	21	1.40	.95
G-19	22	1.47	.99
Average Density For All Master Cassette Films: $\bar{D}_R$		1.48	

Remarks/Comments: Cassette #G-17 outside of acceptable tolerance. Returned to manufacturer for replacement.

Signature _____

Figure 35. Example of data form to be used for recording test results illustrating representative data obtained.

- 4.10.6 **Interpretation of Test Results:** For the group of cassettes/screens tested determine the average film density of all master cassette/screen test films. Record this value on the data form. For all other cassette/screens measured in the test, calculate the ratio

$$D_i/\bar{D}_R$$

where D_i is the central film density of the given test film and $\bar{D}_R$ is the average value of the central density of all master cassette/screen test films. Record the ratio on the data form. For any given cassette/screen with a given class of screen speed the ratio $D_i/\bar{D}_R$ should fall within the range of .85-1.15. For any cassette/screen which does not fall within this range corrective action is required.

4.10.7 Action Limits and Corrective Action: (These limits are indications for action only, and do not necessarily indicate non-compliance with any applicable standards. A test result exceeding these action levels should be verified by retesting prior to further action.) Any individual cassette/screen within a given speed group which does not meet the above criteria should be checked to try to determine the cause of the problem. One obvious item to check for is misidentification of a cassette with respect to the type of screens which are contained in it. Poor film screen contact is another likely cause. Also, if screens of the same speed are contained within cassettes of different manufacturers it is possible that variations in attenuation of the cassette front can cause significant variations in film density. Should no identifiable cause for density variation be determined it is reasonable to replace the cassette/screen in question.

4.10.8 Test Procedure Limitations: The test procedure described above is a purely relative test relying on referencing all measurements to that of the master cassette. It is therefore very important to include the master cassette in all tests. Also, variations in x-ray exposure output of the x-ray generator can cause problems from one group of four cassettes/screens to the next. To overcome this problem choose an x-ray system which has been previously tested for exposure reproducibility and employ low mA values and the longest practical exposure times. The uniformity of the radiation field is important and for this reason a long source-to-cassette distance and use of the central portion of the field is of considerable importance.

The radiographic film used will in itself exhibit certain normal variations in density for a constant exposure even if all film is from the same box. These variations are usually small and are compensated for to some extent in averaging the density of the master cassette/screen test films. Also, to minimize processor variations all test films must be processed in the same processor over a reasonably short period of time.

4.10.9 Alternate Test Procedures: No alternative test procedure for uniformity of screen speed is known which is suitable for routine quality assurance procedures.

4.11 UNIFORMITY OF RADIOGRAPHIC ILLUMINATORS

4.11.1 Objective of Test: To determine the uniformity of radiographic illuminators used for viewing radiographs.

4.11.2 Recommended Test Equipment: Shown in Figure 36 is the equipment recommended for performing this test. In addition to the equipment shown, Data Form RF 19 is required.

4.11.3 Testing Frequency: Routinely tested at 6-month intervals, and following any light bulb replacement.

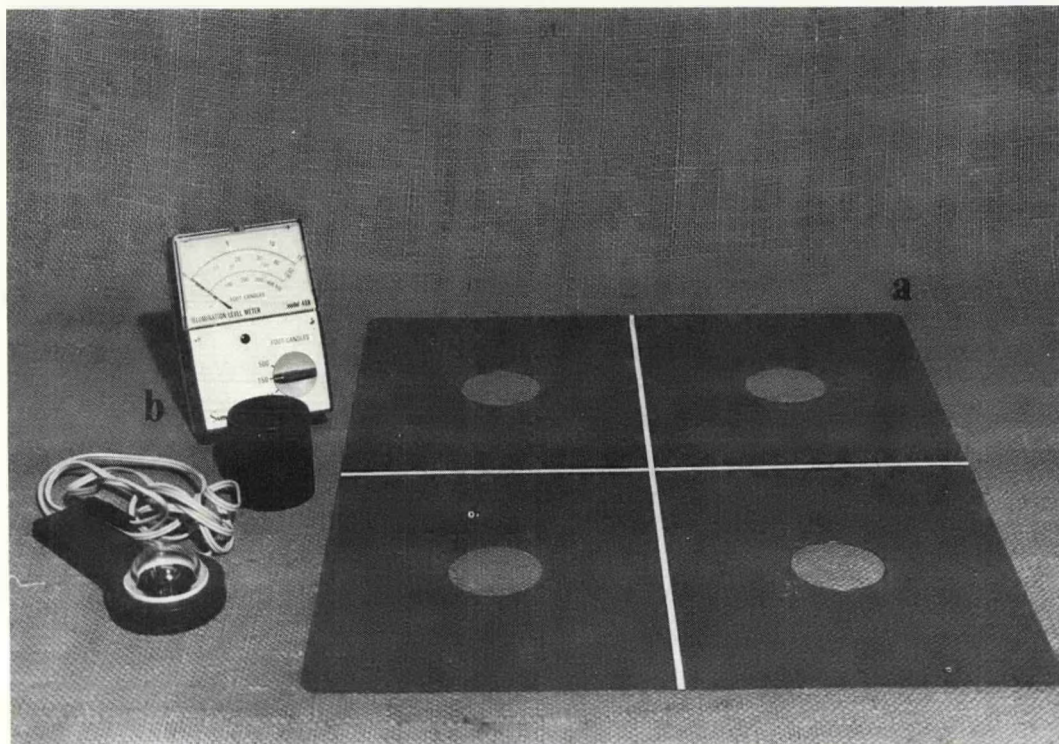


Figure 36. Recommended equipment for performing radiographic illuminator uniformity test: a. radiographic illuminator measuring mask; and b. Simpson 408 foot candle illumination level meter.

4.11.4 Test Procedure

1. Place the 14- x 17-in film mask on the radiographic illuminator to be measured. This mask contains a series of positioning guides for the light meter and defines the numerical indication of measurement to be made in each of the radiograph illuminator's quadrants (Fig. 37).
2. Starting with quadrant 1, position the sensing assembly of the illuminator meter in contact with the viewbox. Note the reading on the scale of the illumination meter and record on the data form.
3. Repeat the above measurement for the other quadrants of the viewbox and record the readings.
4. Repeat #1, #2, and #3 for all other viewboxes to be tested and record the appropriate data.

4.11.5 **Documentation of Test Results:** The measured data should be recorded for all radiographic illuminators tested as indicated on the data form as illustrated in Figure 38. As most radiographic illuminators will be located clustered in different areas around the department, it is wise to separate the illuminators into identifiable groups by the common use and then number them within a group.

4.11.6 **Interpretation of Test Results:** In reviewing the data for a given group of radiographic illuminators, determine the average illumination level for each illuminator (defined as the average value of the illumination level for the four

quadrants) and the average illumination level for the entire group of illuminators (defined as the average value of the average illumination level of the individual illuminators). Record these values on the data form. For each illuminator, determine the maximum variation in the illumination level between quadrants defined as

$$(I_{\max} - I_{\min}) / (I_{\max} + I_{\min})$$

and determine the maximum deviation between the averages of the individual illuminators defined as

$$(\bar{I}_{\max} - \bar{I}_{\min}) / (\bar{I}_{\max} + \bar{I}_{\min}).$$

Record the results on the data form.

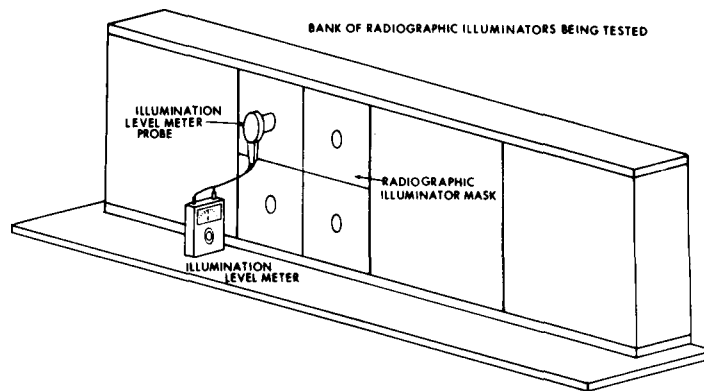


Figure 37. Illustration of equipment set up for performing test.

- 4.11.7 Action Limits and Corrective Action:** (These limits are indications for action only, and do not necessarily indicate non-compliance with any applicable standards. A test result exceeding these action levels should be verified by retesting prior to further action.) In reviewing the radiographic illuminator, data maximum acceptable variations of illumination levels between individual quadrants in a given illumination should not exceed 10 percent. Within a given group of radiographic illuminators, the maximum deviation should not exceed 15 percent. Group to group variations within the department should not exceed 20 percent. If these levels of deviation are exceeded, take corrective steps to determine the cause. The most frequent causes of unacceptable radiographic illuminator performance include the use of more than one type of fluorescent light, lack of cleaning of internal or external illuminator surfaces, and discoloration of external illuminator surfaces with age.
- 4.11.8 Test Procedure Limitations:** In that the radiographic illuminator test procedure describes a relative test it is essential that the maximum of consistency be used in performing all measurements. The illuminator mask is incorporated in the test to help minimize positioning variations. Also, the illumination level may change slightly once it has stabilized after being turned on. To help minimize this variation always allow the illuminator to stabilize for approximately 2 minutes after being turned on before making measurements.
- 4.11.9 Alternate Test Procedures:** All common test procedures employed for measurement of radiographic illuminator uniformity employ some form of light meter and are thus similar to the one desired. Variation of the test procedure may be found in the cited references.

DATA FORM RF 19

Date: 9-27-77

Location of Radiographic

Illuminator Group Tested: Pediatric Reading Room

Light Bulb Type Used In Illuminators: Daylight

Light Meter Used For Test:

Simpson 408

Figure 38. Example of data form to be used for recording test results illustrating representative data obtained.

For a diagnostic radiologic facility, implementation of the procedures described in this manual should improve the consistency with which adequate information is obtained from roentgenographic images. This objective is the most important purpose of a quality assurance program, because the absence of adequate information may be difficult to identify (i.e., it is difficult to assess what information is missing on a roentgenogram) and yet may have serious consequences to the patient. The degree to which this important objective of improved diagnostic information is attained is difficult to evaluate because the interpretation of the information is subjective, as are the benefits of improved diagnostic information to the referring physician and patient. However, certain other important

benefits of a quality assurance program can be evaluated in terms of dollars and patient exposure saved by the diagnostic radiologic facility each year. One of these benefits is the reduction in roentgenographic retakes accomplished by implementation of a quality assurance program.

To estimate the minimum cost savings associated with a reduction in retakes in a diagnostic radiologic facility, the following example may be helpful.

EXAMPLE

A diagnostic radiologic facility conducts 80,000 examinations per year with an 11 percent retake rate. The facility operates with an annual budget which includes 300,000 sq ft of film at a cost of \$0.60/sq ft and an appropriation of \$17,000 for film and processing chemistry. By implementation of a comprehensive quality assurance program, the retake rate is reduced to 5 percent. What are the estimated cost savings in film and processing chemistry alone?

With 300,000 sq ft of film used for 80,000 exams and a retake rate of 11 percent, the average square footage of film per examination excluding retakes is:

$$\begin{aligned} & (300,000 \text{ sq ft}) / (1.11)(80,000 \text{ exams}) \\ & = 270,000 \text{ sq ft} / 80,000 \text{ exams} \\ & = 3.38 \text{ sq ft/exam at a retake rate of 11 percent.} \end{aligned}$$

The cost of the retakes is $(300,000 - 270,000) \text{ sq ft} \times \$0.60/\text{sq ft} = \$18,000$ for film and $(\$17,000 - \$17,000/1.11) = \$1685$ for film chemistry. With reduction of the retake rate to 5 percent, the square footage of film required is $(270,000 \text{ sq ft})(1.05) = 283,500 \text{ sq ft}$, and the film cost for retakes is $(283,500 - 270,000) \text{ sq ft} \times \$0.60/\text{sq ft} = \$8100$ at a retake rate of 5 percent, the processing chemistry costs for retakes is

$$\$17,000 (1.05/1.11) - \$17,000/1.11 = \$766.$$

The film and film chemistry cost savings accomplished by reducing the retake rate from 11 to 5 percent is

$$\$18,000 + \$1685 - \$8100 - \$766 = \$10,819.$$

These cost savings do not include other important improvements accomplished by the quality assurance program such as consistent high quality roentgenographic images, improved patient flow, reduced manpower requirements, decreased equipment loading and breakdowns in the department, and reduced exposure of patients to radiation.

