TECHNIQUE FOR CHEST RADIOGRAPHY FOR PNEUMOCONIOSIS

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Prepared for

The National Institute for Occupational Safety and Health
Department of Health and Human Services
Public Health Service
Centers for Disease Control

Supported in part by
Contract 210-81-2101

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20 North Wacker Drive
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1982

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Preface

Routine radiographic chest examinations have been performed using a variety of techniques. Although chest radiography is one of the most commonly performed radiographic examinations, it is often difficult to obtain consistently good quality roentgenograms. The purpose of this publication is to provide a simple guide and relatively easy solution to the many problems which radiologic technologists might encounter. It is the product of the experience of many radiologists and highly qualified technologists in producing films of optimum technical quality for the study of the pneumoconioses, while restricting the radiation dose to the patient to a minimum.

The American College of Radiology feels that valid interpretation of the subtle findings of pneumoconiosis depends upon a technically superior chest radiograph. In previous programs with the National Institute of Occupational Safety and Health (NIOSH), the ACR has stressed film quality and has worked with other physician groups, radiologic technologists, the x-ray industry, and the several involved federal and state agencies, in programs to achieve uniformly good technique. Radiographs produced using the best current techniques are required for the program and those films produced to any lower standard are not acceptable.

The language is purposely relatively simple and care has been taken to avoid difficult mathematical and physical explanations. The intent is to provide an easily referrable text for those who may encounter difficulties in producing acceptable chest radiographs. Optimum film quality is an absolute prerequisite for the detection and accurate classification of the pneumoconioses using the ILO-1980 system. The technologist plays a very important role in submitting acceptable films to the physician for accurate interpretation. Poor film quality not only results in an added burden to the patient, who must often lose time from work to return for repeat examinations, but also increases the total cost of the examination. Misinterpretation of films as a result of poor film quality is a great disservice to the patient and may cause marked delays in the government agencies which must use these films as a basis for compensation. The primary objective of the authors is to assist technologists in the recognition and correction of problems which commonly degrade the radiographic image to the extent that it is unacceptable for the detection of the pneumoconioses.

The Editor wishes to thank the authors of the various chapters particularly for their patience and their unfailing efforts required for the publication of their manuscripts.

In addition, I would like to thank James A. Merchant, M.D. of NIOSH for his efforts in obtaining the necessary funds required for the publication of this text.

My deepest gratitude is also extended to the staff of the American College of Radiology particularly Mr. Otha W. Linton and Miss Maurine H. Trautz who administered the contract and Mr. Earle V. Hart, Jr. who spent many hours in the actual mechanics of producing the printed text.

It is hoped that improved film quality along with a decrease in repeat examinations will result in more accurate diagnoses, less radiation, and decreased costs in both time and money. The ultimate beneficiary of this publication is not the technologist and the radiologist involved in the study of the pneumoconioses, but the patient.

E. Nicholas Sargent, M.D.
Editor

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Chapter I

Chest Radiography for the Detection and Study of the Pneumoconioses

E. Nicholas Sargent, M.D.

Today's energy crisis and technologic advances have reemphasized the importance of the dust pneumoconioses, particularly coal workers' pneumoconiosis, silicosis, and asbestosis. Without a tissue biopsy, the diagnosis of pneumoconiosis during life is made by the use of a chest radiograph and a lifetime occupational history. One must be aware of the radiographic changes that are associated with the more common pneumoconioses. The words "associated with" are used advisedly because many other nonpneumoconiotic interstitial diseases will show similar changes on the radiograph. The changes are not pathognomonic but they do occur in association with the inhalation of various types of dust.

Classification System

The radiographic changes associated with the pneumoconioses are classified according to the current ILO-1980 classification (1). This scheme is designed for classifying the appearances of the pneumoconioses on a posteroanterior chest radiograph. The classification does not attempt to define pathologic entities but it is very important in recording the type and extent of radiographic changes, as well as describing any progressive changes. It has been used extensively internationally for epidemiologic research, for the surveillance of those in dusty occupations, and for clinical purposes. The use of the scheme has made possible a meaningful international comparison of pneumoconiosis statistics. It can also be used in part for recording, in a systematic way, information needed for assessing compensation. The classification does not connote legal definitions of pneumoconiosis for compensation purposes, and does not set a level at which compensation is payable. The chest radiograph must be used to demonstrate the presence and the extent of any disease process and the classification scheme is a useful means of recording related information.

The ILO-1980 Classification of Radiographs of the Pneumoconioses recognizes and classifies both parenchymal and pleural abnormalities. It also permits the recording of any other abnormalities and disease processes (e.g., cardiac disease, cancer, tuberculosis) which may or may not be related to the pneumoconioses.

Parenchymal abnormalities (i.e., "small opacities") resulting from pneumoconiosis are classified as to both size and shape. The letters "P", "Q", and "R" denote the presence

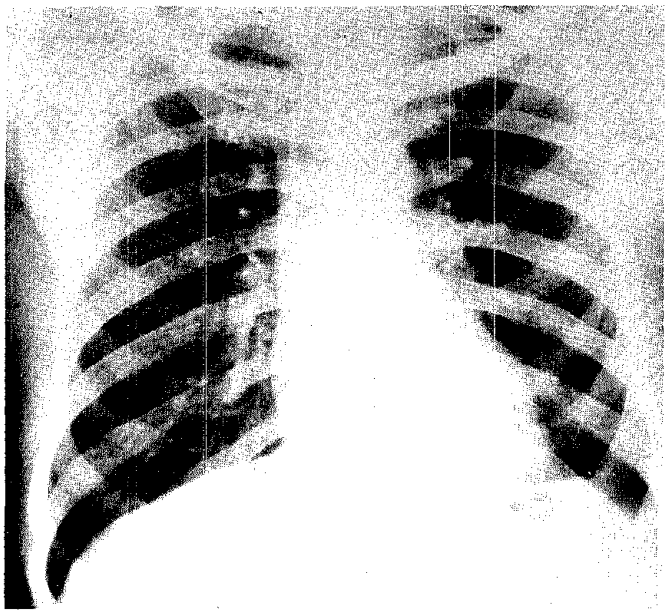

Figure 1A. "Q" type opacities few in number (low profusion) in upper portions of the lungs.

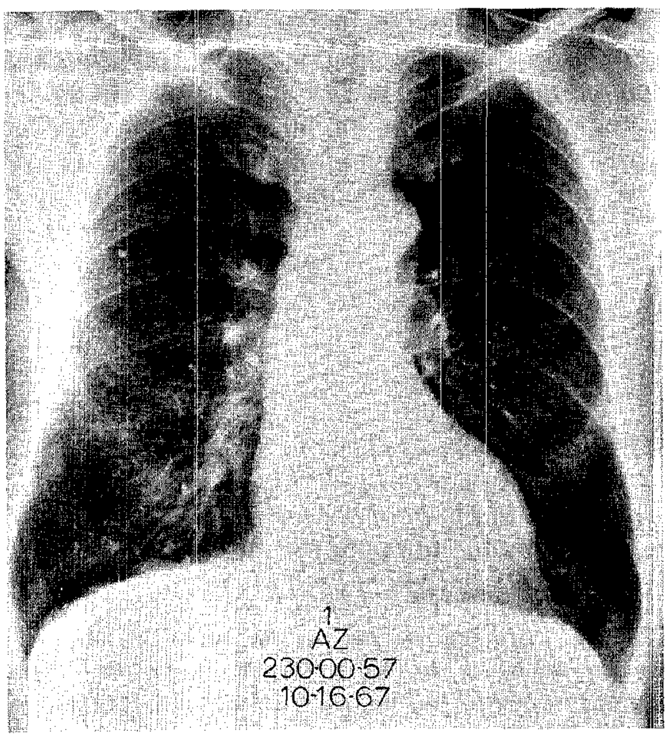

Figure 1B. "Q" type opacities throughout both lungs in larger numbers (high profusion). "Q" type opacities are the most common type of rounded opacities.

of <u>small rounded opacities</u>: "P" equals a diameter up to about 1.5 mm.; "Q" equals a diameter exceeding about 1.5 to approximately 3 mm. (Figures 1A and 1B); and "R" equals a diameter exceeding approximately 3 mm. and up to about 10 mm. The letters "S", "T", and "U" denote the shape of <u>small irregular opacities</u> and these are also

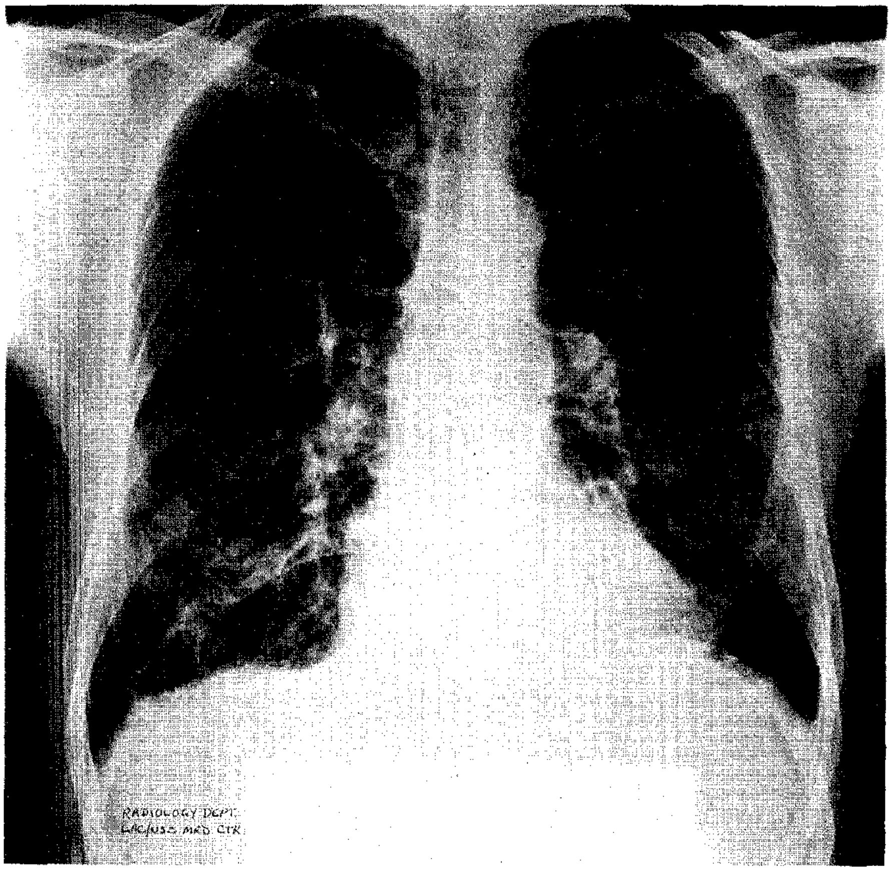

Figure 2A. Illustration of the "T" variety of irregular opacities mostly in the middle and lower lung zones, few in number (low profusion).

classified according to size. "S" equals a width up to about 1.5 mm.; "T" equals a width exceeding about 1.5 mm. to approximately 3 mm. (Figures 2A and 2B); and "U" equals a width exceeding 3 mm. and up to about 10 mm. The classification system also permits the recording of any mixtures of sizes and shapes.

For classification purposes, each lung is divided into upper, middle, and lower "zones" by extending a line from the apex to the diaphragm and dividing it into thirds. The location of small opacities, whether rounded or irregular, are recorded as to their location in each of the six lung zones. Small irregular opacities are more commonly associated with asbestos dust exposure and these opacities occur first in the lower lung zones. Following coal and silica dust inhalation, small rounded opacities are found in the upper and middle lung zones, and these do not reach the lower lung zones until they are very profuse.

An assessment is made of the concentration (numbers) of the small opacities in all lung zones and this is recorded on a 12 point epidemiologically related scale. This is known as the "profusion" of small opacities throughout both lungs. Film quality is extremely important in the assessment of profusion (Figure 3). Generally speaking, the greater the profusion of the small opacities, the greater the amount of dust in the lungs, and the greater the decrement in the pulmonary function. The profusion of small opacities is also used in part for compensation purposes particularly when correlated with pulmonary function abnormalities.

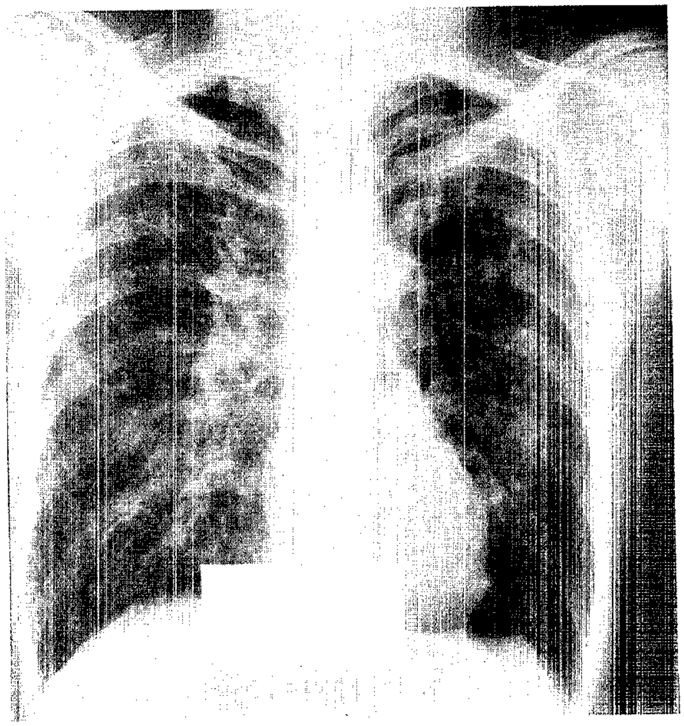

Figure 2B. Irregular opacities of the "T" variety throughout both lungs (high profusion). When a larger number of these opacities involve the lung they are more easily identified.