Balanced against the cost savings is the expense of implementing a quality assurance program in a diagnostic radiologic facility. This expense fluctuates widely depending on the level and management of the quality assurance program performed for the facility. For the program outlined in this manual together with a quality control program for automatic film processors, the cost may be estimated as shown below for a typical radiologic facility consisting of three general purpose radiographic units, two general purpose fluoroscopic units, one tomographic unit, one special procedures laboratory, three mobile x-ray units (two radiographic and one fluoroscopic), and emergency and operating room facilities equipped with radiographic x-ray equipment:

Approximate test equipment cost (assuming 5-year life)	\$ 950/year
Labor costs (55 man-hrs/month at \$6.25/hr)	4125/year
Supplies and expendables	<u>1700/year</u>
Total Cost	\$6775/year

Approximate annual costs of a quality assurance program = \$6,050. From the preceding example, a net cost savings of \$10,819 - \$6775 - \$4044 is accomplished by the quality assurance program based solely on reduction in the rate of retakes from 11 percent to 5 percent. This estimate of cost savings would be even more substantial if additional cost factors such as reduced use, and hence prolonged life, of x-ray equipment could be considered quantitatively. Also, improved and less costly servicing of radiologic equipment should be achievable with a quality assurance program for diagnostic radiologic equipment.

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Molar, C. Problems associated with quality assurance in diagnostic radiology.

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Gross, R.E. and W. S. Properzio. Quality assurance in diagnostic radiology - what needs to be done? Presented at 21st Annual Meeting of the Health Physics Society, July 1976.

Haskin, M.E. Our concept of quality control. Proceedings of the Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine, IV, September 25-27, 1975 (Vol. 70).

Quality control is an objective system designed to determine that the performance of components in a radiology system is or is not labeled by the manufacturer. It is suggested that the most opportune time to start a quality assurance program is after installation of a new room is complete and before the room is formally accepted and payment made. Important considerations for generator quality assurance include KW rating, kVp, timing and mA.

Hendee, W.R. and R.P. Rossi. Performance specifications for diagnostic x-ray equipment. Radiology 120:409-412 (1976).

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Oregon State University, The X-Ray Science & Engineering Laboratory. Course manual for x-ray applications (O.S.U.Course GS-463). HEW Publication (FDA) 73-8028 (January 1973).

A course manual for study in radiologic science and engineering which includes both text and laboratory exercises. Material covered includes: x-ray film, latent image formation, x-ray film processing, sensitometric properties of x-ray film, x-ray screens, radiographic definition, x-ray grids, medical radiography, dental radiography, industrial radiography, research application of x rays, analytical and special industrial uses of x rays and x-ray therapy.

Oregon State University, The X-Ray Science and Engineering Laboratory. Course manual for x-ray measurements (O.S.U.Course GS-462). HEW Publication (FDA) 73-8027 (January 1973).

A course manual for study in radiologic science and engineering which includes both text and laboratory exercises. Material covered includes: interaction of x rays with matter, attenuation of x rays, radiation quarters and units, x-ray detection, gas ionization instrumentation, energy dependence of ionization chamber instruments, survey meter response time, x-ray beam factors, personnel monitoring devices, chemical dosimetry, thermoluminescent dosimetry, correlation of exposure and absorbed dose, x-ray shielding and radiation protection surveys.

Oregon State University, The X-Ray Science and Engineering Laboratory. Course manual for machine sources of x rays (O.S.U. Course GS-461). HEW Publication (FDA) 73-8026 (January 1973).

A course manual for study in radiologic science and engineering which includes both text and laboratory exercises. Material covered includes: fundamental atomic structure, history and properties of x ray, x-ray production, transformers, basic x-ray circuit,

rectification, poly-phase, high frequency and other modern x-ray generators, x-ray timers, x-ray tubes, fluoroscopy, industrial x-ray equipment, megavolt x-ray sources and biological effects of radiation.

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The authors described their experiences in the acceptance testing of five generator models produced by four manufacturers. A total of 14 new installations were included in the study. Several problems were discovered after the vendor had installed the equipment and certified it for clinical use. The authors concluded that the presence of these malfunctions indicate a need for revisions of the manufacturer's installation and setting instructions.

Siedband, M.P. and R.R. Allen. First-level quality control methods for diagnostic radiology. Applied Radiology 5:93-97 (May/June 1976).

Radiologic x-ray technologists can perform a series of tests to ensure proper performance of radiographic apparatus. Testing at this first level should be kept simple, and should be on a pass-fail basis; in addition, it must not involve dismantling of the equipment. In order to be effective, testing must be done routinely to discover system degradation before its effects appear in the radiographs. An effective program will have the enthusiastic support of radiologists and technologists alike. The series of tests in use at the University of Wisconsin Medical Center is described herein.

Simons, A.D. A quality control program for a diagnostic radiology department. Master's Thesis, University of Miami (1974).

The author describes a quality control program involving minimal equipment which he suggests can be performed by the average technologist. Tests for processors, effective focal spot size, light beam/x-ray beam congruency, total filtration, linearity of mAs, and kilovoltage are discussed.

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This course discusses the various parameters which influence the quality of the radiographic image. Discussion of image receptors, generator performance, radiographic technique and viewing conditions is included. Selected quality assurance procedures are also discussed.

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The University of Minnesota Hospitals program for monitoring the output of radiographic systems is discussed. Four methods (step-wedge, pocket dosimeter, digital dosimeter, and Machlett dynalyzer) are evaluated. Recommendations are made as to which of these methods should be used by the staff technologist, physicist, and service engineers.

Taylor, K.W. Quality control in a large teaching hospital. Proceedings of Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine, IV, 70:146-150 (1975).

The author stresses the need to select for monitoring in a quality assurance program only those variables which have definite impact, either economical or in terms of improved image quality. In particular, the measurement of x-ray waveforms is suggested as being a valuable but overlooked technique. A method of measurement and interpretation of

the waveforms is discussed. A discussion of other possible measurements and their value is given. The author concludes by stating that his facility feels that appointment of a full time senior technician for quality control purposes is justified for their 1200 bed facility.

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U.S. Department of Health, Education and Welfare, PHS, FDA, Bureau of Radiological Health. Quality control in medical x-ray. *Proceedings of the Radiological Health Section of the American Public Health Assoc. Meeting*, HEW Publication (FDA) 74-8002 (1972).

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Vucich, J.J. Quality assurance: a fundamental whose time has come. *Proceedings of the Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine, IV*, 70:138-144 (1975).

Walker, Jr., W.J. A program for diagnostic x-ray quality assurance in the hospital radiology department. *Proceedings of Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine, IV*, 70:151-153 (1975).

Winkler, N.T. Quality control in diagnostic radiology. *Proceedings of the Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine, IV*, 70:125131 (1975).

LIGHT LOCALIZER

Doering, M.D., K.E. Weaver, C.K. Showalter and E.W. Denny. The response of direct print paper to x radiation. *Proceedings of the Health Physics Society Seventh Midyear Topical Symposium*, pp. 431 (1972).

Penn, C.A. and R.T. Mooney. Simple photometer for federal x-ray standard light localizer compliance testing. *Health Phys* 29:347-348 (1975).

U.S. Department of Health, Education, and Welfare. Direct-print paper: a new material for x-ray imaging. HEW Publication (FDA) 72-8013 (1971).

EXPOSURE TIMERS

Goldberg, R.M. A portable instrument for measuring the exposure time of diagnostic radiologic equipment. *Health Phys* 27:399-400 (1974).

Lott, S.H. and J. Pagel. Measurement of timer accuracy on x-ray machines. *Proceedings of the Health Physics Society Seventh Midyear Topical Symposium, Health Physics in the Healing Arts*, pp. 415-418 (1972).

X-RAY TUBES

Machlett Laboratories, Inc. How to get maximum life from your rotating-anode x-ray tubes.

An excellent discussion of the factors which influence the performance and life of x-ray tubes. The principles of extending tube life are discussed with particular emphasis on anode ratings, anode heat storage capacity, beaming wear, housing heat capacity and filament characteristics.

Machlett Laboratories, Inc. "Trade-offs" a guide to the selection of diagnostic x-ray tubes.

This guide covers the practical considerations for selection of x-ray tubes for use in diagnostic radiology. Target angle vs. field coverage, focal spot size vs. geometric unsharpness, and anode size and speed vs. thermal capacity are among the topics discussed.

Wallace, R.J. Diagnostic x-ray tube failure and prevention. *Radiol Technol* 48 (No. 5):565-570 (1977).

The radiologic technologist is educated in the composition and function of the x-ray tube. He also has the responsibility of tube protection. This paper describes common causes of tube failures and lists specific preventive measures that should be taken to prolong the life of the x-ray tube.

FOCAL SPOTS

Bernstein, H., R.T. Bergeon and D.J. Klein. Routine evaluation of focal spots. *Radiology* III:421-425 (May 1974).

The star test pattern is the optimum method for routine quality control investigations of focal spots since its radiographic image patterns are directly related to the resolution capability of the tube. The pinhole image of the focal spot can also be used. The two methods are compared. Both methods were used to study "blooming" from tube current. The extent to which target resolution capability may be degraded by heat was evaluated. Data indicate that the heat which results from operating the tube within approved load conditions causes no detrimental effects on resolution capability; in fact, the focal spot size decreases slightly. No deterioration is produced in serial radiography.

Hendee, W.R. and E.L. Chaney. X-ray focal spots: practical considerations. *Applied Radiology*, pp. 25-29 (May/June 1974).

Some important clinical considerations for x-ray focal spots are discussed, including selection criteria, measurement techniques, industry standards, purchaser specifications and variations in focal spot size with tube operating conditions.

Perry, J.T. Measurement and characteristics of rotating anode x-ray tube focal spots. Presented at the Eleventh Annual Meeting of the American Society of Neuroradiology, April 26-28, 1973. Published by EIMAC Division of Varian.

Rao, G.U.V. The importance of focal spot characteristics in clinical radiography. *Proceedings of the Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine III*, 47:214-217 (1974).

Spiegler P. and W.C. Breckinridge. Imaging of focal spots by means of the star test pattern. *Radiology* 103:679-684 (March 1972).

Zermeno, A. Measurement of focal spot size and distribution. *American Association of Physicists in Medicine Summer School*, July 27 - August 1, 1975, pp. 71-74.

EXPOSURE REPRODUCIBILITY, EXPOSURE LINEARITY AND BEAM QUALITY

Ardran, G.M. and H.E. Crooks. The measurement of inherent filtration in diagnostic x-ray tubes and the effect of target angle on x-ray quality. *Br J Radiol* 45:599-602 (August 1973).

Capintec, Inc. A diagnostic x-ray quality control program.

Unnecessary multiple or repeat diagnostic x-ray studies result in needless patient and personnel radiation exposure. To reduce exposure and increase patient flow, variations in kVp and mAs which cause film density and contrast problems, should be determined for every diagnostic x-ray machine. Consequently in order to eliminate this problem a diagnostic quality control program and an inexpensive dosimetry system which permits accurate and routine evaluations of diagnostic x-ray equipment by relating variations in exposure to kVp and mAs was developed. The diagnostic x-ray quality control program can be implemented without interrupting normal departmental operations and is easily run by existing personnel. The program is divided into three stages and requires approximately thirty minutes per x-ray equipment. Details of the program are presented.

Jennemann, P.V. Diagnostic x-ray quality assurance procedure. *Keithley Instruments, Inc.* (1976).

The dosimeter, long thought of as an instrument for only the radiation physicist, is now a required tool for the Service Engineer and is becoming a necessary instrument in a busy diagnostic radiology department.

Radiologic technologists, service engineers, and physicists have discovered that invaluable information can be gained with several rapid and relatively easy tests. This information can insure an accurate and stable base for the radiologic technologist, thus reducing the number of repeated radiographs because of improper quantity and/or quality of x-ray exposure. The following information can be obtained with a series of exposures:

1. Consistency/reproducibility.
2. mA-time reciprocity.

3. Timer accuracy/tracking.
4. Output compared to a "standard" unit.

The following tests are performed:

1. All mA stations - fixed time (1/10 sec.) at 60 kVp, and 100 kVp. If the generator being tested has continuous mA or mAs selection, select 8 values between 5 mAs and 100 mAs.
2. Timer Selections - at 80 kVp using the lowest mA on the large focal spot make exposures at 10 to 15 selections between 0.008 seconds and 0.50 seconds and at 0.75, 1.0, 2.0, 3.0, and 4.0 seconds.

Shapiro, J.S., A.J. Pellegrino and V. Berluti. Application of dynalyzer II to x-ray quality control. Proceedings of the Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine, V, 96:37-42 (1976).

Starchman, D.E. and R.G. Johnson. Expanded role of health physics survey in evaluating operations and radiation safety of medical x-ray units. Presented at the 19th Annual Meeting of the Health Physics Society, Medical Health Physics Session (July 7-11, 1974).

Starchman, D.E., R.G. Johnson and W.J. Howland. Linearity of exposure with indicated time and current for diagnostic radiography units. Radiology 122:489-492 (February 1977).

The authors emphasize the importance of the reciprocity between the time and current control values to the maintenance of reliable radiographic technique. A method which permits determination of the variation of mR/mAs for the diagnostic range of times and currents in about one hour per unit is discussed. Results using this method with nearly 300 radiographic and fluoroscopic units are presented and show that mR/mAs with newly installed units can vary as much as + 50 percent. Sixty-two percent of the fixed radiographic units tested exceeded the acceptable + 10 percent variation. The need for regular checks was illustrated by the results from one machine which showed that the variation increased from + 6 to + 53 percent in one year. The authors demonstrate that such variation can significantly affect diagnostic information and thus will lead to masking of pathology and an increase in retake rates if not controlled.

Tuohy, J.B. and D. Reekie. A portable instrument for the measurement of single-phase radiographic x-ray tube currents. Phys Med Biol 19:101-104 (January 1974).

An instrument for the measurement of exposure current is described. The principle of operation involves an externally attached coil which measures the magnetic field created about the cable bearing the exposure current from an x-ray generator. This allows measuring the current parameter without the need of disrupting the circuit by inserting a meter.

U.S. Department of Health, Education and Welfare. Integrating milliamperere-seconds meter. HEW Publication (FDA) 73-8004 (July 1972).

KILOVOLTAGE

Brening, J.R. Testing x-ray equipment by examining emitted x-rays. Radiography 25:199-210 (1959).

Simple methods of examining the distribution in space, time and energy of the x rays emitted by x-ray equipment are described, which make it possible to determine the size, shape, position and structure of the focal spot, the condition of the target of both stationary and rotating anodes, the condition of the filament in therapy tubes, the

accuracy of timers, the condition of rectifiers, the adequacy of filament boost, the phase of contactor make and break, the presence of contactor bounce or electrical transients, faults in stabilizers, the adequacy of smoothing condensers, the effects of cable capacitance, the peak kilovoltage and voltage drop under load.

Cooke, R., K. Weaver and C. Showalter. A method for field measurement of diagnostic x-ray tube potential. Presented at 15th Annual Meeting of the American Assoc. of Physicists in Medicine, July 30 - August 2, 1973.

A technique for determining the kVp of an x-ray generator for x-ray attenuation measurements is described. Using an ionization chamber and suitable thickness of vanadium attenuators the authors showed that kVp can be estimated to within $\pm$ kVp from the measurement of an effective attenuation coefficient of a heavily filtered x-ray beam.

Giarratano, J.C., R.G. Waggener, J.M. Hevezi and R.J. Shalek. A comparison of high voltage bleeder resistance, modified Ardran-Crooks cassette, and Ge(Li) spectrometer methods to determine the kVp of diagnostic x-ray units. *Med Phys* 3:142-148 (May/June 1976).

The relative advantages of several methods for determining the kVp of single-phase and three-phase diagnostic x-ray units in both the radiographic and fluoroscopic mode are discussed. The use of a high voltage bleeder resistance with oscilloscope display allows viewing the waveform directly. Digital display of the voltage via a multichannel analyzer in conjunction with a high voltage bleeder resistance was said to be the most accurate and reproducible method. A version of the Ardran-Crooks cassette technique provides the greatest economy and ease of operation of the methods examined. A Ge(Li) spectrometer method allowed visualization of the x-ray spectrum.

High, M.D. and L.N. Rothenberg. Extensive evaluation of commercially available kVp cassettes. Presented at 19th Annual Meeting of American Asso. of Physicists in Medicine, July 31 - August 4, 1977.

The verification of x-ray generator kilovoltage calibration by invasive techniques is unsuitable for use in a quality assurance program. Noninvasive techniques employing some form of penetrometer has found wide acceptance. Three such devices which are commercially available were evaluated. The authors conclude that these devices are accurate to within ± 3 kVp and have a precision on the order of ± 1.5 kVp.

Jacobson, A.F., J.R. Cameron, M.P. Siedband and J. Wagner. Test cassette for measuring peak tube potential of diagnostic x-ray machines. *Med Phys* 3:19-25 (January/February 1976).

Rauch, P.L., E.L. Chaney, P.L. Carson and W.R. Hendee. Absolute kilovoltage calibration of a diagnostic x-ray generator. *Med Phys* 2:1-4 (January/February 1975).

A method for absolute calibration of diagnostic x-ray generators is presented and discussed. The method employs a Ge(Li) detector and relies on the direct observation of the onset of fluorescence radiation from scattering foils placed in the primary beam.

Starchman, D.E., R.G. Johnson, D.L. Hykes and W.J. Howland. The role of kVp accuracy of diagnostic x-ray units and other performance parameters in quality assurance. *Proceedings of Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine*, V, 96:31-36 (1976).

Zermeno, A. Measurement of kV, mA, and time. The Expanding Role of the Diagnostic Radiologic Physicist, American Association of Physicists in Medicine Summer School, July 27-August 1, 1975, pp. 67-70.

A brief review of various techniques for calibrating and/or checking the calibration of kVp, mA and time for diagnostic x-ray units.

AUTOMATIC EXPOSURE CONTROL SYSTEMS

Chaney, E.L., W.R. Hendee and D.L. Hare. Performance evaluation of phototimers. *Radiology* 118:715-717 (March 1976).

Phototimers detect x rays impinging on or emerging from an x-ray film cassette and terminate the exposure after a predetermined amount of radiation has been received from the film. A phototimer must provide reproducible film exposures over a wide range of target-to-film distances, patient thicknesses, and technique variables. A method is needed which verifies the phototimer is functioning properly and identifies exposure techniques and practices which are compatible with its use. Several techniques are presented for evaluating phototimer performance, and data accumulated during application of these techniques to the use of three spot-film phototimers are presented.

Craig, J.R. Characteristics and evaluation of automatic exposure controls. *Proceedings of Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine, IV*, 70:189-195 (1975).

Hare, D.L., W.R. Hendee, R.P. Rossi and E.L. Chaney. Acceptance testing and performance monitoring of radiographic phototimers. *Op Eng* 15:335-337 (July-August 1976).

Hendee, W.R., D. Hare, R.P. Rossi and E.L. Chaney. Field evaluation of radiographic phototimers. *Proceedings of the Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine, IV*, Vol. 70, September 25-27, 1975.

Joseph, E.S. and J.E. Schneble. X-ray automatic exposure timing and control circuitry. *Proceedings of the Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine, IV*, Vol. 70, September 25-27, 1975.

Pei-Jan, P.L. Phototimers, user's point of view. *Proceedings of the Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine, IV*, 70:196-200 (1975).

Stanhope, G.P. X-ray automatic exposure control. *Proceedings of the Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine, IV*, 70:171-175 (1975).

The characteristics of an acceptable radiograph are discussed as preliminary to describing the role of an automatic exposure device in helping to achieve such radiographs. Several design problems associated with automatic exposure devices are also discussed.

SCREENS/CASSETTES/GRIDS

Ardran, G.M., H.E. Crooks and V. James. Testing x-ray cassettes for film-intensifying screen contact. *Radiography* 35:143-145 (June 1969).

The British Standards Institute standard method for testing film screen constant is discussed. The method employs perforated zinc sheets with 2.4 mm diameter perforations with a pitch of 7 per 2.5. cm. It is claimed that test radiographs produced

by the method described demonstrate contact problem easier than conventional wire mesh techniques.

Liebel-Flarsheim Company, Technical Staff. Characteristics and applications of x-ray grids. Liebel-Flarsheim, 111 East Amity Road, Cincinnati, Ohio 45215.

The principles of grid construction and use are presented. Types of grids and significance of grid ratio are explained. Practical considerations in grid selection are discussed. Interested parties may receive quantities of the publication (at no charge) by writing to Liebel-Flarsheim Company.

RADIOGRAPHIC TECHNIQUE

Burger, G.C.E. Phantom tests with x-rays. Philips Technical Review 11:291-298 (April 1950).

Following an introduction concerning the factors affecting an x-ray image, the construction is discussed of some phantoms enabling the merits of various radiologic methods to be compared. Some applications of these phantoms are dealt with; comparisons of the properties of x-ray apparatus in different situations, selector of doctors and others for x-ray screening. Investigation into the influence of enlargement on the x-ray image, and the effect of movement of the object upon the x-ray image. Finally a phantom of smaller dimensions is described which serves for regular checking of radiographs, which is particularly of importance when several radiographs have to be made of the same patient.

Eastman, T.R. Measurement: the key to exposure with manual techniques. Radiol Technol 45:75-78, No. 2 (1973).

Eastman, T.R. Radiographic calibration. E.I. duPont de Nemours and Co., Inc., Photo Products Department, X-ray Technical Service, Wilmington, Delaware.

Eastman, T.R. Technique charts: the key to radiographic quality. Radiol Technol 46:365-368, No. 5 (1975).

Gilbertson, J.D. and A.G. Fingerhut. Standardization of diagnostic x-ray generators. Radiology 93:1033-1036 (November 1969).

Measurements of kVp with a bleeder tank and capacitor divider, mA with high-voltage milliamperage probe, and filament current with a high-voltage current probe were described. These measurements reveal striking differences between machines in the author's x-ray department. The equipment was used further to calibrate kilovoltage and milliamperage to allow producing the same film density and contrast with the same factors by all machines in the department.

Hiss, S.S. Technique management. Radiol Technol 46:369-375 (March/April 1975).

Good technique management is an imperative in modern, efficient departmental routine and patient care. The control of processor efficiency and generator output, along with the production of comprehensive technique charts are factors that contribute to this effective management. They fall well within the responsibility area of the radiologic technologist and require minimal time in department routine.

Kratzer, B. A technique computer: scientific approach to radiologic technology. Radiol Technol 45:142-150, No. 3 (1973).

Pei-Jan, P.L. Penetration quality measurement for standardization of radiographic image quality. Med Phys 2:5-8 (January/ February 1975).

Pei-Jan, P.L. and L.F. Rogers. Simplified method for standardization of roentgenographic image quality using penetration quality measurements. *Am J Roentgenol* 127:659-662 (1976).

The use of the measurement of penetration quality (PQ) for standardization of roentgenographic image quality was studied. Using a cadaver for patient simulation, it was seen that PQ can be used instead of kVp to specify the roentgenographic technique factors. The steps for standardization of roentgenographic techniques with the PQ measurement were given. The validity of the standardization was checked through subjective evaluations by radiologists.

Soila, P. and T. Esko. A test device for radiodiagnostic systems. *Br J Radiol* 38:602-606 (1965).

Trout, E.D. and J.P. Kelley. A phantom for the evaluation of techniques and equipment used for roentgenography of the chest. *Am J Roentgenol* 117:771-776 (April 1972).

Winkler, N.T. A practical water phantom. *Radiol Technol* 35:65-71 (September 1963).

A practical water phantom is described. It is built from inexpensive materials that are readily available to most x-ray departments. The water phantom can be used for various tests including the evaluation of new screen/film and the standardization of radiograph techniques.

ROUTINE EQUIPMENT EVALUATION

Collier, W. C. Routine evaluation of the diagnostic x-ray equipment in a large hospital. *Proceedings of the Health Physics Society Seventh Midyear Topical Symposium, Health Physics in the Healing Arts, December 11-14, 1972*, pp. 163-167.

Morgan, T.J. and L.B. Smith. Test procedures for routine evaluations of diagnostic and fluoroscopic x-ray equipment. *The Expanding Role of the Diagnostic Radiologic Physicist, American Association of Physicists in Medicine Summer School, July 27 - August 1, 1975*, pp. 218-262.

Rothenberg, L.N. Calibration of medical diagnostic x-ray equipment. *Proceedings of the Health Physics Society Seventh Midyear Topical Symposium, Health Physics in the Healing Arts, December 11-14, 1972*, pp. 149-155.

U.S. Department of Health, Education and Welfare. BRH routine compliance testing for diagnostic x-ray systems or components of diagnostic x-ray systems to which 21 CFR subchapter J is applicable. HEW Publication (FDA) 77-8001 (Revised October 1976).

OPERATIONAL ASPECTS OF QUALITY ASSURANCE PROGRAMS

Donohue, D.P. An analysis of radiographic quality. *School of Radiologic Technology, Daniel Freeman Hospital, 333 N. Prairie Avenue, Inglewood, California 90301*.

Edgerton, R.E. Management by commitment: theoretical personnel management. *Radiol Technol* 47:382-384, No. 6 (1976).

Irvine, W.G. Management of the radiographic environment. *Proceedings of the Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine, V, Vol. 96 (September 16-19, 1976)*.