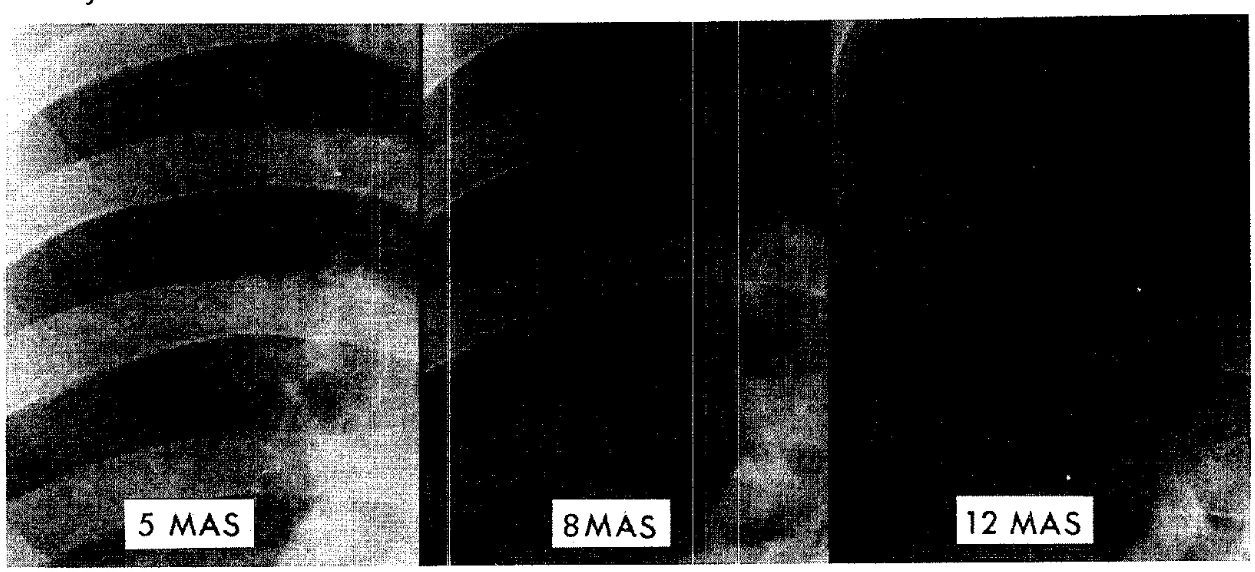

Figure 3. Overexposure of the film causes the disease process to disappear. There are small rounded opacities of the "P" variety. They are the most difficult to detect on the radiograph and require optimum film quality. Overexposure results in inaccurate interpretation.

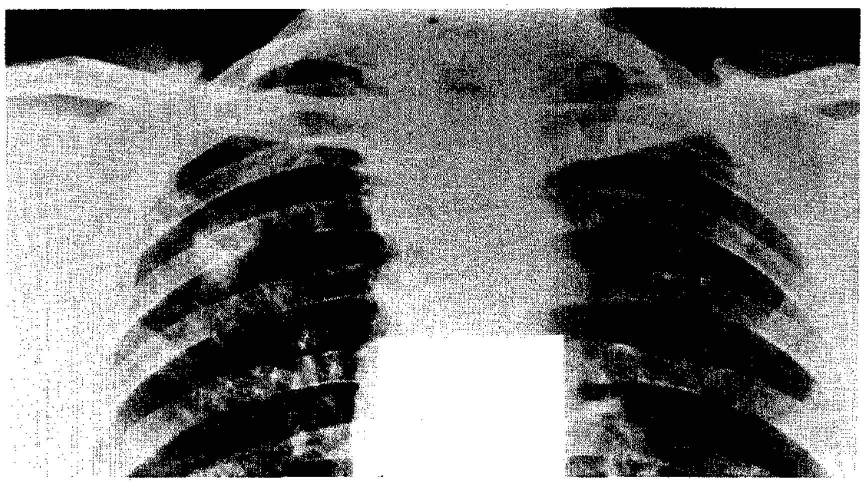

Figure 4A. Large opacity of the "A" variety (under 5 cm. in diameter) in the right upper lung zone. Note background of small rounded opacities of the "Q" variety.

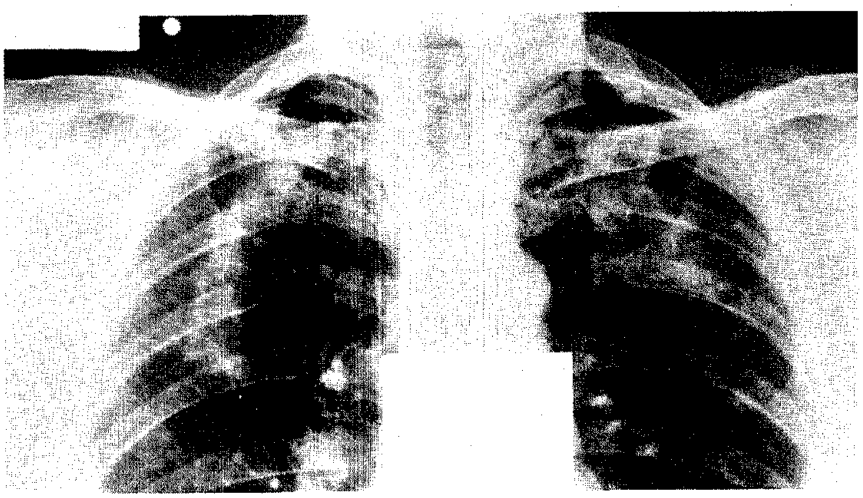

Figure 4B. Large opacities of the "B" variety bilaterally. The sum of the measurements is less than the area of the right upper lung zone.

When other opacities appear on the radiograph following dust inhalation, which are larger than a centimeter in size, these are classified separately as "large opacities". These are divided into categories, "A", "B", and "C" depending on their size and number (Figures 4A, 4B, and 4C). The large opacities correlate well with abnormal pulmonary function studies. They are usually associated with a great deal of lung fibrosis and tissue destruction. Many of these patients eventually die of respiratory and cardiac failure. Thus, the recognition of a large opacity usually portends a more grave prognosis and should influence the compensation decision.

Pleural abnormalities must also be recognized, recorded, and classified. These abnormalities are more commonly associated with asbestos dust exposure. Pleural thickening is recorded as either "diffuse" or "circumscribed" (localized in the form of plaques).

On the routine posteroanterior survey radiograph, pleural thickening is found laterally

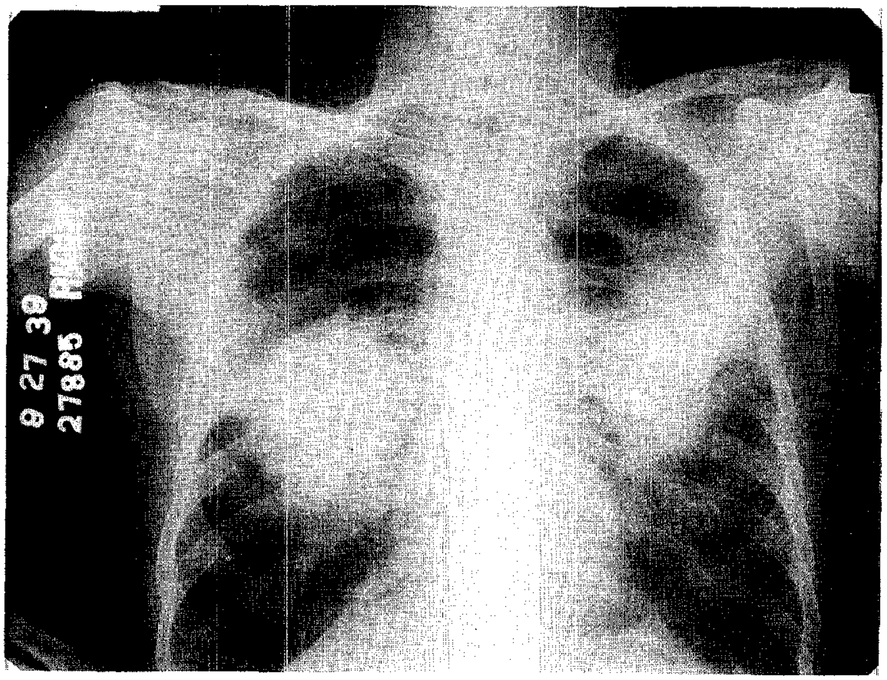

Figure 4C. Large opacities of the "C" variety. The sum total of the measurements is greater than the area of the right upper lung zone. Note how the small rounded opacities disappear due to envelopment by the large fibrotic masses and obscuration by the surrounding areas of marked emphysema.

along the costopleural junctions, inferiorly on the diaphragmatic surface, medially along the mediastinal margins, and within the interlobar fissures.

Circumscribed and diffuse pleural thickening along the costopleural junction of the chest walls are recorded as to whether or not they are seen in profile or en face. When they are recorded in profile they are divided into category "A", "B", and "C" depending on their cross-sectional width and into category "1", "2", and "3" depending on their circumference or length (Figures 5A and 5B).

Circumscribed or localized pleural thickening on the leaves of the diaphragm is also recorded separately. Obliteration of the costophrenic angle as a result of pleural thickening is also recorded. It is mandatory that on every film the costophrenic angles be included in the radiograph and be well visualized.

Recognition, recording, and grading of the extent of calcification within areas of pleural thickening is also part of the classification system.

Technical Quality

Physicians interpreting radiographs which demonstrate evidence of pneumoconiosis will find difficulty unless the exposure factors used in producing the radiographs are maintained within an optimum range. Use of the classification system will not be satisfactory unless optimum radiographic technical quality is maintained. It is known that by far the greatest causes of poor technical quality in chest radiographs (well over 90%) are overexposure and underexposure, unsatisfactory contrast, poor screen-film

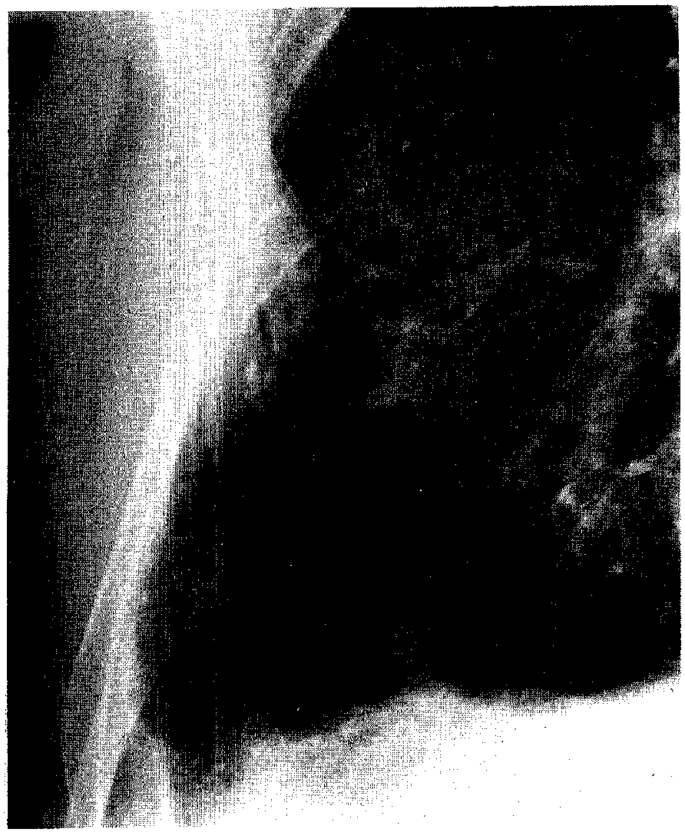

Figure 5A. Large pleural plaque is seen in profile adjacent to the ribs (containing a small amount of calcification). On the medial side of this plaque is an ill-defined shadow which is a result of an additional plaque seen en face with poorly marginated edges. There is also obliteration of the right costophrenic angle with diffuse pleural thickening along the inner edge of the rib margin. A calcified plaque is seen on the right leaf of the diaphragm.

contact, and fog. It is important to recognize and correct any technical defects prior to submitting the chest radiograph to the physician for the proper classification and to prevent persistent problems on future examinations.

Recording of technical quality is now formally part of the classification system. It permits comparison of the general quality of radiographs in different surveys and allows exclusion from analysis of data too poor to permit an accurate and satisfactory classification of the radiograph. Four grades of technical quality are recorded: 1 = good; 2 = acceptable with no technical defects likely to impair classification of the radiograph for pneumoconiosis; 3 = poor with some technical defects but still acceptable for classification purposes; and 4 = unacceptable. If the technical quality is not grade 1, comments must be recorded about the technical defects.

Optimum Techniques for Pneumoconiosis Studies. The question of optimum radiographic technique remains a controversial matter among experts internationally. However, it is universally agreed that optimum film quality is a prerequisite not only for the early detection and proper classification of profusion of small opacities of the radiograph, but also for detecting progressive changes that may occur on future

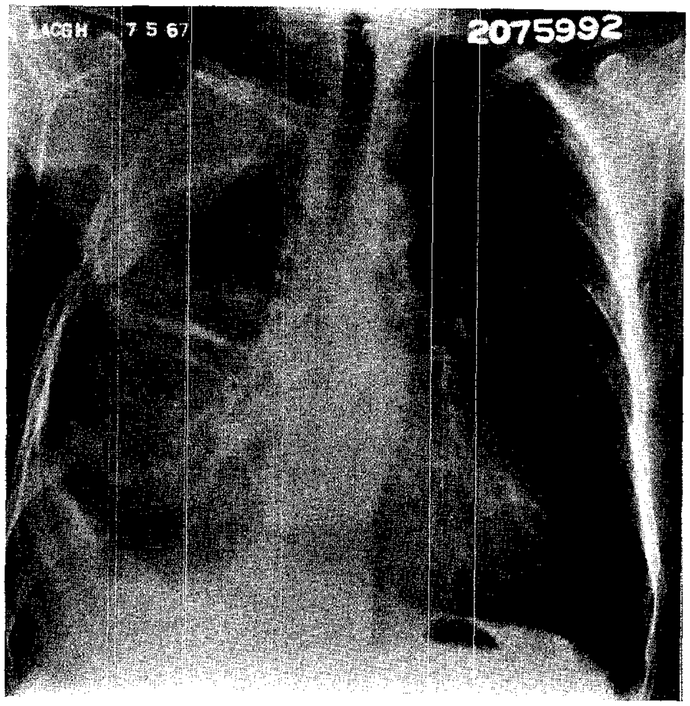

Figure 5B. Diffuse lobulated pleural thickening seen both in profile and en face associated with a malignant mesothelioma on the right.

examinations. Recognizing that there may be variance among radiologists as to what is considered an "optimum" radiograph, it is usually accepted that the exposure of the radiographs of the chest will have a marked influence not only on the radiographic appearance of the lesions of the pneumoconioses but in differentiating normal from abnormal shadows.

The most desirable chest radiography for detection of the abnormalities of the pneumoconioses involves techniques and procedures which will demonstrate the finer lung structures in greatest detail. While it is highly desirable to visualize the mediastinal structures equally as well as the peripheral pulmonary parenchymal structures on a single routine screening film, this is difficult to achieve except with extremely thin patients (2). Therefore, as a compromise for the study of the pneumoconioses, a film in which the vertebral bodies and the larger pulmonary blood vessels are faintly visualized through the overlying cardiac shadow is acceptable. In addition, the costopleural junctions along the lateral thoracic wall must be clearly visualized with sufficient detail along their entire extent from the apex to the costophrenic angle (Figure 6).