Koenig, G.F. Management of a quality assurance program for a diagnostic x-ray department. Presented at the Fourth International Conference on Medical Physics, July 25-30, 1976.

Nelson, R.E., G.T. Barnes and D.M. Witten. Economic analysis of a comprehensive quality assurance program. *Radiol Technol* 49:129-134, No. 2 (1977).

The quality assurance program at the University of Alabama in Birmingham is briefly reviewed and its economic efficacy examined. The development of the program was the result of the cooperative effort of the quality control technologists, the radiological service engineering staff, and the radiation physicists. Analysis of our film and chemistry consumption before and after the program was established indicates that its implementation has saved the hospital approximately \$27,000 per year after personnel cost for the last four years. A further \$32,000 to \$55,000 savings per year is realized by having in-house rather than contracted service.

Reagan, T.A. DuPont quality assurance program for the radiology department. *Proceedings of the Society of Photo-Optical Instrumentation Engineers, Application of Optical Instrumentation in Medicine, V*, Vol. 96 (September 16-19, 1976).

MULTIPLE TEST PROCEDURES

Barone, G.J. Test method development and utilization. HEW Publication (FDA) 73-8003, Fourth Annual National Conference on Radiation Control, April 30 - May 4, 1972, pp. 70-80.

A description of the Bureau of Radiological Health's program of testing radiographic/fluoroscopic equipment for compliance with the Federal Performance Standard for Diagnostic X-ray Equipment.

Burkhart, R.L. Diagnostic radiology quality assurance catalog. HEW Publication (FDA) 77-8028 (1977).

The catalog describes quality assurance resources presently available to facilities which perform diagnostic radiology. The information was compiled by the Bureau of Radiological Health in order to assist diagnostic radiology facilities in pursuing quality assurance programs; inclusion of an item does not constitute endorsement by the Food and Drug Administration. The catalog has three sections: (1) test devices and services, (2) training courses and materials, and (3) publication.

Rothenberg, L.N. Quality control in diagnostic radiology: physicist/engineers tests. *Proceedings of the International Seminar on Medical Physics*, October 19-22, 1977, pp. 331-357.

U.S. Department of Health, Education, and Welfare. Suggested optimum survey procedures for diagnostic x-ray equipment. HEW Publication (FDA) 76-8014 (July 1975).

The Nationwide Evaluation of X-ray Trends (NEXT) Task Force was formed by a resolution of Workshop Number 3 of the 1971 Conference of Radiation Control Program Directors. Among the objectives for the Task Force was to identify the optimum components of a diagnostic x-ray survey and develop a set of suggested optimum survey procedures. The survey procedures are organized in a way parallel to the compliance regulations of the 1974 revision of Part F of the Suggested Regulations of the Council of State Governments. For each regulation there is given an optimum procedure, and in some cases optional procedures which may be more advantageous to the surveyor to use depending on his experience, availability of equipment, time, etc.

PATIENT EXPOSURE AND RADIATION SAFETY

Church, W.W. and B.M. Burnett. The clinical testing of male gonad shields. HEW Publication (FDA) 76-8025 (1975, Printed February 1976).

Elder, R.L., R.G. Britain and G.J. Barone. Federal performance standards for diagnostic x-ray equipment. Proceedings of the Health Physics Society Seventh Midyear Topical Symposium, Health Physics in the Healing Arts, December 11-14, 1972, pp. 564-567.

Krohmer, J.S. Radiation protection in diagnosis radiology: requirements, modalities, and costs. Proceedings of the Health Physics Society Seventh Midyear Topical Symposium, Health Physics in the Healing Arts, December 11-14, 1972, pp. 175-178.

McCullough, E.C. Exposure requirements in diagnostic roentgenologic procedures. Applied Radiology 5:95-101(January/February 1976).

This paper is intended to provide a detailed discussion of exposure requirements in almost all diagnostic roentgenologic procedures. Topics discussed include radiation limits thought to be "safe;" technical factors which determine patient exposure for a given imaging modality; typical values of radiation exposures for certain diagnostic procedures; and "trade-off" possibilities aimed at reducing patient exposure.

Moseley, Jr., R.D., H.L. Twigg and M. Barnett. How to protect patient and physician during x-ray examinations, Installment 1: Effects of radiation programmed instruction. Am Fam Physician/GP 1:113-128 (January 1970).

Moseley, Jr., R.D., H.L. Twigg and M. Barnett. How to protect patient and physician during x-ray examinations, Installment 2: Responsible use of diagnostic x rays. Am Fam Physician/ GP 1:105-120 (February 1970).

Rosenstein, M. Organ doses in diagnostic radiology. HEW Publication (FDA) 76-8030 (May 1976).

U.S. Department of Health, Education, and Welfare. Gonad doses and genetically significant dose from diagnostic radiology, U.S., 1964 and 1970. HEW Publication (FDA) 76-8034 (April 1976).

U.S. Department of Health, Education, and Welfare. Gonad shielding in diagnostic radiology. HEW Publication (FDA) 76-8024 (Revised June 1975).

U.S. Department of Health, Education, and Welfare. Population exposure to x-rays, U.S., 1970. HEW Publication (FDA) 76-8047 (November 1973).

An extensive compilation of data relating to the exposure of the U.S. population to exposure to medical sources of radiation. Useful estimates of patient exposure for various examinations and anthropometric data.

U.S. Department of Health, Education, and Welfare. Specific area gonad shielding, recommendation for use on patients during medical diagnostic x-ray procedures. HEW Publication (FDA) 76-8054 (August 1976).

U.S. Environmental Protection Agency, Report of Subcommittee on Technic of Exposure Prevention. Background report: recommendations on guidance for technic to reduce unnecessary exposure from x-ray studies in federal health care facilities. Interagency Working Group on Medical Radiation (June 1976).

Recommendations for the reduction of unnecessary patient exposure are presented. Quality assurance programs, equipment operator performance and patient exposure considerations are discussed.

U.S. Environmental Protection Agency. Federal guidance report No. 9, radiation protection guidance for diagnostic x-rays. EPA 520/ 4-76-019 (October 1976).

Recommendations relative to radiation protection are presented. Areas addressed include: prescription of x-ray studies, equipment considerations, radiographic technique and dental radiology. The report was developed for use within the Federal Health Care System but is of value to any diagnostic x-ray facility.

Wochos, J.F. and J.R. Cameron. Patient exposure from diagnostic x rays, an analysis of 1972-1974 NEXT Data. HEW Publication (FDA) 77-8020 (April 1977).

RETAKES

Bourne, D. Repeats—an aspect of department management. Radiography 35:257-261 (November 1969).

Burnett, B.M., R.J. Mazzaferro and W.W. Church. A study of retakes in radiology departments of two large hospitals. HEW Publication (FDA) 76-8016 (July 1975).

Mazzaferro, R.J., S. Balter and M.J. Janower. The incidence and causes of repeated radiographic examinations in a community hospital. Radiology 112:71-72 (1974).

Mazzaferro, R.J., W.W. Church, B.M. Burnett. Retakes in diagnostic radiography. Proceedings of the Health Physics Society Seventh Midyear Topical Symposium, Health Physics in the Healing Arts, December 11-14, 1972, p. 142.

MISCELLANEOUS

Morgan, R.H. and H.E. Chaney. Darkroom practice and unnecessary patient exposure. Radiology 94:236-240 (May 1965).

A study of the practices of darkrooms associated with hospitals and physicians' offices is reported. From a knowledge of the exposure characteristics of test film employed when developed to completion it is estimated that improvements in darkroom technique could reduce patient exposure by 40 percent and the diagnostic quality of films would be improved.

Trout, E.D., J.P. Kelley and V.L. Larson. A densitometer for radiologic use. Radiol Technol 46:90-97, No.2, (1974).

7. LISTING OF QUALITY ASSURANCE TEST EQUIPMENT

Listed below is the quantity and type of equipment used in performing the test procedures described in this manual.

<u>Number Required</u>	<u>Description of Item</u>
1 each	Radiographic beam restriction system test cassette
4 each	Radiopaque markers strips, 3" x ½" x 1/16"
1 each	Set of lead numbers and markers
1 each	Centering and alignment test tool
1 each	6" rule (graduated in 1/16")
1 each	6" ruler (graduated in 1/32")
1 each	12" ruler (graduated in 1/16")
1 each	24" ruler (graduated in 1/16")
1 each	Bubble level
1 each	Plywood board (24" x ½" x 20")
1 each	Digital x-ray generator timer
1 each	Remote detector for digital x-ray generator timer
1 each	Digital x-ray generator timer-remote detector interconnecting
1 each	Cable (12" long BNC-BNC)
1 each	Keithley Model 35050 dosimeter
1 each	Keithley Model 96030 ionization chamber
1 each	Keithley Model 86204 ionization chamber triax cable with 5" aluminum stem, cable length 4'
1 each	Ionization chamber test stand
1 each	LCD digital readout for Keithley dosimeter
1 each	Dosimeter-readout interconnecting cable (12" long banana plug each end)
1 each	Focal spot test tool
1 each	Wide range kVp test cassette
1 each	Grid alignment test tool
1 each	Radiographic automatic exposure control system evaluation phantom (consists of 1 x 2" base section of Plexiglas containing an orientation marker and reference area for density measurements and 4 - 11" x 14" x 2" Plexiglas blocks)
1 each	Ring stand with clamp
1 each	Lead beam stop (8" x 8" x 1/8" lead plate)
1 each	Film-screen contract test pattern
1 each	Simpson Model 408 illumination level meter
1 each	Radiographic illuminator mask

8. CONSTRUCTION DETAILS OF SELECTED QUALITY ASSURANCE TEST TOOLS

This section contains construction details of certain quality assurance test tools used for tests described in this manual. They are provided for those individuals who wish to build or have built the test tools described. In some cases equivalent test tools are available from a number of commercial sources. All test tools shown in the accompanying drawings may be purchased (prices quoted on request) directly from

Bioengineering
University of Colorado Medical Center
4200 East Ninth Avenue
Denver, Colorado 80262

Test tools for which construction details are provided include:

- Radiographic beam restriction system test cassette
- Centering and alignment test tool
- Ionization chamber test stand
- LCD digital readout for Keithley dosimeter
- Focal spot test tool
- Grid alignment test tool
- Radiographic automatic exposure control system evaluation phantom
- Film screen contact test pattern
- Radiographic illuminator mask

DIGITAL READOUT FOR KEITHLEY 35020 DOSIMETER

The Keithley 35020 dosimeter can employ as its readout any suitable $3\frac{1}{2}$ digit voltmeter. However, a very convenient battery operated unit as illustrated in this manual may be easily constructed at nominal cost. The requirements to build this readout include:

- 1 EEP Liquid Crystal Display Digital Panel Meter Design Kit
- 1 Single pole, single throw (SPST) subminiature switch
- 1 Single pole, double throw (SPDT) subminiature switch
- 2 Banana jacks (1 red, 1 black)
- 1 Plastic/metal box for enclosing the meter
- Dry transfer lettering

To construct the readout device begin by assembling the EP meter according to the instructions supplied with the kit. The meter as supplied by the manufacturer has a full scale range of 200 millivolts. It will be necessary to modify the meter to provide a full-scale range of 2.00 volts. The manufacturer's instructions provide detailed information for carrying out this modification.

Using the illustration of the readout found in either tests 4.4 or 4.10 as a guide, cut out the opening for the display, install the switches and banana jacks and letter with the dry transfer lettering. Locate an open area within the box and install the battery holder.