Radiographic Exposure (Density and Contrast). The importance of radiation exposure relative to image density and contrast for technical excellence in chest radiography cannot be overemphasized. On physical grounds a radiograph of satisfactory technical quality may be defined as one in which the exposure has been such that the optical densities of the images of interest fall between 0.3 and 1.7, and one in which the differences in optical density between the darkest image of interest and the lightest is 1.0 or more (see Chapter VI). The inherent contrast, or density differences (i.e., the density vs. log of the exposure gradient of radiographs), falls off rapidly as optical

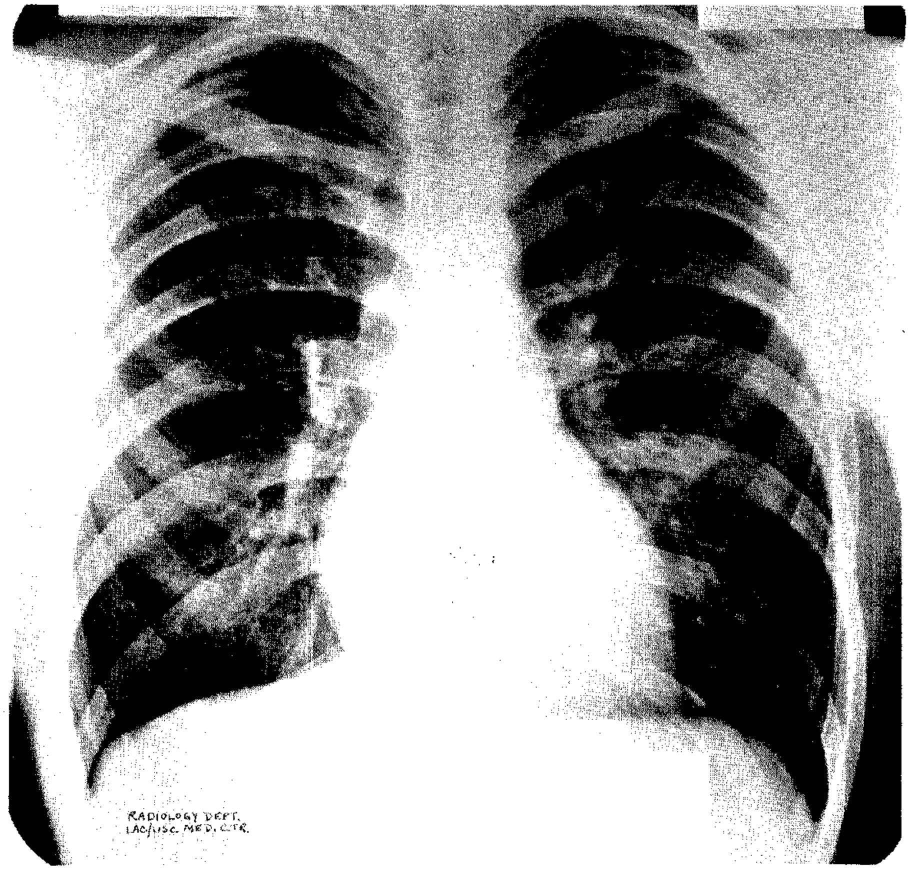

Figure 6. Normal chest radiograph. There is good visualization of the blood vessels throughout both lungs with faint visualization through the heart shadow. This film includes both costophrenic angles and the apices of the lung. The patient is in deep full inspiration. The costopleural margins are well outlined with no obscuration from the overlying scapulae. The patient and x-ray beam are properly aligned to the cassette.

densities descend below 0.3. Hence, image quality becomes increasingly unsatisfactory as this occurs. Above an optical density of 1.7, the inherent contrast of radiographs remains good, but extraneous light entering the observer's eyes from light sources other than the x-ray viewing boxes tends to impair the contrast of the radiographic image when projected on the retina. Hence, the technical quality deteriorates for images having optical densities much above 1.7 density units. (As a maximum acceptable range, the hilar regions should exhibit a minimum of 0.2 units of optical density above base fog and the parenchymal regions should exhibit a maximum of 1.8 units of optical density above base fog.) The gross image contrast (the difference in optical density between the darkest segment of the lung parenchyma and the lightest portion of the hilar regions) should fall within a range of 1.0 and 1.4 units of optical density. Since some technologists may work without adequate supervision by knowledgeable physicians, it is proposed that convenient densitometric instruments be available so that the quality of each radiograph can be measured by the technologist at the time the radiograph is made. A more widespread use of recently available improved pocket densitometers to determine technical quality of the chest radiograph is suggested.

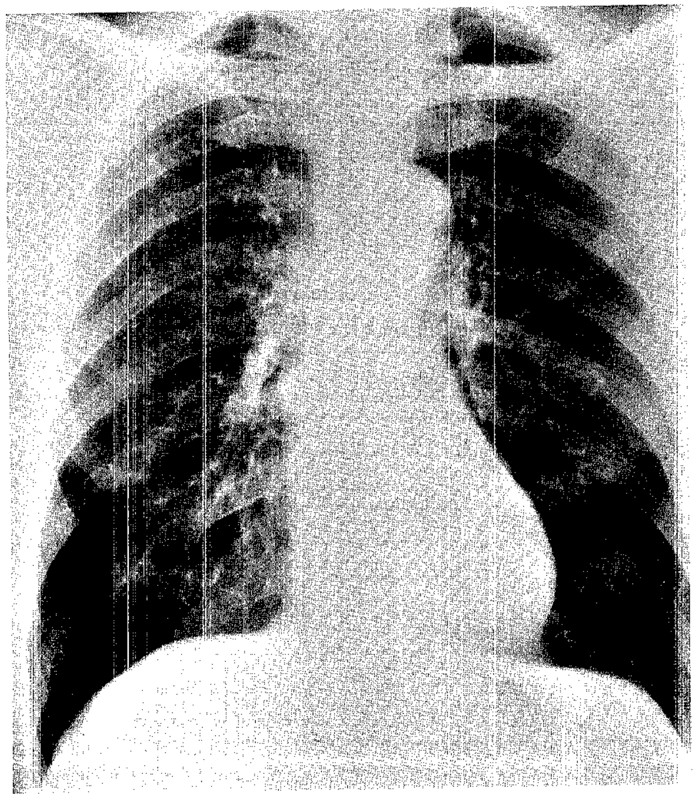

Figure 7A. This film is properly exposed for the lungs and mediastinum.

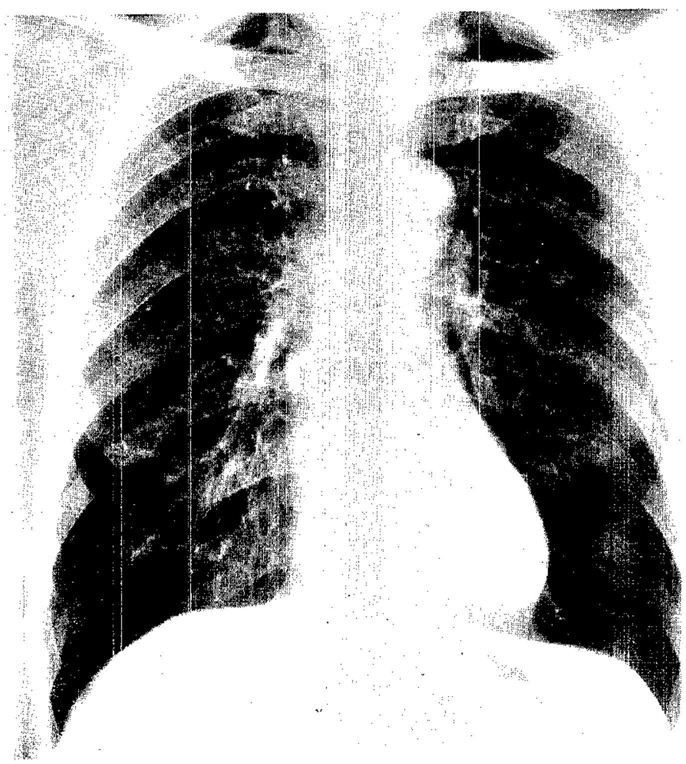

Figure 7B. The film is properly penetrated for the mediastinum but overexposed for lung detail. Note how the small rounded opacities disappear resulting in classification of less disease than is actually present on the film illustrated in Figure 7A.

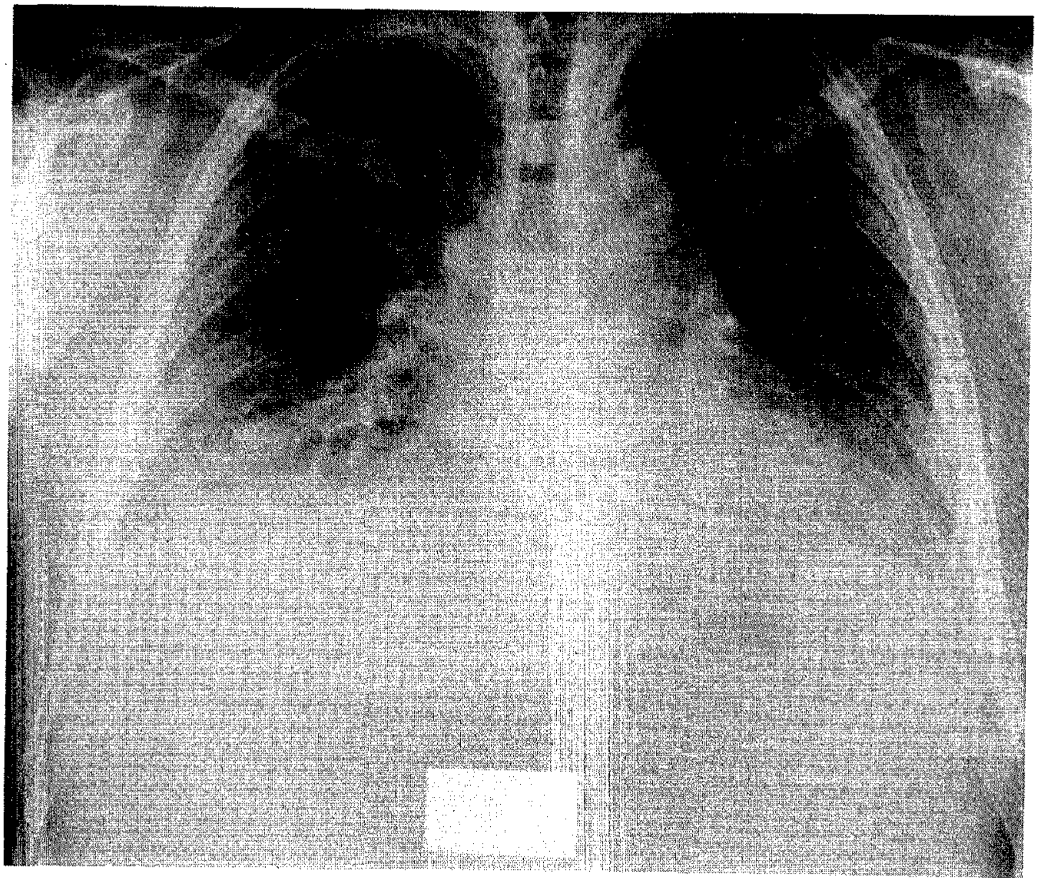

Figure 8A. A film with a patient in expiration.

It can be shown that a film which is overexposed will cause the disease process to disappear (Figures 7A and 7B) and a film which is underexposed will cause readings of profusion of small opacities in an abnormally higher category (3). Furthermore, underexposure of the costopleural margins will cause great difficulty in determining the presence or absence of pleural changes, as well as the presence or absence of pleural calcifications (Figures 8A and 8B).

There is more structural variation in patients' chests than in their skulls or extremities. Another reason for variation of chest radiographs is the estimation of technique factors from the physical appearance of a patient (which is usually imprecise at best). It is recognized that a well trained technologist can use almost any equipment or combination of techniques and "tailor-make" a radiograph for each patient, which would be acceptable for the study of the pneumoconioses. However, the techniques proposed in this publication are designed to take advantage of present day radiographic equipment, film-screen combinations, and processing.

The thoracic cage is composed of structures with marked variation in their ability to absorb x-rays. The chest contains air density in the lungs; water equivalent density of the heart, muscles and mediastinum; and heavy metal (calcium) density of the bones (thoracic spine and ribs). Furthermore, in order to observe possible abnormalities in the lung upon which the tissues of the thorax of varying density and thickness are superimposed, it is necessary to penetrate the tissues of the thorax adequately. Particularly for the study of the pneumoconioses, this requires image receptor

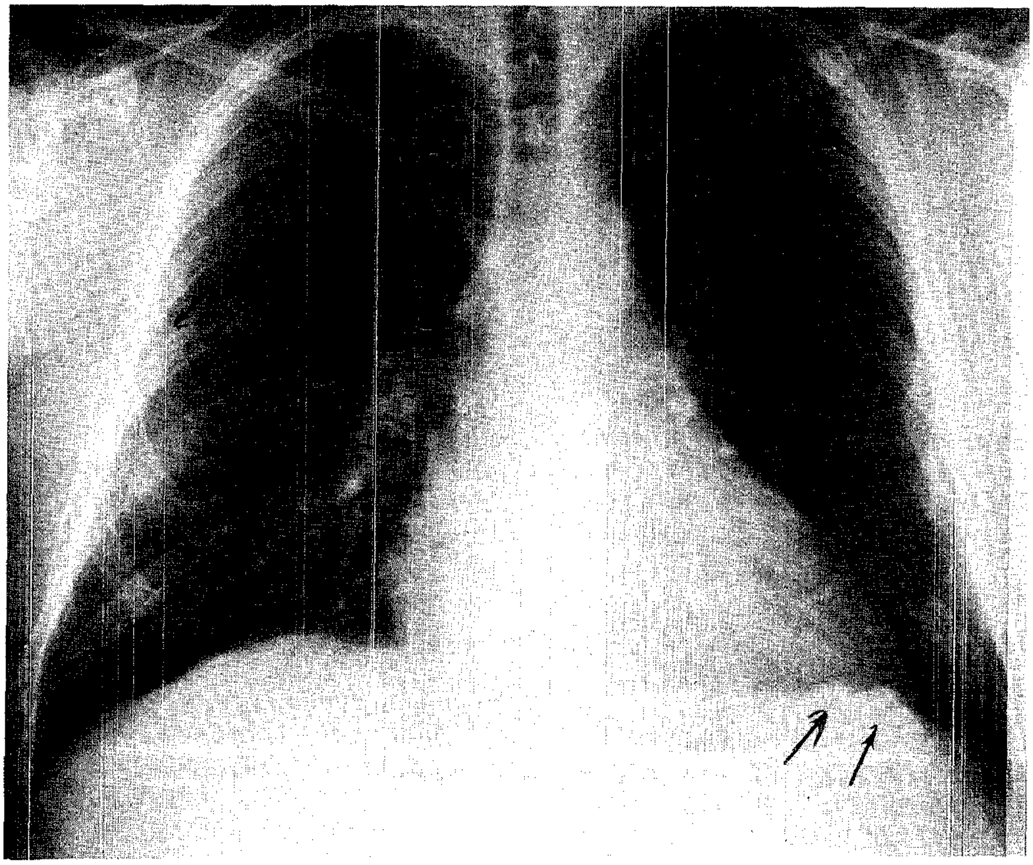

Figure 8B. A film with the same patient in deep inspiration. Numerous noncalcified plaques seen both in profile and en face along the lateral costal margins, and on the left diaphragm. The disease process would have been completely overlooked if the technique illustrated in Figure 8A was acceptable.

techniques resulting in long gray scale images. It is felt that films with a relatively long gray scale (many differences between "black and white") are more desirable than films of very high contrast with a short gray scale (few differences between "black and white"). Low kilovoltage, characteristically high contrast radiographs should be avoided. It is generally agreed that a film produced by the use of moderate to high kilovoltage (broader range of contrast and long gray scale) provides more diagnostic information than one produced with low kilovoltage x-rays.