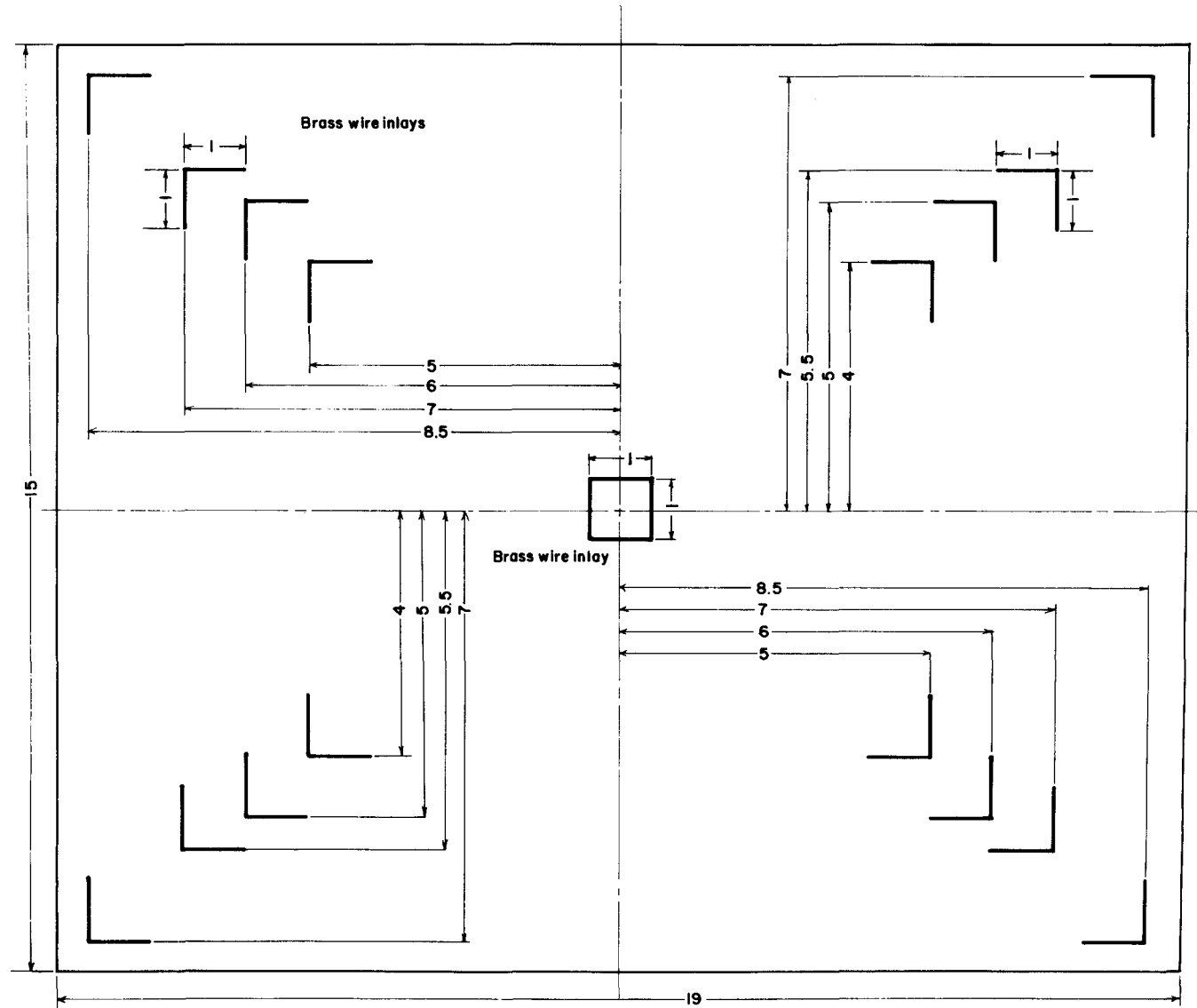
Wire the meter as follows:

- Connect the red banana jack to the "+" signal input on the meter printed circuit board.
- Connect the black banana jack to the "-" signal input on the meter printed circuit board.
- Connect the battery "+" to the "OFF" side of the SPST switch.
- Connect the "ON" side of the SPST switch to the V+point on the meter printed circuit board.
- Connect the battery "-" to the V- point in the meter printed circuit board.
- Connect the center lug of the SPDT switch to the decimal point comma on the meter printed circuit board.
- Set the SPDT switch so that the lever is to the "Rate" position and connect the "tens" decimal point jumper on the printed circuit board to the lug on the SPDT switch which causes the decimal point to illuminate.

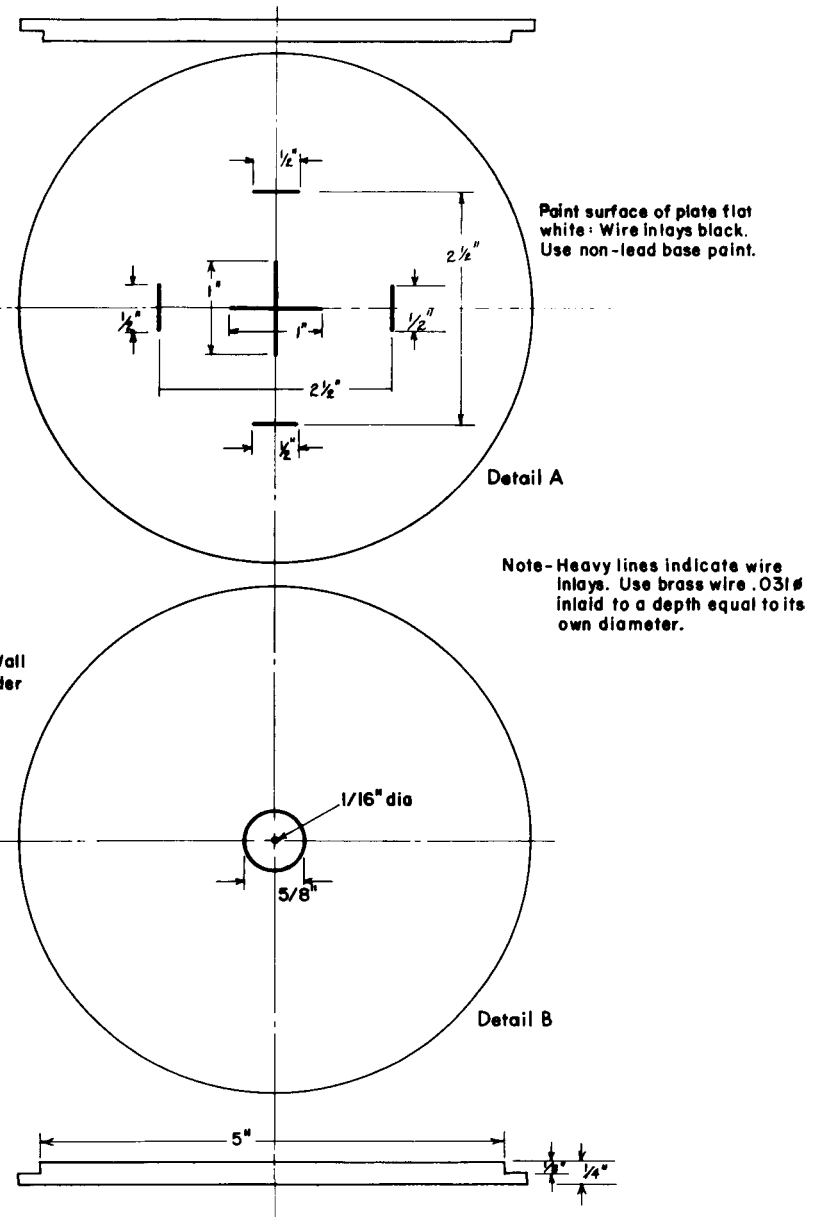
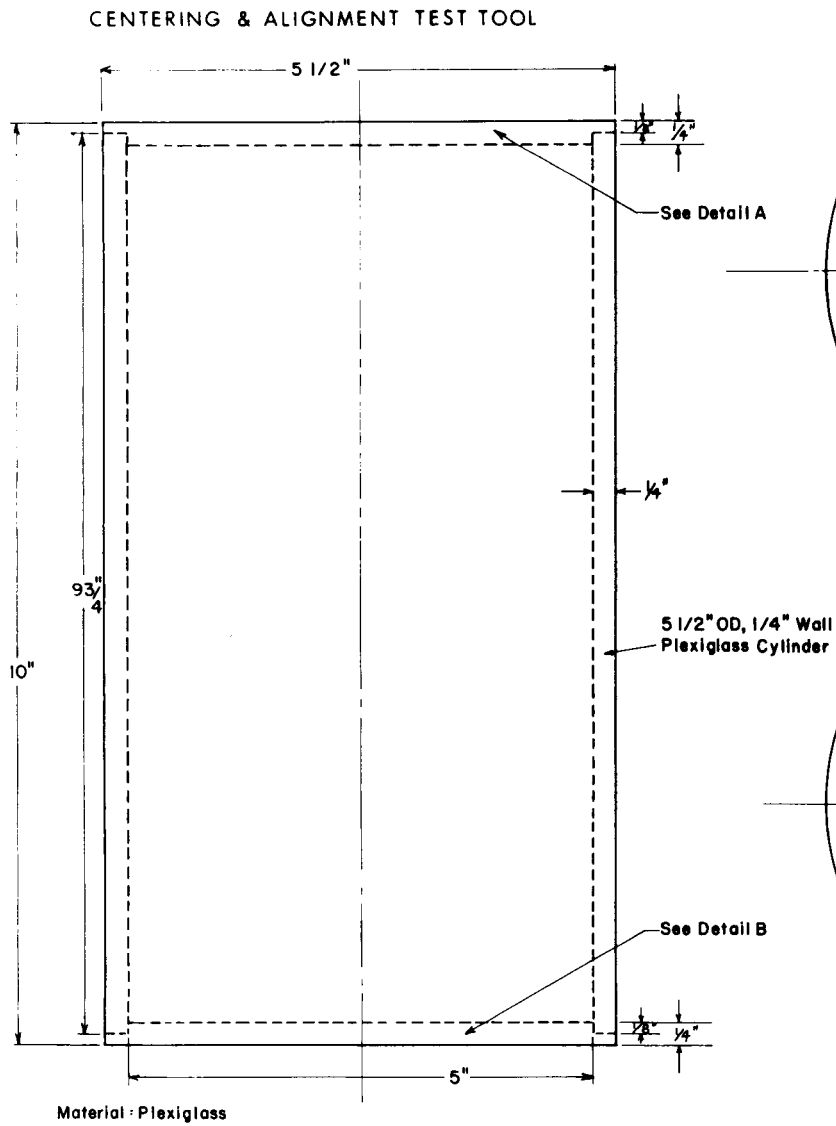
RADIOGRAPHIC BEAM RESTRICTION TEST CASSETTE

Brass wire (1/32" ϕ) pattern inlaid into front surface of radiographic cassette. Use Dupont Cronex cassette with Par Speed screens.

Note: Also required are 4 brass strips, 1/2" x 3" x 1/16" painted flat white.



All Dimensions in inches.



Technical drawing of a Plexiglass Cylinder assembly. The drawing includes the following dimensions and callouts:

- Vertical dimensions on the left: $10 \frac{3}{4}$ and 10.
- Horizontal dimensions at the bottom: $1 \frac{1}{2}$, 4, $2 \frac{1}{2}$, $1 \frac{1}{2}$, and a total of 7.
- Vertical dimensions on the right: $\frac{1}{4}$, $\frac{3}{8}$, and $\frac{1}{4}$.
- Callouts:
 - See Cy
 - See Clamp Detail.
 - 5 $\frac{1}{2}$ " OD, $\frac{1}{4}$ " wall Plexiglass Cylinder
 - See Aperture Detail

Technical drawing showing the front and top views of a square plate with a circular hole.

Front View (Top): A square plate with a side length of 7. A circular hole is centered on the plate. The hole has an outer diameter of $5\frac{1}{2}$ and an inner diameter of $2\frac{1}{2}$. The plate has a thickness of $\frac{3}{8}$.

Top View (Bottom): A square plate with a side length of 7. The hole is centered. The hole has an outer diameter of $5\frac{1}{2}$ and an inner diameter of $2\frac{1}{2}$. The plate has a thickness of $\frac{3}{8}$.

The technical drawing consists of two views of a circular object with a square base.

Top View: A square with a side length of 7. Inside the square are two concentric circles. The outer circle has a diameter of 5 1/2, and the inner circle has a diameter of 2 1/2. Dashed lines indicate the center and the edges of the circles.

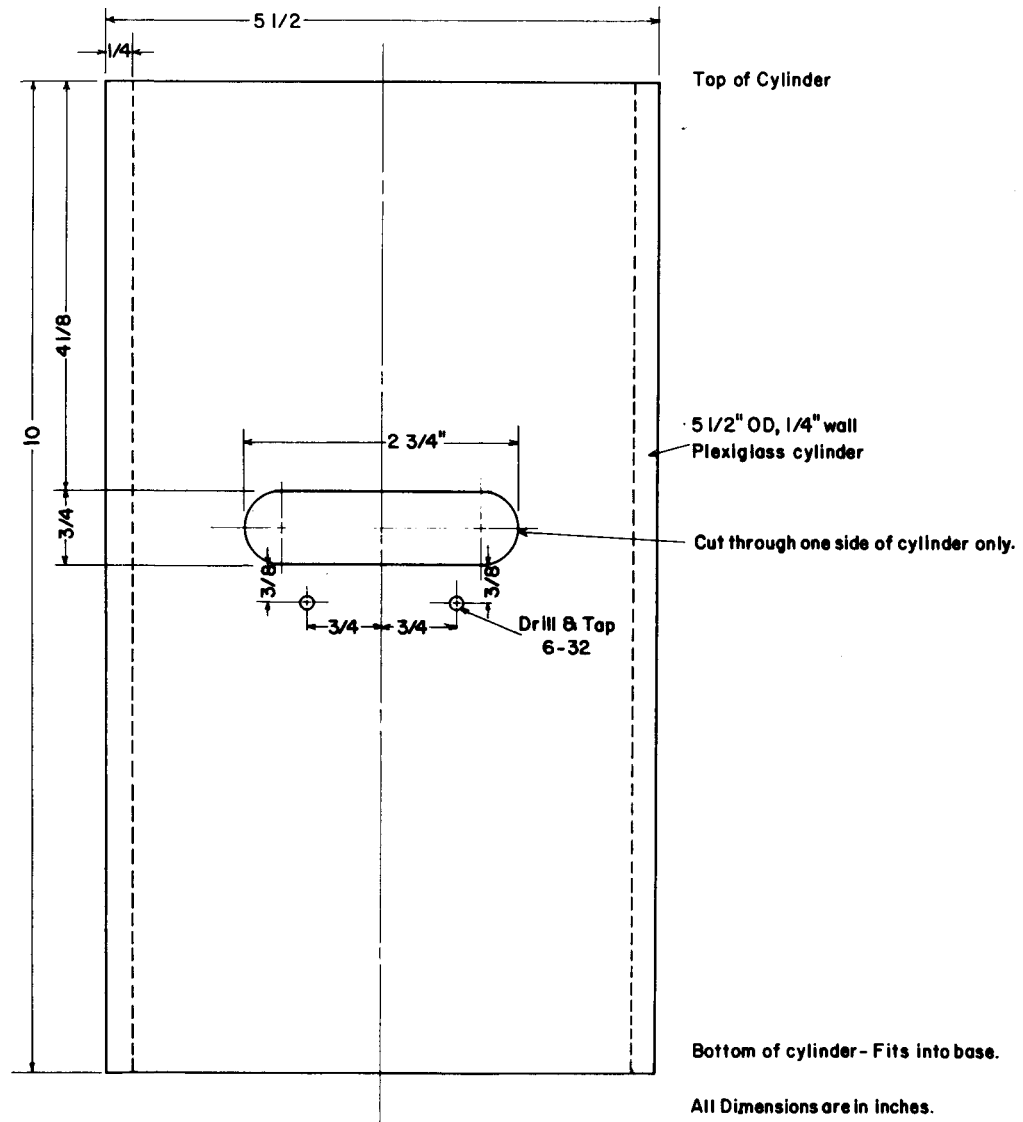
Side View: A cross-section of the object. The base is a rectangle with a width of 7 and a height of 3/8. The top surface is a stepped cylinder. The outer radius is 5 1/2, and the inner radius is 2 1/2. The height of the outer cylindrical part is 1 1/2, and the height of the inner cylindrical part is 4. Dashed lines indicate the hidden edges of the object.

The technical drawing consists of two views of a square plate with a circular hole.

Top View: A square plate with a side length of 7. It features a circular hole with a diameter of $5\frac{1}{2}$. The hole is centered on the square. Dashed lines indicate the center lines of the square and the hole.

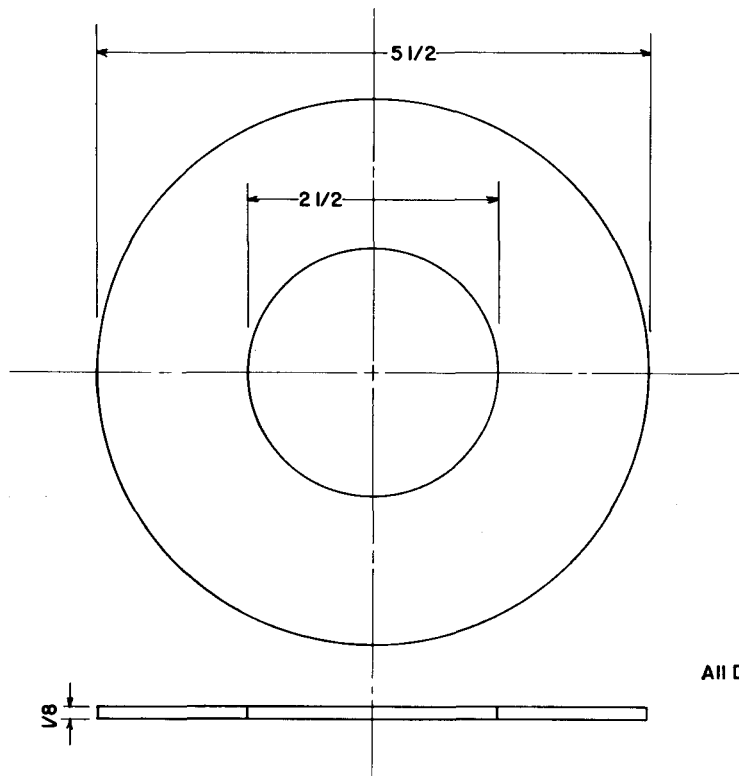
Side View: A stepped profile of the plate. The total width is 7. The profile has a base width of $1\frac{1}{2}$ on the left, a central section of width 4, and a base width of $1\frac{1}{2}$ on the right. The total height is 3. The top surface is at a height of $\frac{3}{8}$ from the base. The central section has a height of $2\frac{1}{2}$. Dashed lines indicate the internal structure of the hole.

Cylinder Detail
Material: Plexiglass



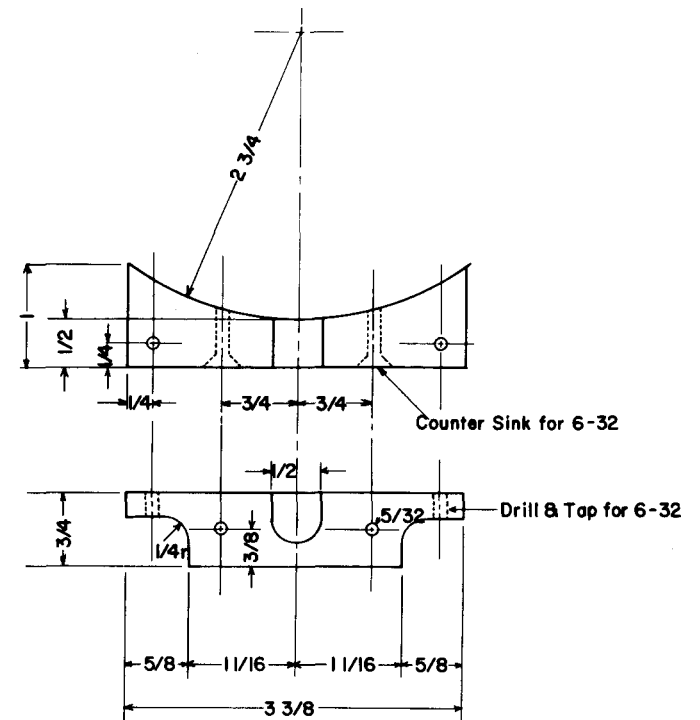
IONIZATION CHAMBER TEST STAND

Clamp Detail
Material: Plexiglass



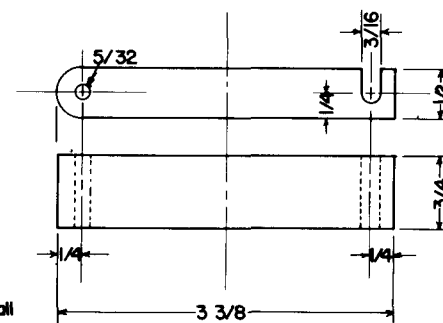
Aperture Detail Material: Lead

Lower Clamp

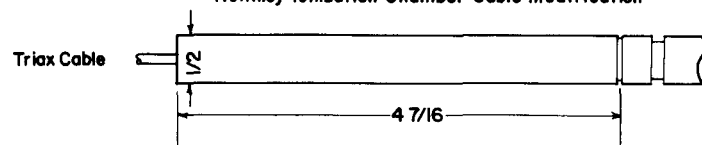


All Dimensions in Inches

Upper Clamp



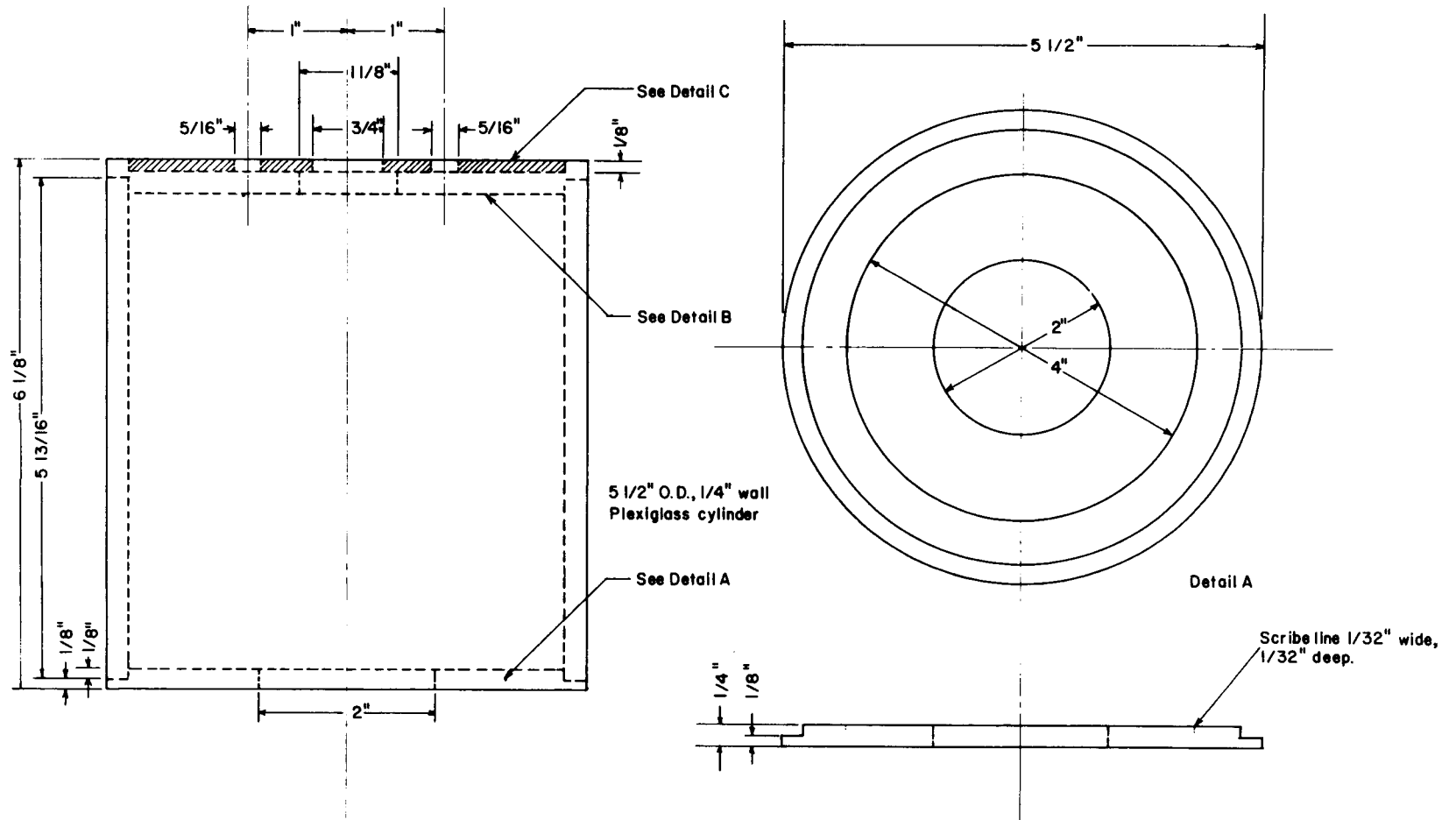
Kelthley Ionization Chamber Cable Modification



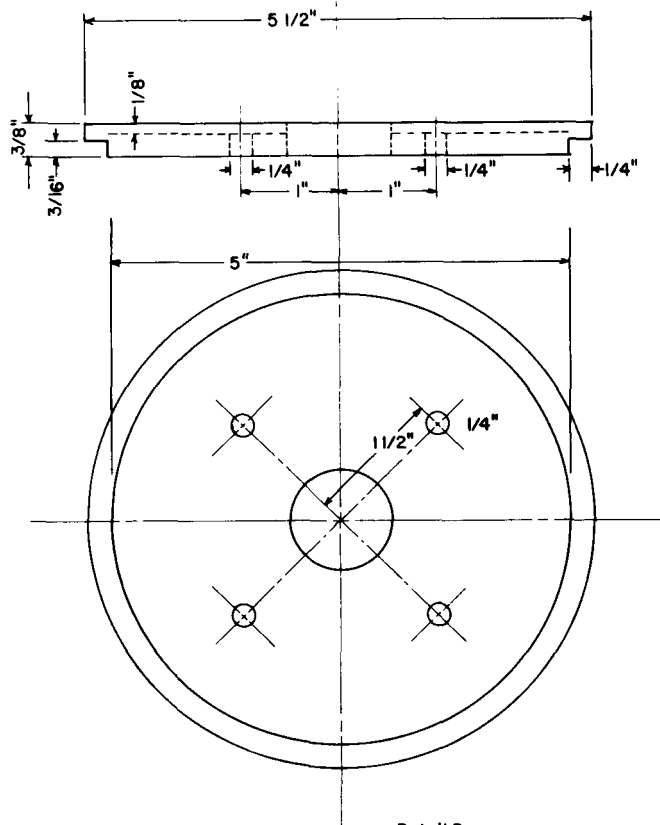
Triax Connector for Ion Chamber
(Not Shown)

Cut groove for keeper ring and install same. Will provide proper ion chamber centering.