The recommended high kilovoltage techniques also have greater latitude. This is an outstanding feature because this technique decreases the effects of technical errors such as the selection of wrong exposure factors, drop in line voltage, poorly functioning phototimers, etc. Radiographs of maximum detail with minimum variations in density and contrast can be produced with this technique. The radiographs are more consistent in quality and the number of unsatisfactory examinations is reduced. For these reasons relatively high kilovoltage techniques are recommended.

In order to prevent cardiac and respiratory motion the exposure time should not be greater than 1/30 second and 1/60 second or less is preferred. If phototimers are used they must be accurate. One should carefully check the phototimers; they are more

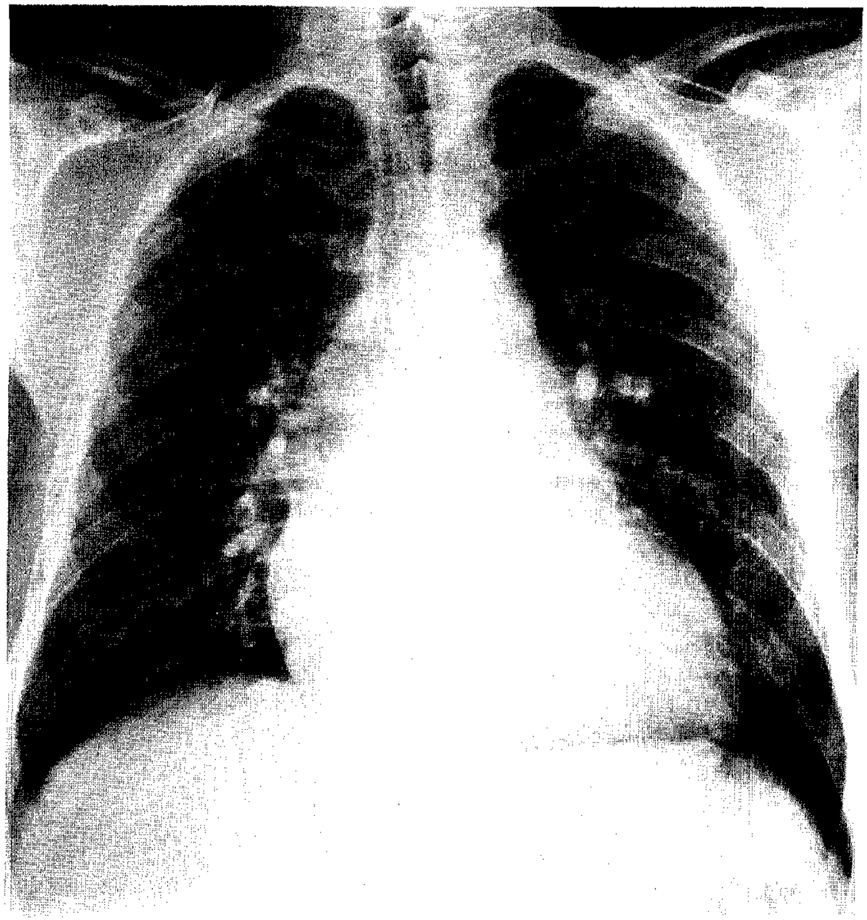

Figure 9. "Cone cut". The x-ray beam is limited to only a small amount of tissue below the costophrenic angles. It is adjacent to the outer margins of the edges of the ribs and includes only a small amount of the tissue in the neck area just above the lung apices. It is mandatory that the edges of the beam ("cone cut") be visualized on the film.

likely to be inaccurate with short exposures.

Exposure factors employed may vary somewhat with each generator and tube, but relatively high kilovoltage and short times should be used. For example, for the average subject with an anteroposterior chest diameter between 21 and 23 cm., the usual exposure factors will be 5 mAs at approximately 125 kVp, with a focal spot-film distance of 1.8 m. (6 feet). The recommended exposure time is 1/60 (0.017) second; not to exceed 1/30 (0.03) second based on 60 Hz current (for 50 Hz current, exposure times are 1/50 (0.02) and 1/25 (0.04) second, respectively). With larger chest diameters, additional exposure is obtained by increasing the kilovoltage. The milliampere-second product is increased only when the kilovoltage required to give a proper exposure exceeds the capability of the generator or x-ray tube. (When extremely obese patients are encountered, a focal spot-film distance of less than 1.8 m. (6 feet) should be adjusted by decreasing the milliampere-seconds product.) When using a lower kilovoltage technique, the exposure factors for an average subject may be approximately 300 mA, 0.05 second (15 mAs) at 75 kV. For larger subjects, greater amounts of radiation exposure are obtained by increasing either the milliampere-second product or the kilovoltage.

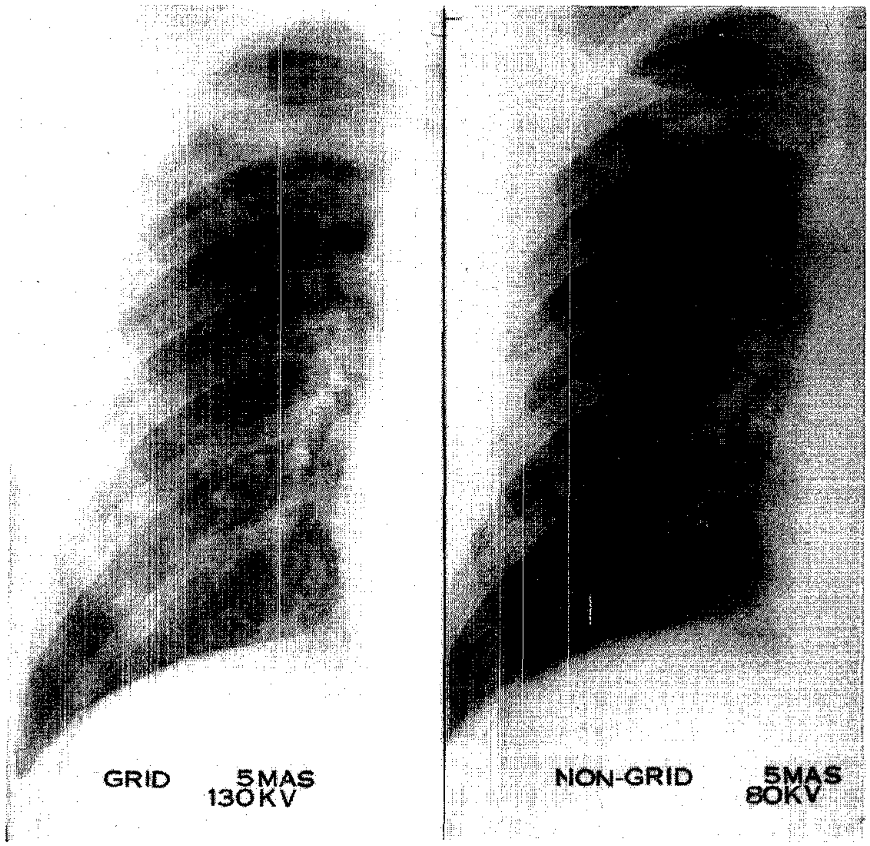

Figure 10A (left). Heavy patient. Note the superior quality of this film when using a grid as compared to the film in Figure 10B. The opacities due to pneumoconiosis are seen in greatest detail.

Figure 10B (right). The same patient as in Figure 10A with nongrid film. The scattered radiation fogging causes loss of detail and contrast, obscuring the entire disease process.

Fogging. Fogging of a film is a common problem that is encountered in the study of the pneumoconioses. It can be caused by light, heat, or chemicals during processing and aging of the film. However, fogging from secondary (scattered) radiation is a more common problem that has been encountered in studies of patients for the detection of pneumoconiosis. The use of a collimator to limit the primary x-ray beam to the chest is mandatory. The radiation must be confined by means of a collimator only to the portion of the subject to be examined. This will not only decrease unnecessary radiation but will also improve detail by reducing scattered radiation. The collimator should have an adjustable diaphragm, a light beam for centering, and be so designed that the projected field cannot exceed the size of the film. Evidence of collimation should be visable at the edges of the film as "cone cuts". However, the costophrenic angles must always be included on the film, but the "cone cuts" should show exclusion of all of the tissues immediately inferior to the costophrenic angles (Figure 9).

Reduction of Secondary Radiation from the patient's tissues, a major cause of film fogging, is essential. This can be accomplished by using a stationary grid or an air-gap

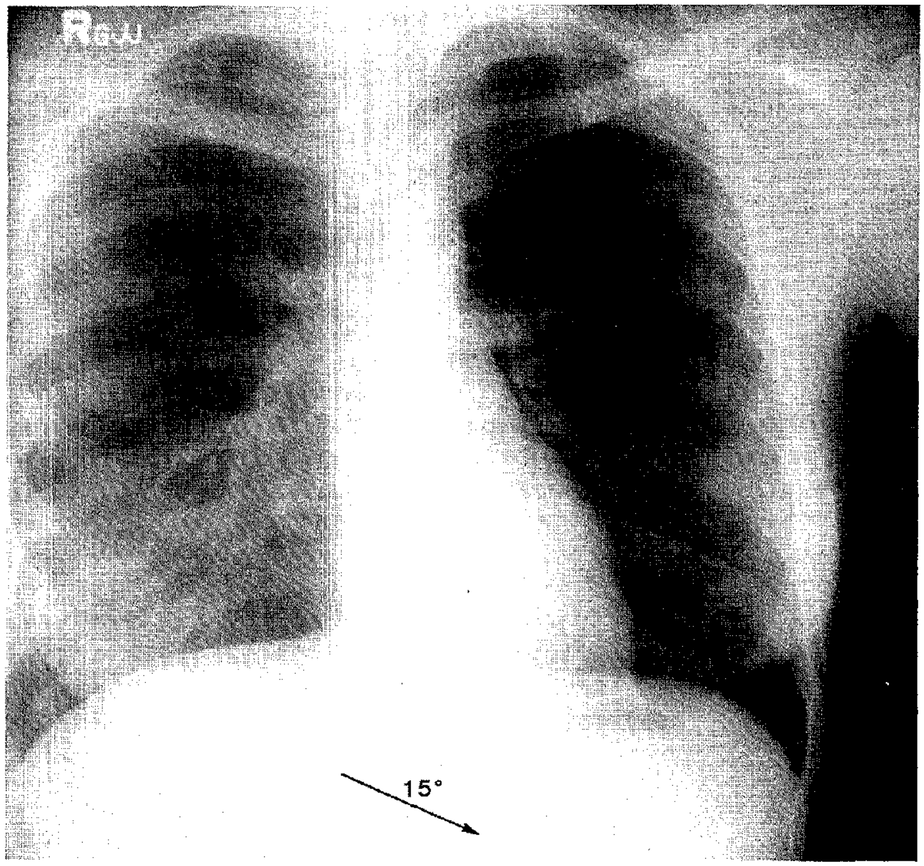

Figure 11. The x-ray tube is misaligned in relation to the surface of the grid and the cassette. Note the unwanted grid line artifact shadows. There is loss of density and detail of the images. The higher the grid ratio the more critical the required focusing, centering, and leveling.

technique. Generally speaking, when using kilovoltages of 80 and above, reduction of secondary radiation by a grid or other means is required. A 10:1 grid ratio with 100 lines per inch grid or an air gap of 20 cm. with a 2.5 m. focal spot-film distance may be used. A good rule of thumb is to use a grid for all subjects whose posteroanterior dimensions exceed 22 cm. when the two potentials that are being used are only between 70 to 100 kVp. However, with the use of modern generators, and kilovoltages above 100 kVp, a grid must be used for all subjects (Figures 10A and 10B). Improper manufacture of modern thin grids may result in artifacts. Aluminum spacing is superior to organic spacing material because the spacing is more accurate and the aluminum will also absorb the secondary radiation from the adjacent lead lines. The grid should be focused at 6 feet. Improper distance, improper leveling, as well as an off center focal spot will cause troublesome grid artifacts and image degradation (Figure 11).

Film-Tube Distance. With the use of grids, the focal spot-film distance should be fixed between 5 and 6 feet, although 6 feet is optimum (approximately 1.5 and 2.0 m.). Shorter focal spot-film distances result in abnormal magnification of anatomic structures and also loss of detail. Air-gap techniques utilize longer distances (e.g., 2.5 m.).

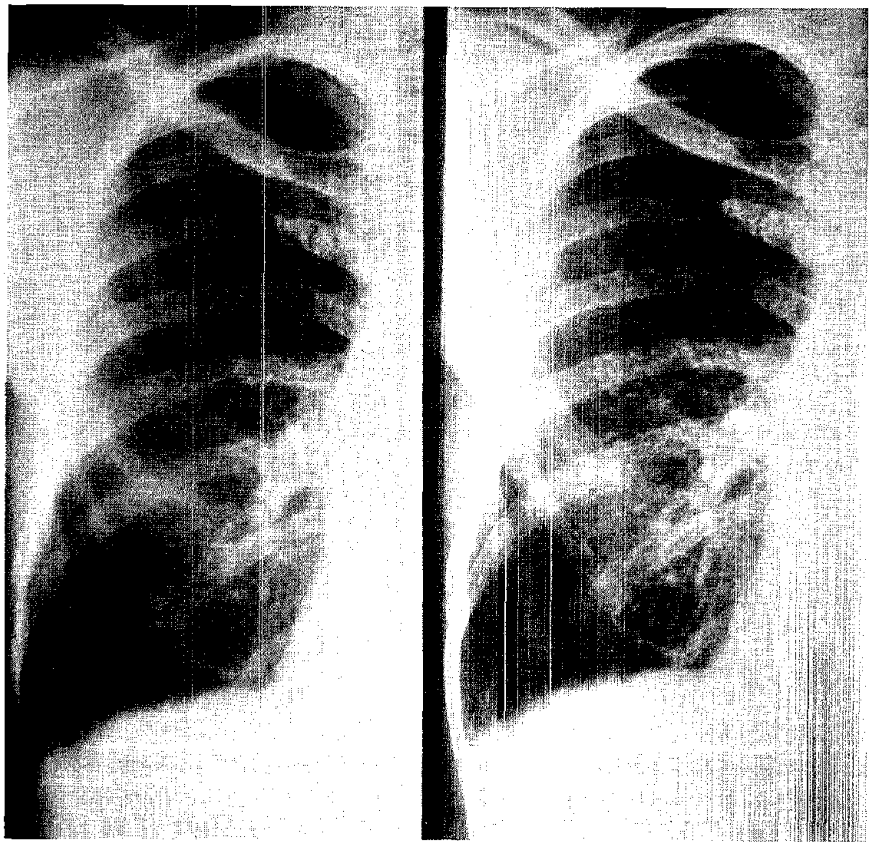

Figure 12A (left). There is poor screen contact due to a damaged cassette. Note the poor quality and loss of detail (compare to Figure 12B). Poor screen contact results in the inaccurate evaluation of the presence and number of small opacities.

Figure 12B (right). Demonstration of good screen contact with the disease process clearly outlined.

Film-Screen Combinations. Medium speed (par speed) intensifying screens and general purpose x-ray film of medium sensitivity are recommended to provide the best compromise between sharp definition and short exposure. Faster films with the larger crystal size and thickness may result in a loss of definition. Detail screens which have a smaller crystal size have better resolution but require a greater x-ray exposure. Similarly, high speed film with the greater grain size does not produce as good resolution as medium speed film. Nonscreen film with very small grain size has superior resolution but would require a longer exposure than desirable to arrest respiratory and cardiac motion. Some of the new rare earth screens in combination with slower speed films will, in the future, prove to be advantageous in decreasing the radiation exposure to the patient. Further investigation with patients is being conducted to determine if the detail required for chest radiography for pneumoconiosis assessment is as satisfactory as with conventional screens. The latitude or margin for error may be smaller so that more "retakes" to obtain an optimum film may be required in large survey studies.

Good Screen-Film Contact is essential with periodic testing being mandatory. Any area of poor screen contact will cause degradation of the image on the film with

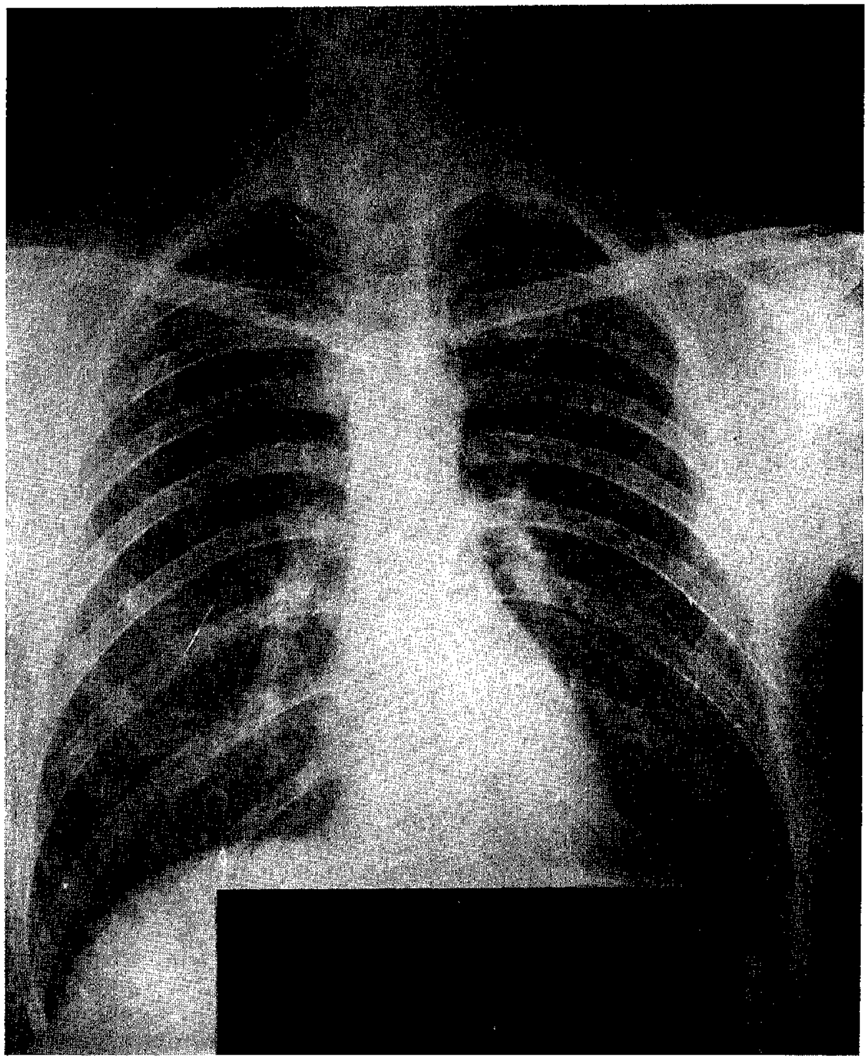

Figure 13. A clinically useless film. The screens are dirty. The film is underprocessed. It has also been light exposed. This film should be declared unacceptable under all circumstances for the study of the pneumoconioses.

decreased resolution and loss of information (Figures 12A and 12B). It is also assumed that cleanliness of the screens is mandatory. Dirty screens, damaged screens and cassettes, and mishandled films result in artifacts which may simulate a disease process or may degrade the image resulting in a loss of information (Figure 13).

Film Identification. The films should be properly identified with markers, including the name of the patient and the radiographic facility permanently imprinted. Films in which identifications are written so that they may be easily erased are not acceptable. The films should have the date and a right or left marker, with the patient's name, and/or social security number, and/or film identification number permanently imprinted. Whenever possible the original films should be submitted for study rather than film copies. If copied or "duplicated" films are submitted, some of the image detail and information has been lost in the copying process, resulting in less desirable interpretation and diagnosis.

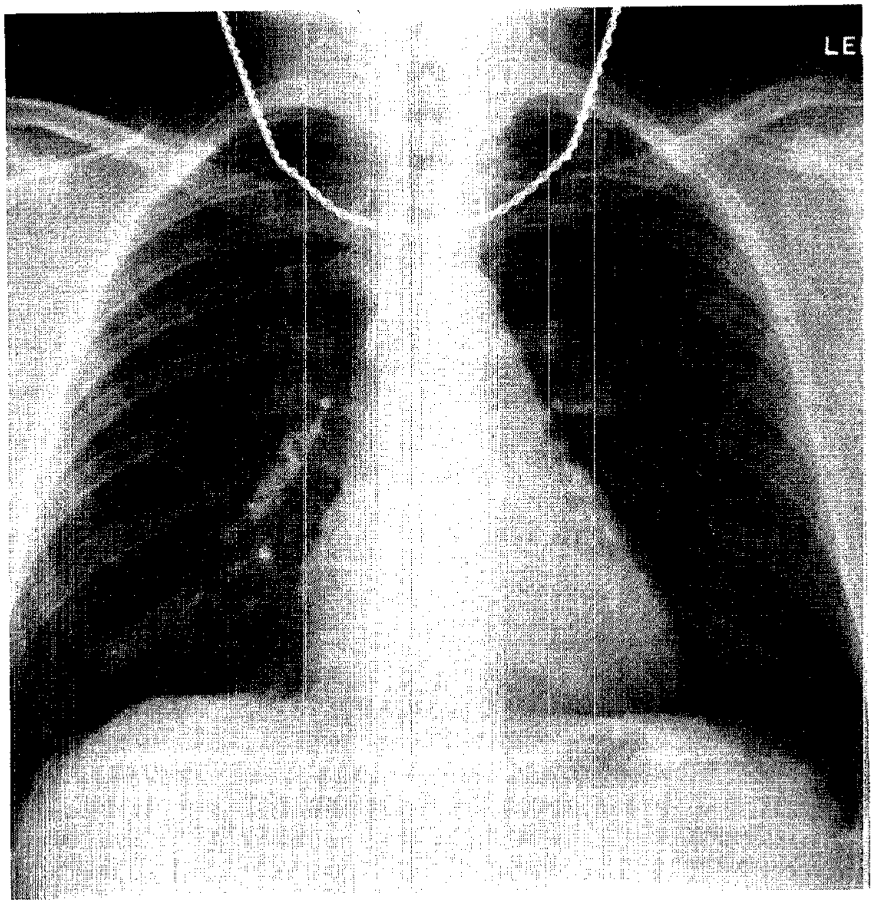

Figure 14. There is tuberculosis in the left apex. Part of the disease process is obscured by the overlying chain extending from the neck over the chest.

Film Processing. The chemical strength and temperature of processing chemicals must be maintained within the limits recommended by the manufacturer. Automatic processing should be employed wherever possible. If only manual processing is available, a constant time-temperature technique must be followed meticulously. An improper exposure cannot be corrected by improper processing (Figure 13). Film emulsion artifacts and dirty rollers in automatic processors can cause problems. A regular quality control program is essential to producing consistently good quality radiographs.

X-Ray Equipment. The installation and maintenance of the radiographic equipment is also very important. The electric power source should be independent of other users and must be of adequate capacity; i.e., subject to no more than a 5% fluctuation. The radiographic unit must be carefully calibrated at the time of installation and should be recalibrated periodically. Preventive maintenance at regular intervals, preferably by factory trained personnel, is strongly recommended. The generator should have a minimum capacity of 300 mA at 125 kVp, but a generator with a capacity of 150 kVp is strongly recommended. The generator must be full-wave rectified, although a capacitor discharge unit is acceptable. It should be equipped with an accurate timer ($\pm$ 1%) capable of a minimum exposure of no more than 10 milliseconds. A rotating anode tube is essential. It should have as small a focal spot as feasible for the anticipated load, but in no instance should this exceed 2 mm. in diameter. The total filtration of

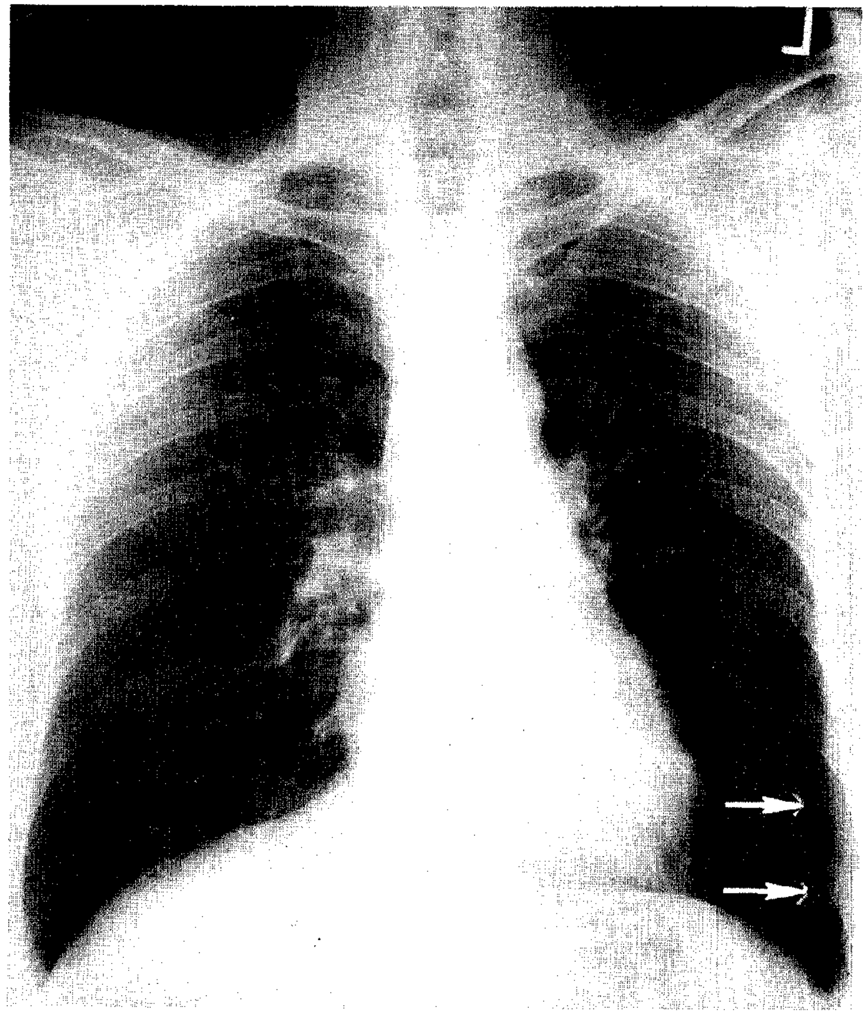

Figure 15. The soft tissue shadow along the lower left costopleural margin is due to the arm at the side. This could easily be misinterpreted as a pleural plaque. The arms must be abducted away from the chest wall to exclude any artifacts due to overlying soft tissue shadows.

the primary x-ray beam, inherent and added, shall be the equivalent of at least 2.5 mm. of aluminum. Further improvement in radiographic quality may be expected with the use of three-phase generator or other means of increasing the effective photon energy, high-speed rotating anode tubes, smaller focal spots, etc.

Positioning of the Patient. It is desirable that all clothing above the waist be removed, using a suitable gown. If the patient is not disrobed, resultant artifacts, can be troublesome. Synthetic fibers in sweaters, hair braids, jewelry, materials in pockets, etc. can cause artifacts on the film which can simulate or obscure disease processes (Figure 14).