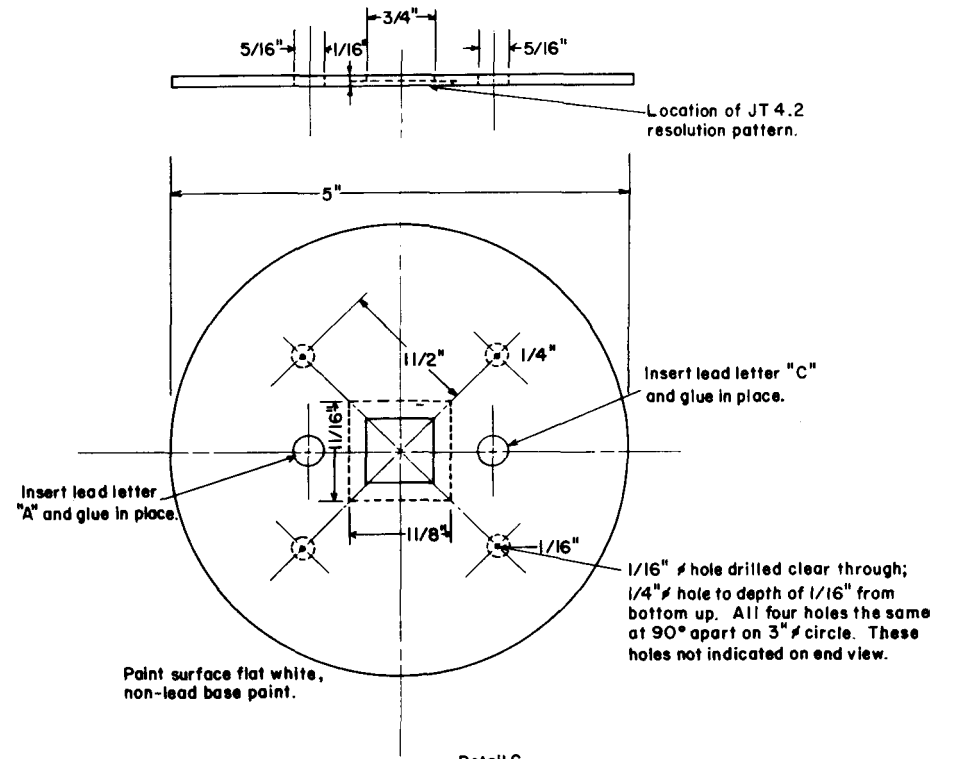
FOCAL SPOT TEST TOOL



FOCAL SPOT TEST TOOL



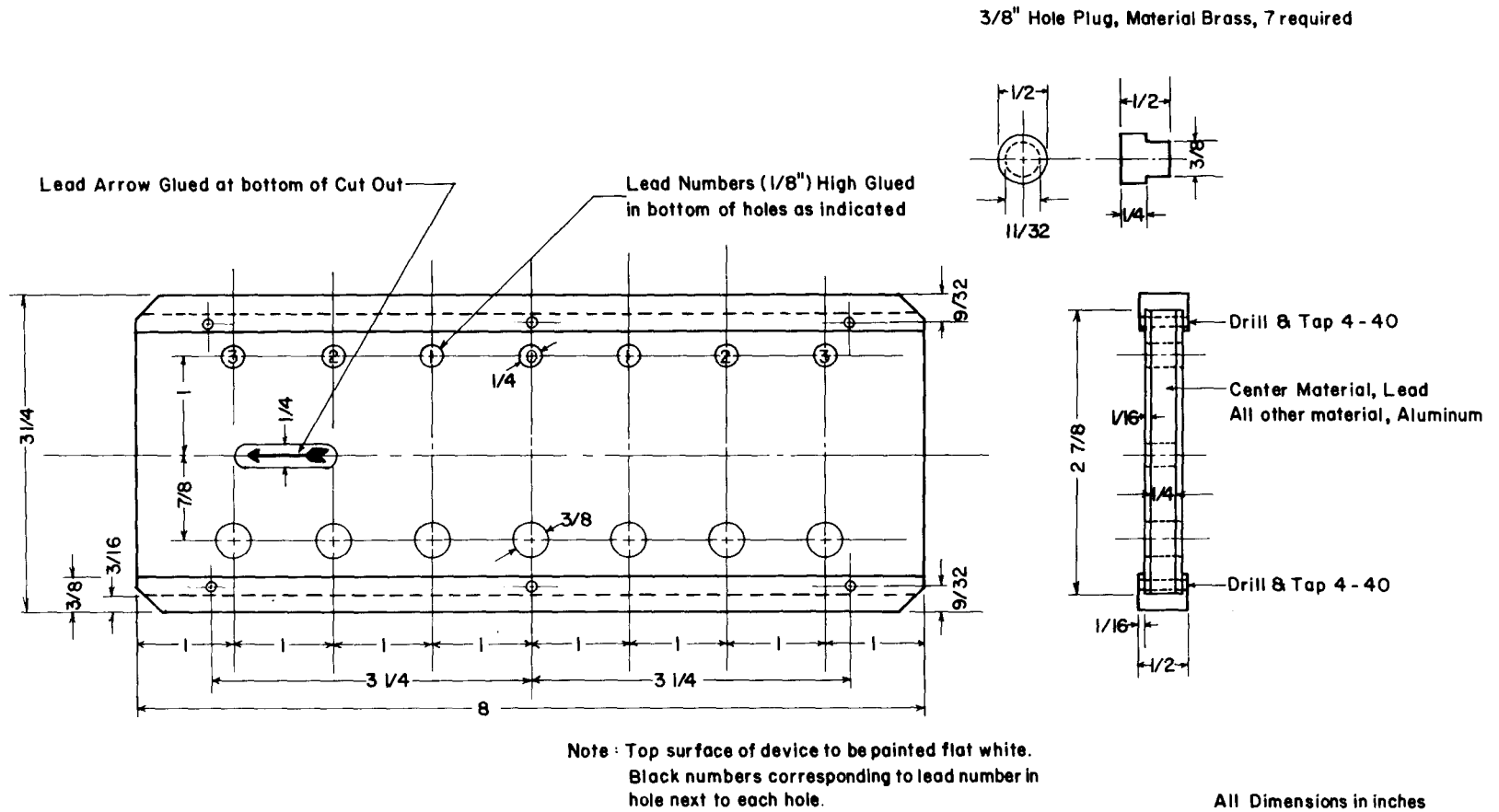
Detail B
Material - Plexiglass



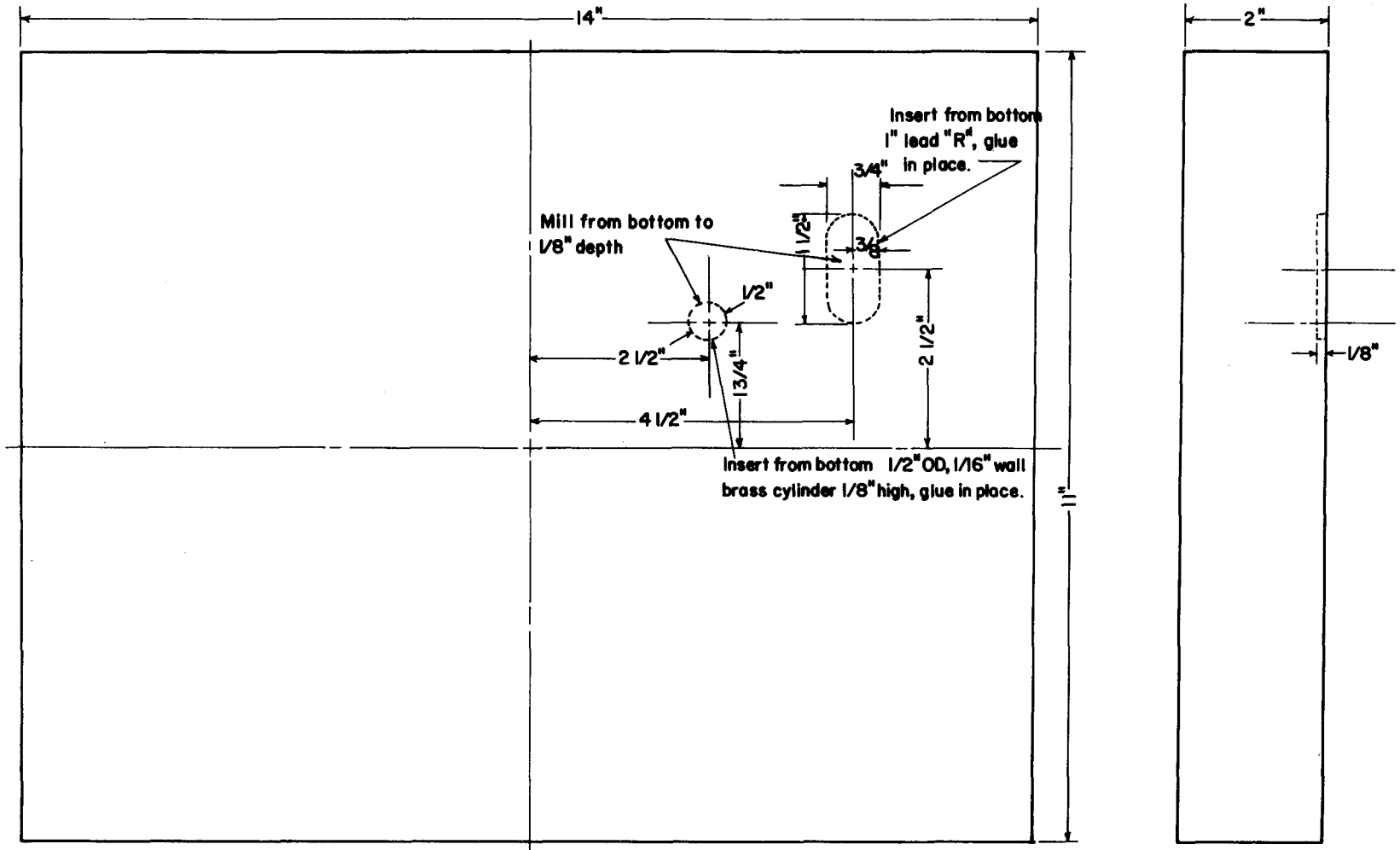
Detail C
Material - Brass

GRID ALIGNMENT TEST TOOL

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RADIOGRAPHIC AEC PHANTOM



PHANTOM BASE SECTION

Plexiglass (1 required)

Require also 4 pieces 11" x 14" x 2" Plexiglass

FILM/SCREEN CONTACT TEST TOOL

Construction:

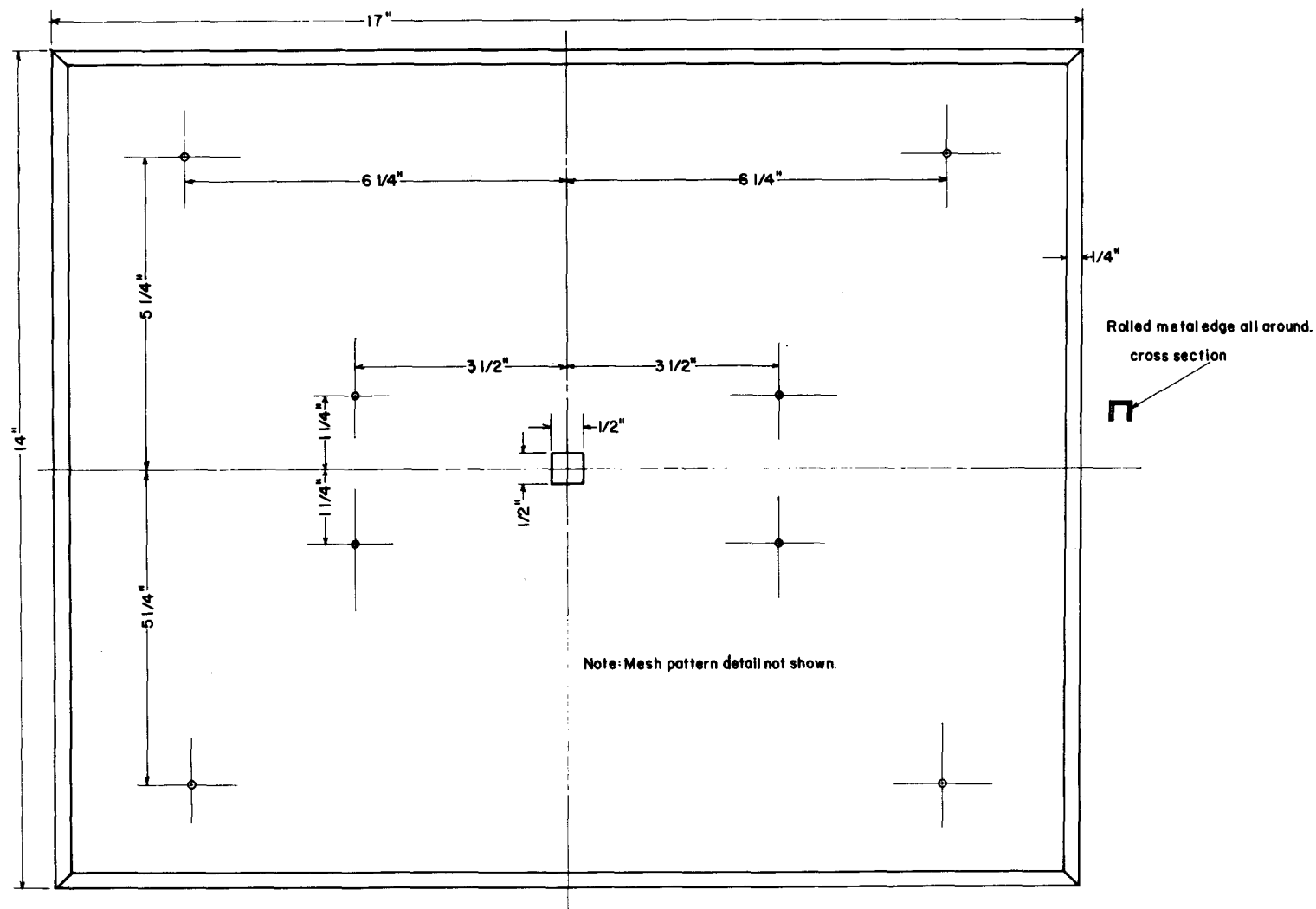
Front plate: 1/16" Plexiglass with indicated center cut out.

Center plate: 2 pieces of perforated brass mesh pattern; 1/16" diameter holes on 1/8" centers.

Indicated cut out to be included.

Rear plate: 1/16" aluminum solid - no cut out.

Plate held together with pop rivets denoted $\oplus$ and rolled metal edges.



9. DATA FORMS USED FOR TESTS DESCRIBED IN MANUAL

This section provides full size reproductions of the data forms illustrated in this manual which are used to record test data. They are presented here so that they may be copied directly by an individual who wishes to carry out a given test or group of tests and thus ease in data recording.

SOURCE TO IMAGE RECEPTOR DISTANCE ACCURACY
AND BEAM RESTRICTION SYSTEM ADEQUACY

DATA FORM RF 1

Date: _____ Room No.: _____

Equipment Identification: _____

Beam Restriction System

Identification: Manufacturer: _____ Model No.: _____ Serial No. _____

Beam Restriction System _____ Manual _____ Positive Beam _____ Manual _____
Operational Modes: _____ Limitation: _____ Automatic _____

Beam Restriction Configuration Tested: _____

Source to Image Receptor Distance Used for Test: _____ (SID_s)

Tabletop to Cassette Surface Distance: _____ (p)

SID Indicator Accuracy

SID _s	h	O	p	I _L	I _T	<I>	<SID>	ΔSID

MANUAL BEAM RESTRICTION SYSTEMS OR POSITIVE BEAM LIMITATION SYSTEM IN MANUAL MODE

Numerically Indicated Field Size				
L _S				
W _S				
L _R				
ΔC _{RI}				
ΔL _{RL} ¹				
ΔL _{RL} ²				
ΔW _{RL} ¹				
ΔW _{RL} ²				
A _L				
A _W				
A _T				
M _L				
M _W				
M _T				

Remarks/Comments:

SOURCE TO IMAGE RECEPTOR DISTANCE ACCURACY
AND BEAM RESTRICTION SYSTEM ADEQUACY

POSITIVE BEAM LIMITATION SYSTEMS				DATA FORM RF 1
Does the system automatically adjust the field size to the size of the image receptor inserted in the cassette tray or prevent x-ray exposure until the field size is manually adjusted?				☐ Yes ☐ No
Image Receptor Size				
L_I				
W_I				
ΔC_{RL}				
L'_R				
W'_R				
$\Delta' L^1_{RL}$				
$\Delta' L^2_{RL}$				
$\Delta' W^1_{RL}$				
$\Delta' W^2_{RL}$				
L^P_R				
W^P_R				
RIC_L				
RIC_W				
RIC_T				
M'_L				
M'_W				
M'_T				
Remarks/Comments: _____ Signature				

ACCURACY AND REPRODUCIBILITY OF EXPOSURE TIMER

DATA FORM RF 2

Date: _____ Room No.: _____

Equipment Identification: _____

Generator Identification: _____ X-Ray Tube Identification: _____

High Voltage Waveform: _____

Test kVp: _____ Test mA: _____

[illegible]

Remarks/Comments:

Signature

X-RAY TUBE PROTECTIVE CIRCUITRY

DATA FORM RF 3

Date: _____ Room No.: _____

Equipment Identification: _____

Generator Manufacturer: _____ Model: _____
Identification: _____

X-Ray Tube	Manufacturer:	Model:		
Identification: Serial No.:		Nominal	Focal	Small
Anode Thermal Capacity:		Spot Sizes:	Large	

High Voltage Waveform: _____ X-Ray Tube Application: _____

[illegible]

Remarks/Comments:

Signature

Date: _____ Room No.: _____

Equipment Identification: _____

Generator Identification: Manufacturer: _____

Model: _____

X-Ray Tube Identification: Manufacturer: _____

Model: _____ Serial No.: _____

Nominal Focal Spot Sizes: Small _____ mm, Large _____ mm

	60 kVp	90 kVp										120 kVp
mA												
time (secs.)												
mAs												
X_o^1												
X_o^2												
X_o^3												
X_f												
$\bar{X}_o$												
$0.95\bar{X}_o - 1.05\bar{X}_o$												
$R(\bar{X}_o/X_f)$												
mR/mAs												
L												

Remarks/Comments:

Signature _____

EXPOSURE REPRODUCIBILITY, EXPOSURE LINEARITY AND BEAM QUALITY

FOCAL SPOT SIZE AND CONSISTENCY

DATA FORM RF 5

Date: _____

Room No.: _____

Equipment Identification: _____

Generator: Manufacturer: _____ Model: _____

X-Ray Tube: Manufacturer: _____ Model: _____

Serial No.: _____ Nominal Focal Small _____ mm
Spot Sizes: Large _____ mm

	SMALL FOCAL SPOT	LARGE FOCAL SPOT
kVp		
mA		
Exposure Time		
Number of Smallest Group Resolved		
Implied Focal Spot Size		

Remarks/Comments:

Signature _____

kVp ACCURACY

DATA FORM RF 6

Date: _____ Room No.: _____
 Equipment Identification: _____
 Generator Identification: Manufacturer: _____ Model: _____
 X-Ray Tube Identification: Manufacturer: _____ Model: _____
 Serial No.: _____
 High Voltage Waveform: _____ Single Phase: _____ Three Phase: _____
 Test kVp: _____

mA				
Exposure Time				
Test Film Identification				

Step Number	Optical Density Readings							
	Refer.	Atten.	Refer.	Atten.	Refer.	Atten.	Refer.	Atten.
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								

Match Step				
Implied kVp				

Remarks/Comments:

Signature _____

GRID ALIGNMENT

DATA FORM RF 7

Date: _____ Room No.: _____

Equipment Identification: _____

Grid Tested: _____

Grid Ratio: _____ Line Number: _____ Focal Distance: _____

SID Used for Test: _____

kVp: _____ mA: _____ Exposure Time: _____

Measured Optical Density

Reference
Location



3

2

1

0

1

2

3

Remarks/Comments:

* ← Indicates orientation arrow on
test device. Always orient
arrow towards front of table.

Signature _____

RADIOGRAPHIC AUTOMATIC EXPOSURE CONTROL SYSTEM EVALUATION

DATA FORM RF 8

Date: _____ Room No.: _____
 Equipment Identification: _____
 Automatic Exposure Control System Tested: _____
 Cassette/Screen/Film _____
 Combination Used for Test: _____
 Processor Used for Processing Test Films: _____
 Processing Parameters: Speed: _____ Contrast: _____ Base/Fog: _____
 SID Employed for Test: _____

REPRODUCIBILITY

Test Conditions: 80 kVp _____ mA
 Normal Density _____
 6" Phantom Thickness _____ Selected Sensitive Field(s)

Test Film Identification	Measured Exposure Time (milliseconds)	Measured Film Density
Average Exposure Time		
Average Film Density		
Maximum Exposure Time Variation		
Maximum Film Density Variation		

kVp COMPENSATION

Test Conditions: 6" Phantom Thickness _____ mA
 Normal Density _____ Selected Sensitive Field(s)

kVp	Test Film Identification	Measured Exposure Time	Measured Film Density
60			
80			
100			
120			
Maximum Film Density Variation			

RADIOGRAPHIC AUTOMATIC EXPOSURE CONTROL SYSTEM EVALUATION

DATA FORM RF 8

FIELD SENSITIVITY MATCHING

Test Conditions: 80 kVp _____ mA
 Normal Density
 6" Phantom Thickness

Selected Sensitive Field	Test Film Identification	Measured Exposure Time	Measured Film Density
Average Exposure Time			
Average Film Density			
Maximum Exposure Time Variation			
Maximum Film Density Variation			

DENSITY CONTROL FUNCTION

Test Conditions: 80 kVp _____ mA
 6" Phantom Thickness _____ Selected Sensitive Field(s)

Density Control Setting									
Test Film Identification									
Measured Exposure Time									
Measured Film Density									
Fractional Change in Exposure Time*									
Fractional Change in Film Density*									

*Relative to that obtained at Normal density control setting.

RADIOGRAPHIC AUTOMATIC EXPOSURE CONTROL SYSTEM EVALUATION

DATA FORM RF 8

RESPONSE CAPABILITY

Test Conditions: Normal Density _____ mA _____ Selected Back-Up Time _____
 _____ Selected Sensitive Field(s) _____

	60 kVp			80 kVp			100 kVp			120 kVp		
Phantom Thickness	Test Film Identification	Measured Exposure Time (milliseconds)	Measured Film Density	Test Film Identification	Measured Exposure Time (milliseconds)	Measured Film Density	Test Film Identification	Measured Exposure Time (milliseconds)	Measured Film Density	Test Film Identification	Measured Exposure Time (milliseconds)	Measured Film Density
2"												
4"												
6"												
8"												
10"												
Maximum Variation in Film Density of Constant kVp												
Maximum Variation in Film Density of Constant Phantom Thickness			2"	4"	6"	8"	10"					

BACK-UP TIMER

Test Conditions: 80 kVp _____ mA
 6" Phantom Thickness _____ Selected Sensitive Field(s)
 plus lead beam stop _____ Selected Back-up Time

Measured Exposure Time: _____ sec.
 mA-time produce: _____ mAs

Remarks/Comments:

Signature

FILM SCREEN CONTACT

DATA FORM RF 17

Date: _____

X-Ray Equipment Used for Test: _____

Focal Spot Size Used for Test: _____ mm

Technique Factors: _____ kVp _____ mA _____ Time

Film Type Used for Test: _____

[illegible]

Remarks/Comments:

Signature

DATA FORM RF 18

X-ray Equipment Used for Test: _____

Processor Used for Processing Test Films: _____

Screen Type: _____ Film Type Used for Test: _____

Master Cassette/Screen Identification:

Remarks/Comments:

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DATA FORM RF 19

Light Meter Used For Test: _____

[illegible]

Maximum Illumination Variation Between Illuminators

Remarks/Comments:

Signature

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