The x-ray tube should be aligned with the center of the film and the x-ray beam directed horizontally. Careful positioning of the subject is required for the proper visualization of anatomic structures and for comparison of serial examinations. Misalignment of the x-ray source or rotation of the patient must be avoided. The image produced should show the sternal ends of the clavicle equidistant from a line drawn through the center of the spine. The arms should be at the sides with the back of the hands on the hips and the shoulders forward. The shoulders should be positioned so the scapulae are abducted outside the lungs and lateral to the costopleural margins. The patient's arms may be at the side but must not cover the edges of the film as the soft tissue of the arms can cause artifacts simulating pleural thickening (Figure 15). The image obtained must include the apex and the diaphragm, including the costophrenic angles and the entire lateral chest wall. If the subject is too large to include on a single film (in which the long axis of the film (14 by 17 inches) is at right angles to the floor) then the cassette should be rotated and placed transversely (so that the long axis is parallel to the floor). If it is felt that the subject is too large to obtain an image to include all of the required anatomic structures on a single film, then two films must be used. A film in the recumbent position (e.g., bedside examinations) is not acceptable because in this position the blood flow is toward the upper lung zones. Furthermore, if the film is not taken at a distance of 6 feet, there is a loss of detail resulting from magnification of the anatomic structures. The exposure must be made at full inspiration and taken immediately after this has been achieved in order to avoid the Valsalva effect. A film with the patient in deep inspiration (one in which the superior margin of the diaphragm is visualized at least at the level of the 6th rib anteriorly or 10th rib posteriorly) is very important. With the patient in expiration (Figure 8A) the basilar portions of the lung are compressed simulating a disease process and the costopleural margins are poorly outlined. Not only is the detection of the disease process hampered but the extent of the disease cannot be accurately determined.

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Chapter II

Equipment Requirements and the Use of the Test Phantom

John P. Kelley

The basic x-ray machine system for radiography of the chest consists of the generator (including control and transformer assemblies), the tube unit (including the x-ray tube, its housing, and the beam defining collimator), the tube stand or support, and the vertical cassette holder. These components are interrelated and improper selection, installation, or use may lead to loss of image sharpness or visibility of detail and, in general, radiographs that are not of adequate diagnostic quality. In this chapter we will briefly review the function of each of the x-ray system components, basic requirements for the components, some common problems that affect the radiographic image, the NIOSH test phantom as a diagnostic tool, and, finally, how to recognize when a problem may exist with the x-ray system and how to correct it.

Generator. The generator supplies and controls the electrical power to the x-ray tube and ancillary equipment. The generator used may be of most any type but must have adequate power to permit exposure times for a chest of average thickness (20 to 22 cm.) not in excess of 1/20 second (50 msec.) and preferably less than 30 msec. for the radiographic technique used. It should be mentioned here that high-voltage techniques with a grid or air gap are preferred for pneumoconiosis radiography although no grid techniques at lower kilovoltages may be used. Single-phase, 2-pulse systems and three-phase, 6- or 12-pulse generators should have a minimum rating of 125 kVp, 300 mA, but a 150 kVp rating is preferred. Capacitor discharge or battery powered systems should have ratings to permit exposure times of 1/20 second or less. Since the pneumoconiosis facilities certification program has been in effect, approximately 75% of the facilities submitting radiographs for certification used single-phase, 2-pulse x-ray systems and 75% used high-voltage (100 to 150 kVp), grid (8:1 to 12:1 ratio) techniques. But more on this later.

Not only must the generator have sufficient power but it must also provide reproducible exposures and adequate adjustment in technique (e.g., mAs) to maintain radiographic density and contrast for varying patient thicknesses. The effect of generator problems on the radiographic image will be discussed in the image degradation cause and cure section of this chapter.

Tube Unit. Due to the power requirements it is obvious that a rotating anode x-ray tube is required. The tube unit should have a rating at least equal to the rating of the generator. The size of the focal spot will effect image sharpness even with the 72 inch (183 cm.) minimum focal-film distance. The size of the focal spot should not exceed 2 mm., and a 1 mm. or smaller focal spot is preferred. For typical radiographic geometry for a posteroanterior chest radiograph, the geometric unsharpness due to the focal spot will be approximately 10% of the focal spot size.

Another source of image unsharpness associated with the x-ray tube is "motion" unsharpness. This may be due to vibration of the tube unit due to worn bearings in the rotating anode or imbalance in the anode assembly. The result, in effect, is a larger focal area during exposure with the associated geometric unsharpness.

Proper beam collimation is important from several standpoints. First, restricting the field to the x-ray film will reduce patient exposure and, second, reduce the quantity of scattered radiation produced. The less scatter, the greater the radiographic contrast. The beam collimator should provide evidence of collimation on the radiograph but not obscure diagnostic information. Since the posteroanterior chest radiographs are to be made using 14 by 17 inch (36 by 43 cm.) film, the collimator must be set to this size at the focal-film distance used. A light beam localizer for alignment of the x-ray beam to the film (patient) is essential for systems that do not provide mechanical linkage between the x-ray tube and vertical cassette holder.

Tube Support. The x-ray tube support must provide a stable mount for the x-ray tube housing and must provide scales, indexes, or other visual, mechanical, or electrical means for aligning the x-ray tube to the x-ray film. Improper alignment will be evident from the radiographic image indicating improper patient positioning. Unstable tube support will be evident by visual motion of the tube unit. A simple test for tube unit stability is to place a test tube stand on the tube unit and watch the vertical bar for motion when an exposure is made. Any significant motion will indicate a possible source of image unsharpness.

Vertical Cassette Holder. The vertical cassette holder must be firmly mounted to the floor and/or wall and provide a minimum 72 inch (183 cm.) focal-film distance. In addition to holding the cassette it may also hold either a stationary or oscillating grid. If an air gap is to be used, a 10 foot (3.05 m.) focal-film distance with a 6 to 8 inch (15 to 20 cm.) air gap is recommended. As noted for the tube support, means must be provided to align the x-ray film with the x-ray tube. Proper alignment of the grid, if used, is also important. It is important to repeat that accurate alignment between the x-ray tube and film must be maintained. If a general purpose diagnostic x-ray system is used wherein mechanical linkage between the x-ray tube unit and a vertical cassette holder is not provided, adequate means must be available to reposition the tube unit and the vertical cassette holder. If a moving grid is used, a rigid vertical cassette holder is imperative, since any motion of the cassette due to vibrations set up by the grid motion will lead to image unsharpness. Stationary grids, discussed later, should be "fine line"; e.g., 100 or more lines per inch (40 lines per cm.) and of 8:1 or greater ratio.

Phototiming of exposures is certainly acceptable provided the technique settings are within the 1/20 second maximum exposure time. It must be remembered that some phototiming systems may be unreliable for the short exposure times used in high mA techniques. This should be investigated if high mA, short exposure time techniques are used.

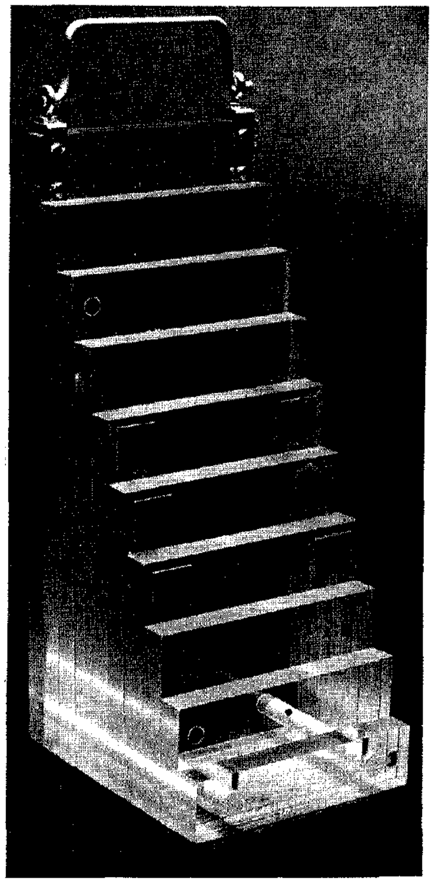

Figure 1. A test phantom.

Image Degradation Cause and Cure

The preceding briefly discussed the x-ray system and some of the factors that can contribute to an unacceptable radiographic image. Let's now look at specific items that can result in an unacceptable radiographic image, specifically those factors associated with the x-ray system. Visibility of radiographic detail will depend upon the radiographic density and range of densities (contrast). Contrast is what makes detail visible. It was determined early in the pneumoconiosis program that some form of "test object" or "test phantom" was needed to evaluate the x-ray equipment and techniques used. This resulted in the NIOSH step wedge or test phantom previously described in detail (1). Since the test phantom is used in the NIOSH pneumoconiosis facilities certification program, a brief description of its construction and use is appropriate here. (See Chapter XI for additional information on the test phantom.)

A photograph of the test phantom is shown in Figure 1. The phantom is a 10-step thermoplastic acrylic resin (Plexiglas) step wedge. It is 6 inches (15.25 cm.) wide and 15 inches (38.1 cm.) long. Each step is 1.5 inches (3.8 cm.) long. The first step is 0.75 inch (1.9 cm.) thick and the step thickness increases 0.75 inch (1.9 cm.) per step so that step 10 is 7.5 inches (19 cm.) thick. When the phantom is radiographed using the factors routinely used for a patient with a chest of average thickness (20 to 22 cm.), the phantom radiograph provides the range of densities that would be found in the posteroanterior chest radiograph. Measurement of the density of each step can be plotted against step number on linear (cross-section) graph paper providing a graph that can be compared with graphs made at other times or under other exposure conditions. Such a comparison can provide information concerning film processing conditions as well as exposure factors or a change in exposure factors.

Many of the x-ray systems used for radiography of the chest are also used for general radiography. As a result, the geometry that results from repositioning of the x-ray tube from radiographic table procedures to the vertical cassette holder can lead to some poor exposure geometry (i.e., improper alignment between the x-ray tube and the film in the vertical cassette holder) unless rigid stops, markers, etc. are provided. To get information on this, the test phantom has a lead pin embedded in the top of step 9 and a brass ring embedded in the bottom of step 10. The pin and ring are positioned in the phantom such that, when a 72 inch (183 cm.) focal-film distance is used and there is a 1 inch (2.54 cm.) space between the front of the cassette holder (bottom of phantom) and the film, the image of the lead pin will be inside the image of the brass ring if proper alignment exists between the x-ray tube and film. If misalignment exists, the degree and direction is indicated by the location of the image of the pin in relation to the image of the ring.

The test phantom also provides other information concerning the geometry used. Two small lead bars are embedded in the thickest step. When a 72 inch (183 cm.) focal-film distance is used, the distance between the images of the lead bars on the radiograph will be 10 cm. If a focal-film distance less than 72 inches (183 cm.) is used, the distance between the images of the lead bars will be greater than 10 cm.

To indicate gross loss of radiographic detail, due to poor film-screen contact, for example, pieces of reasonably fine brass wire mesh (40 and 60) are mounted on steps 5, 6, and 7 of the phantom. In addition to poor film-screen contact, the image of the brass mesh would indicate any other sources of gross loss of detail such as movement of some mechanical structure (tube support, film holder) during exposure.

Positioning of the phantom prior to exposure is illustrated in Figure 2. The test phantom is placed on a suitable sturdy support (stand, work stool, etc.) with the bottom in contact with the front of the cassette holder. It is important that the test phantom not be tilted or skewed. The test phantom should be centered, both horizontally and vertically with respect to the x-ray film, such that the intersection of the centering lines at the junction of steps 5 and 6 of the phantom is at the geometric center of the film. Most vertical cassette holders have centering lines that will aid in phantom positioning. The x-ray beam is then centered to the film center (i.e., the step 5-6 junction of the test object). Collimators with light beam localizers have centering lines as an aid in positioning. The x-ray field size should be set to the 14 by 17 inch (36 by 43 cm.) film size with evidence of collimation being visible on the radiograph. The radiograph, made using the technique factors for a chest of average thickness, can then be analyzed for the exposure and geometry factors previously discussed. A typical radiograph of the test phantom is shown in Figure 3.

The use of this test phantom permits evaluation of density and contrast, focal-film distance, x-ray tube to film alignment, and visibility of detail. By use of this phantom it was determined that optimum density and contrast could be obtained for both no grid and grid techniques (and air gap techniques as described elsewhere (2)). That is, essentially the same density and contrast are obtained by proper selection of kilovoltage, mAs, grid ratio, and air gap. A plot of density vs. test phantom step

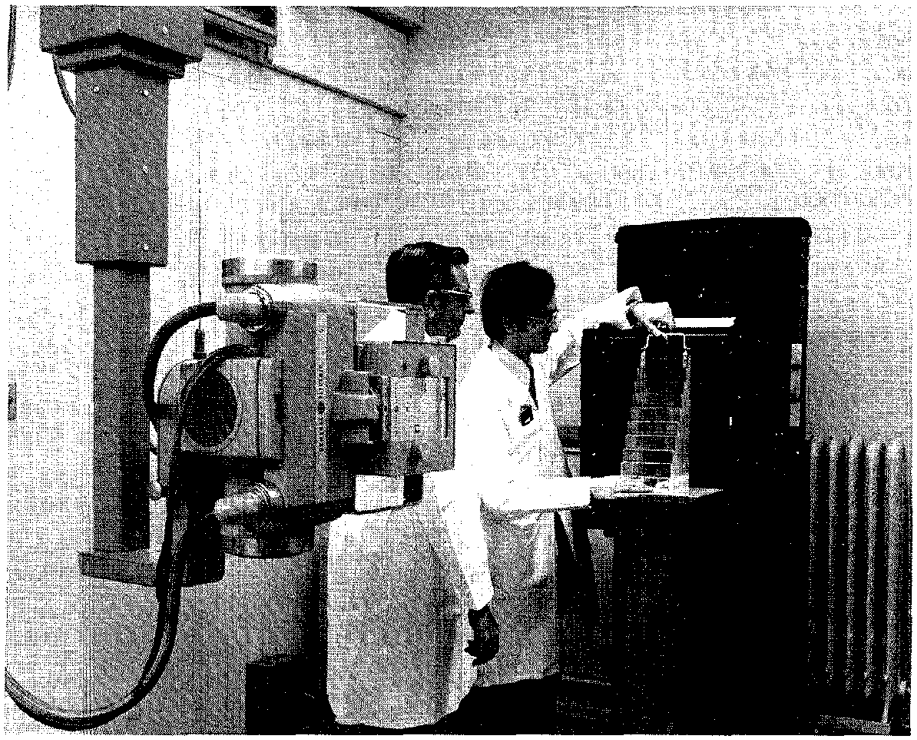

Figure 2. A test phantom positioned in front of a cassette holder.

number using the test phantom for no grid and grid techniques is shown in Figure 4. Data points are not included but the spread is mainly statistical. Note that the graph of density vs. test phantom step number shown in Figure 4 is for single-phase, three-phase, and battery powered (high frequency) x-ray systems. The technique factors used are shown in Table I. Although the energy and exposure rate for three-phase and battery powered systems is greater, for the same kVp and mA, than single-phase systems, technique factors for all three systems can be selected to yield comparable radiographic density and contrast. The whole point is that the radiographic technique can be selected to provide optimum density and contrast since the pneumoconiosis program is a long range one and comparable diagnostic radiographs must be made over a period of many years. The test phantom radiographs provide the range of densities found in an acceptable posteroanterior chest radiograph. It should be kept in mind that the most "useful" range of densities for a posteroanterior chest radiograph is about 0.5 to 1.5 (or possibly 0.2 to 1.8). Higher or lower densities are not of diagnostic value.

If your chest radiographs do not provide the density and contrast that is required, what might be wrong? First of all, obviously, are the correct technique factors being used? Or, if the technique factors previously used to produce an acceptable radiograph now do not do so, what might be wrong? If the change was rapid, it is likely that some equipment failure has occurred. Has a high voltage rectifier failed resulting in the equipment operating half-wave rather than full-wave? If so, the mA meter would indicate half the tube current you should have. Check the mR/mAs exposure and compare to previous values. After all, one set of data is worth 1000 expert opinions. If you do not have the instrumentation to make x-ray exposure measurements, either get the instrumentation (simple systems are not very expensive) or call on a radiologic physicist or health physicist. Since the x-ray output (e.g., mR/mAs) and energy (e.g.,

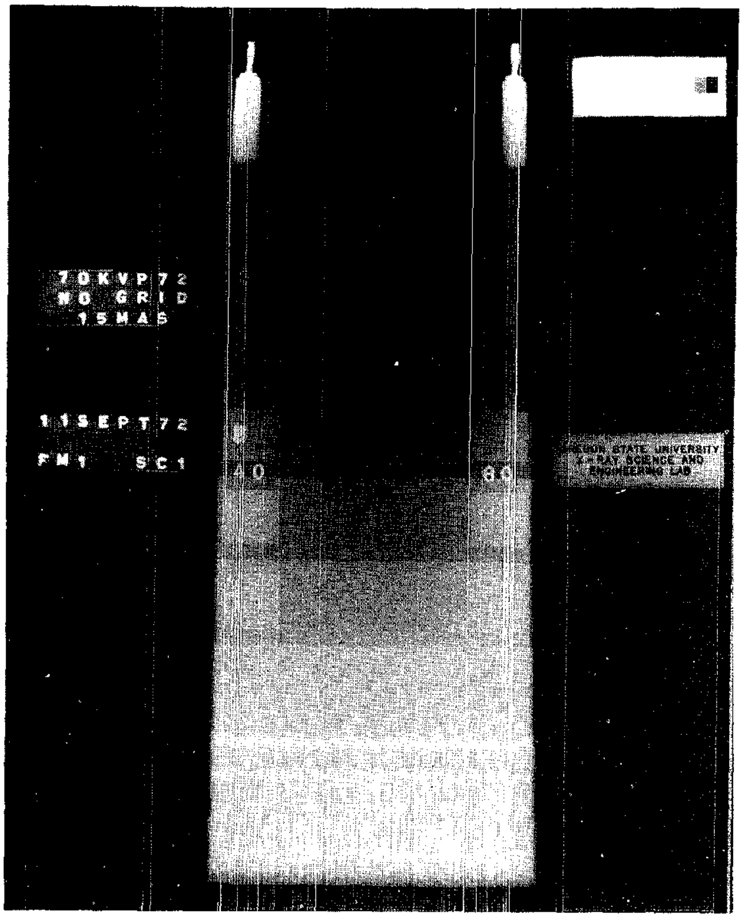

Figure 3. Radiograph of a test phantom.

half-value layer) determine with exposure time the film exposure, exposure measurements are an important part of any quality control program. If you do not have access to instrumentation or physicists, call on the state radiation control agency or your x-ray equipment service group. Have you checked the x-ray timer? Do you have a spinning top? If the change in density/contrast has been gradual there are several possible causes. One of the most likely is roughening (etching, pitting) of the target of the x-ray tube. This may be the result of normal, and not necessarily (but possibly) abnormal, use of the tube. The roughening will result in a decrease in x-ray output, and an increase in beam energy, both due to an increase in x-ray absorption in the target of the x-ray tube. So, if there is a gradual decrease in radiographic density and a decrease in contrast, it is likely due to the increased filtration in the x-ray tube target. An increase in filtration can also occur due to vaporization of tungsten from the x-ray tube anode or filament with deposit on the inside of the x-ray tube envelope including the window area of the x-ray tube. A decrease in exposure could also result from partial failure in the primary autotransformer or in the high voltage transformer but these types of failure would most likely result in increased primary current such that either a fuse or circuit breaker would be actuated. As previously mentioned, a measurement of x-ray beam output compared to earlier output measurements is an indicator of output change. It is important that baseline operation be established (i.e., when the x-ray equipment is producing diagnostic radiographs) so that future operation can be compared to the baseline operation. Patient radiographs may not show subtle

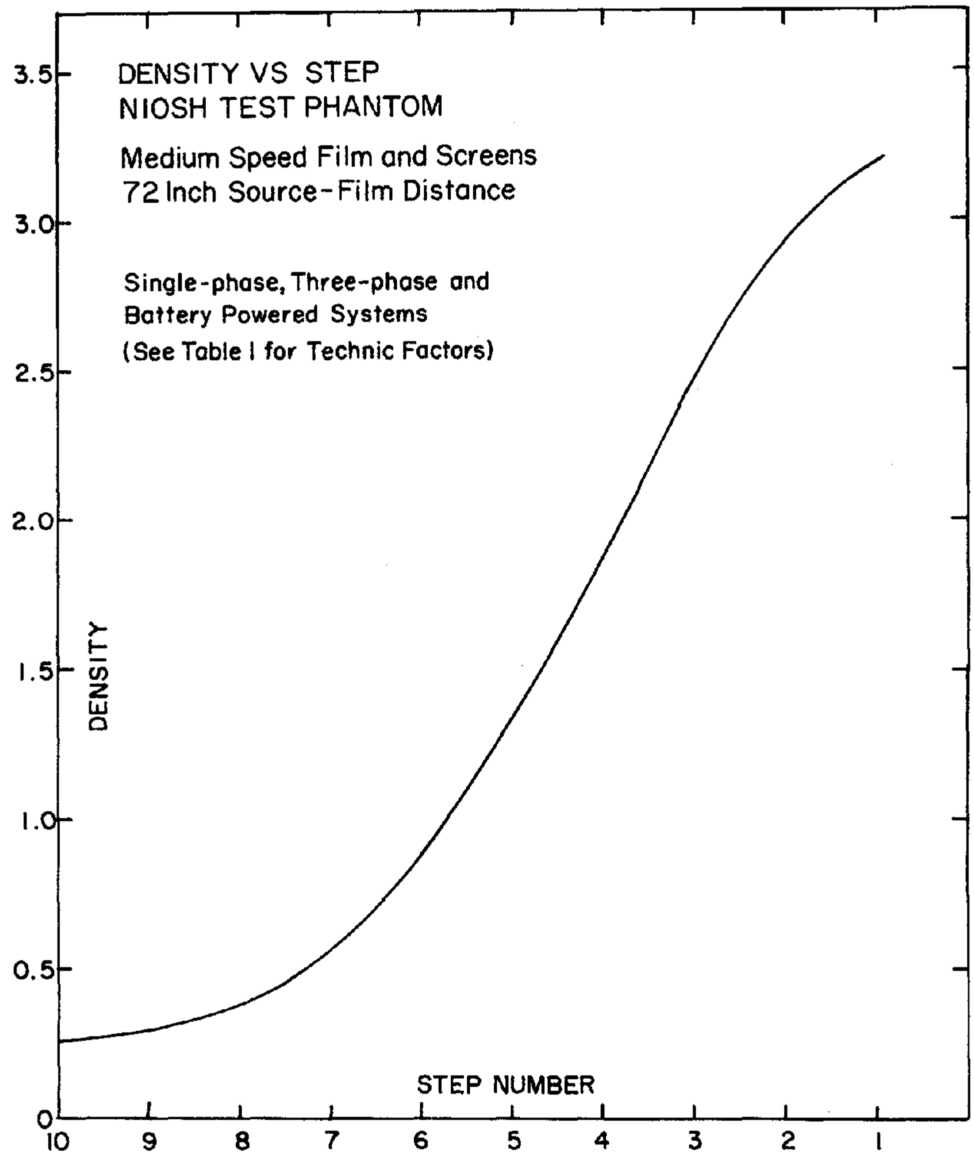

Figure 4. Density vs. step for NIOSH test phantom.

changes. Measurement of x-ray output or a radiograph of some test object (e.g., a test phantom or even an aluminum step wedge) compared to the baseline data (i.e., mR/mAs or density/contrast) will indicate if a change has occurred. Having established that there has been a change in "output", investigate the more likely causes as described above.

Image unsharpness due to x-ray machine factors is most likely to involve "effective" focal spot size or motion of one of the system components during exposure. As noted earlier, the geometric image unsharpness due to the size of the focal spot is approximately 10% of the focal spot size. Thus, a 2 mm. focal spot will produce twice the unsharpness of a 1 mm. focal spot. This is referred to as geometric unsharpness since it is a function of the system geometry; i.e., focal spot size, focal-film distance, and object (chest) film distance. A 2 mm. focal spot is the maximum that can be used for chest radiography and a 1 mm. or smaller focal spot is preferred. Motion of the focal spot, as discussed earlier, can increase the effective size of the focal spot. The NIOSH test object contains brass mesh that can permit detection of image sharpness. For routine checks on image sharpness some reasonably fine brass mesh (40 to 60) can be radiographed. If the sharpness of the radiographic image decreases, what are the likely causes? Most likely it is some form of motion. Maybe after the tube unit was positioned it was still moving back and forth during the exposure. Maybe the rotating anode is causing tube unit vibration. It's possible. So watch it. When the patient is told "take a deep breath and hold it" make sure that the x-ray system is not in motion.

The typical data in Figure 4 are for single-phase, three-phase, and battery powered systems. If a three-phase 6- or 12-pulse system is used, or a high-frequency battery powered system, the effective energy will be higher than single-phase, for the same kVp. As a rule of thumb, use half the mAs at the same kVp for three-phase systems. The contrast, however, will be lower. Typical exposure factors for single-phase, three-phase, and battery powered systems for a chest of average thickness are shown in Table I (3,4).

The data in Table I will provide a starting point for establishing technique factors. Some variation can be expected from one facility to another but any significant change should be investigated using the preceding discussion of factors affecting density and contrast.

Table I

Typical Technique Factors for a Posteroanterior Chest of Average Thickness
72 inch (183 cm.) Focal-Film Distance
Medium Speed Film and Screens

	X-Ray System					
	Single-phase, 2-pulse		Three-phase, 6- or 12-pulse		Battery powered	
Grid	kVp	mAs	kVp	mAs	kVp	mAs
No grid	70	15	62	15	70	10
6:1*	100	110	88	99	95	88
8:1	115	7.5	100	7.5	--	--
10:1	130	5	114	5	--	--

* A 6:1 ratio grid is not recommended. It is listed only as a guide.

Film Densitometry

The matter of radiographic density has been noted in previous sections of this chapter as it relates to x-ray equipment operation and the NIOSH test phantom. It should be obvious that the density of the radiograph is related to the exposure that the x-ray film-screen system receives (i.e., the "mR") and that this exposure is related to the x-ray beam energy (kVp), the tube current-time product (mAs), the patient (chest) thickness, whether or not a grid or air gap is used, and the focal-film distance. The range of densities for pneumoconiosis radiography, that is the densities throughout the lung fields, that are diagnostically useful start at a minimum of about 0.2 and go to a maximum of about 1.8 (optimum 0.5 to 1.5). Radiographic density is the "degree of darkening" of the film upon exposure and processing and is defined as the logarithm to the base 10 of 1 divided by the transmission of visible light through the radiograph. Look at it this way. At a density of 0.5 the light transmitted is about 0.3 or 30%. At a density of 1.0 the light transmitted is 0.1 (10%), at a density of 2.0 the light transmitted is 0.01 (1.0%), etc. Below density 0.5 you are on the "toe" of the film response curve (see Figure 4) where a relatively large change in percent exposure produces a relatively small change in density. In other words, contrast (i.e., density change) which makes detail visible is lost. The same situation exists at high densities where you approach the "shoulder" of the film response curve. Besides, conventional radiograph illuminators do not provide sufficient light for the higher densities (sometimes referred to as the "black as a stove lid syndrome"). In either case, as noted, contrast is lost. So the name of the game is to get the densities in the lung field area of the radiograph in the 0.5 to 1.5-range.

All this is fine but how does one know what the densities are on a radiograph? It really doesn't mean much to say "this film is too dark" or "this film is too light". How dark is dark and how light is light? Such decisions are in the mind of the beholder. Hence the densitometer. The densitometer is an instrument designed and constructed to take the opinion out of how dark and how light. It is an instrument that "measures" the amount of light transmitted through the film and displays this in units of density. With a densitometer "how dark" and "how light" become measured, numerical quantities. A densitometer should be available to all diagnostic radiologic facilities since it is one of the basic instruments necessary for any proper quality control program. You can obtain densitometers from many sources and they can be simple to complex. Or if you are a frustrated electronics buff, you can even build your own (5). However, "store bought", calibrated systems are usually preferable. With a densitometer you can measure the density in various areas of the chest radiographs, or the step densities for a radiograph of the NIOSH test phantom. If you don't have one, get one. Try it, you'll like it, not only for density measurements on radiographs, but also for density measurements on test films run on your film processing system, automatic or manual.

Let's look again, at basics. If the densitometer tells you that the density is too low you should increase exposure (mAs), and if too high, reduce mAs. If contrast is too low, reduce energy (kVp) with corresponding increase in mAs. If contrast is too high, increase kVp. The densitometer can be of significant help in establishing proper exposure factors and in determining when changes have occurred in the radiographic result. A test phantom, such as the NIOSH or similar ones, used with a densitometer for radiographic density readout will indicate if any change has occurred in x-ray equipment operation or film processing conditions.

If a change is noted, the source (x-ray equipment or film processing) can be isolated by use of another very important instrument, the sensitometer. A sensitometer is an instrument that uses a light source to expose x-ray film such that a series of densities result when the film is processed. A number of excellent sensitometers are available commercially or you can build your own (6). Each provide controlled exposures with both short and long time stability. To use the sensitometers one exposes the film, processes it, measures the densities with the densitometer, and compares the measured densities to those previously obtained. The test phantom exposure, therefore, checks for x-ray equipment change, and the sensitometer for processing change.

Summary

In summary, the x-ray equipment used should have a minimum rating of 125 kVp, 300 mA; 150 kVp rating is recommended. The preferred technique is one employing high kilovoltage (e.g., 125 to 150 kVp) with a fine line (e.g., 100 to 110 lines per inch (39 to 43 lines per cm.)), and high ratio (e.g., 10:1) grid.

Optimum radiographic density and/or contrast is associated with the technique factors used (kVp, mA, time). Generally speaking, if density is low, exposure (mAs) should be increased. If contrast is low, energy (kVp) should be decreased.

Radiographic unsharpness is a function of the geometric variables involved in the radiographic process and any unwanted motion. Of the geometric variables (patient-film distance, focal-film distance, and focal spot size) the focal spot size is associated with the x-ray system. The focal spot must not exceed 2 mm. in size and should not exceed 1 mm. Sources of unwanted motion associated with the x-ray system may include motion of the tube unit during exposure and motion of the cassette.

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Chapter III

Positioning

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E. Nicholas Sargent, M.D.

Radiographic examination of the chest requires that exacting attention be paid to a multiplicity of factors including positioning, technique, collimation, etc. Of these factors correct positioning is of primary importance in the recognition and classification of the pneumoconioses. Because a radiograph is a two-dimensional representation of a three-dimensional object, an incorrectly positioned patient creates a confusing array of overlapping structures on the resultant radiograph that often precludes accurate diagnosis. The patients' clothing should not interfere with the image, and must be removed, along with all jewelry and other ornaments, before the radiograph is taken.

Technique requires the adjustment of the kilovoltage and milliampere seconds to obtain optimal contrast and density in the radiograph. These factors are determined by measuring the patient and by using technique charts (see Chapter IV). The exposure must be made without patient motion (voluntary or involuntary).

The correct source image distance (SID*) must be used to avoid excess magnification and distortion. This is particularly important for chest radiography. The standard SID for non air-gap techniques is 72 inches and is the distance at which all radiographs should be made for the study of the pneumoconioses.

The x-ray beam must be limited in area for two critical reasons: (1) the patient must be protected from radiation outside of the area of interest, and (2) the smaller the field size, the sharper the image because of reduced scattered radiation. This is accomplished with the use of a positive beam restricting collimator. <u>All four margins of the radiograph should show collimation lines.</u>

Identification of the radiograph is of the utmost importance. The date and the patient's name should be clearly legible and permanently imprinted on the film. The importance of the correct right or left marker clearly visible on the film cannot be overemphasized.

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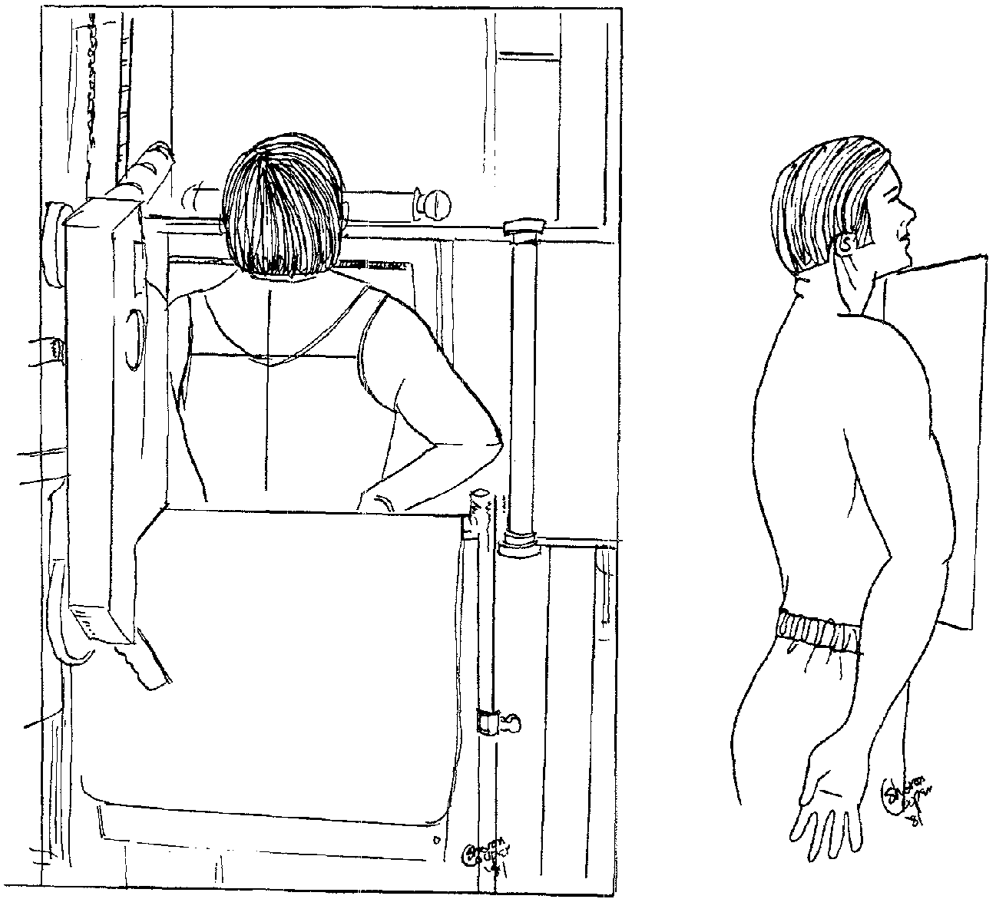
* Focal spot-film distance



Figures 1A (left) and 1B (right). The correct position for an upright posteroanterior chest radiograph.

Although the primary concern of the radiographer is always the patient, the next important objective is the production of an optimal radiograph enabling the radiologist to make a definitive diagnosis. This is especially critical when working with patients in whom occupational lung disease is suspected.

Radiographers must be extremely cognizant of the anxiety of patients. The patient must be made to feel as comfortable as possible. When the radiographer is able to create an atmosphere of confidence, it is much easier to properly position the patient for a chest radiograph.

The Correct Procedure for Positioning a Patient for a Posteroanterior Chest Radiograph. (1) Place the patient in an upright position. (2) Adjust the SID (source image distance) to 72 inches. (3) Align the midsagittal plane to the center of the cassette (which is also the center of the film) (Figures 1A and 1B). (4) Instruct the patient to stand so that the body weight is equally distributed on both feet, with the head facing forward, without rotation. (5) Place the patient's hands on the hips with the shoulders forward, palms rotated internally (dorsum of hands on hips) and the elbows slightly flexed. (6) The long axis of the film should be parallel with the long axis of the body except in very obese or large patients, when the cassette should be placed transversely (Figures 2A and 2B). (7) Adjust the central ray until it is

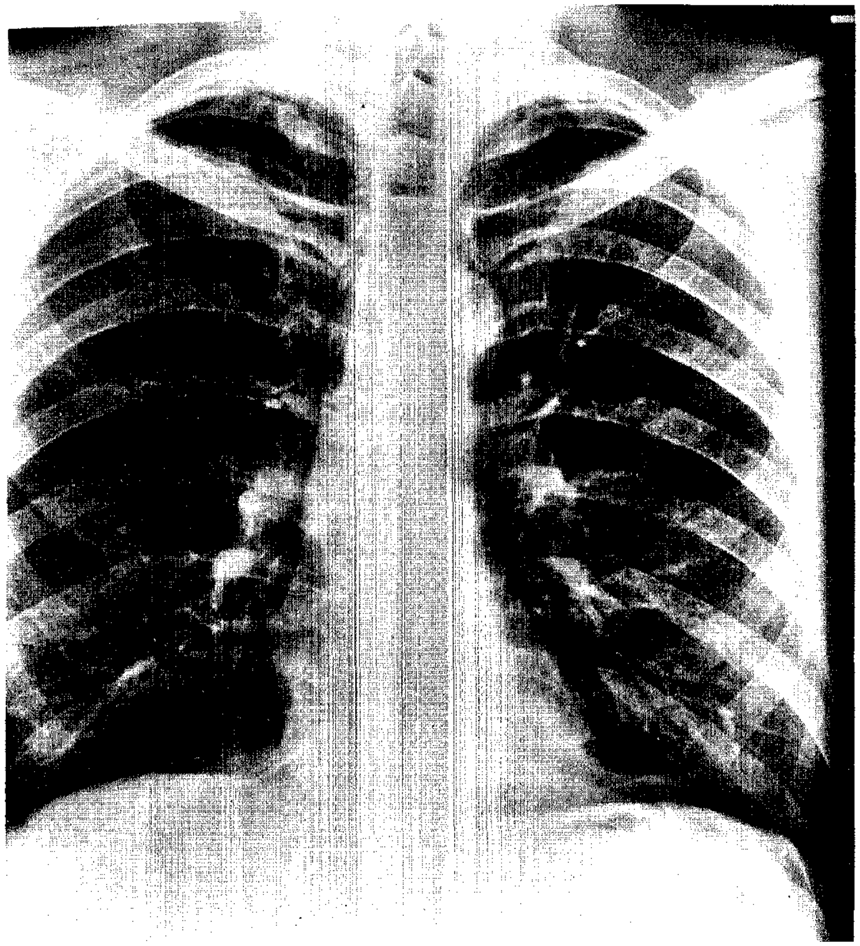


Figure 2A. A large patient, part of the chest cut off.

perpendicular to the film. (8) In addition, adjust the central ray so that it is directed horizontally to the midsagittal plane at approximately the level of the fourth thoracic vertebra. (9) Center the film to the central ray. (10) Instruct the patient to hold the breath at the completion of the second full inspiration and make the exposure immediately to prevent the Valsalva effect (Figures 3A and 3B) (i.e., tell the patient to take a deep breath, blow it all out, take another deep breath, and hold it).

After the radiograph is processed, it should be examined for the following features: (1) The lung fields should be visualized in detail, including the costophrenic angles (Figures 4, 5, and 6). (2) The scapulae should not overlap the lungs (Figures 7A and 7B, and 7C). (3) The medial ends of the clavicle should be visualized at about the level of the fourth posterior rib (Figures 4 and 9). (4) The medial margins of the sternal ends of the clavicles should be equidistant from the spinous processes (providing no scoliosis is present) (Figures 4 and 9). (5) The diaphragm should be approximately at the level of the tenth posterior rib or sixth anterior rib (Figures 4, 8A, and 8B). (6) There should be no detectable rotation of the patient (Figure 9).

The Correct Procedure for Positioning a Patient for a Left Lateral Chest Radiograph. (1) Place the patient in an upright position with the left side against the cassette

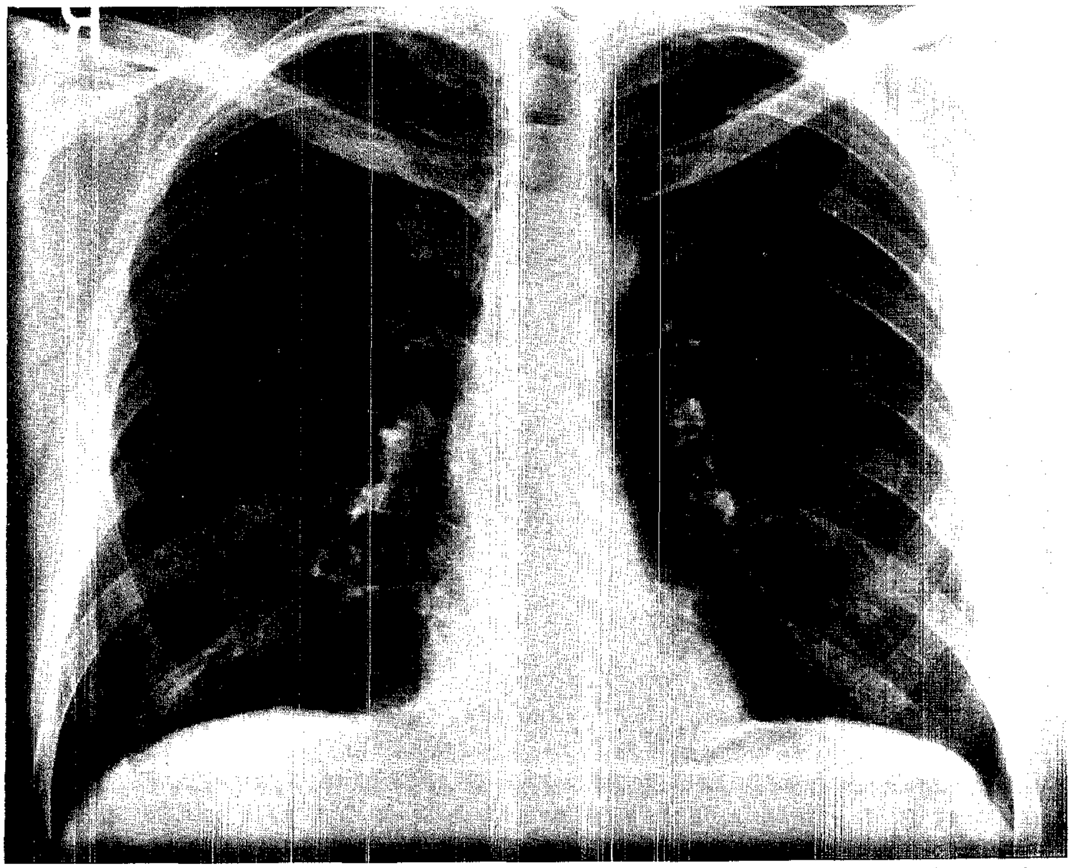


Figure 2B. Same patient, cassette placed in transverse position with the entire chest on the film.

(Figure 10). (2) Position the patient so that a point approximately 5 cm. anterior to the midaxillary plane is centered to the midline of the film. (3) Instruct the patient to adjust the weight so that it is equally distributed on both feet with the head facing forward without rotation. (4) Elevate the patient's arms above the head with the elbows flexed and the forearms resting on top of the head. (5) Be sure that the midsagittal plane is in a true vertical position. (6) Be certain the long axis of the film is parallel with the long axis of the body. (7) Adjust the central ray until it is perpendicular to the film. (8) In addition, adjust the central ray until it is directed horizontally to the level of approximately the fourth thoracic vertebra. (9) Center the film to the central ray. (10) Instruct the patient to hold the breath at the completion of the second full inspiration and make the exposure immediately to prevent the Valsalva effect (i.e., tell the patient to take a deep breath, blow it all out, take another deep breath, and hold it).

After the radiograph is processed, it should be examined for the following features: (1) the the lung fields, diaphragm, and posterior costophrenic angle should be visualized with good detail (Figure 11). (2) There should be no detectable rotation of the patient.

The Correct Procedure for Positioning a Patient for a Right Anterior Oblique Chest Radiograph (it should be noted that by reversing this position, a left anterior oblique chest radiograph can be obtained): (1) Position the patient in the erect right anterior

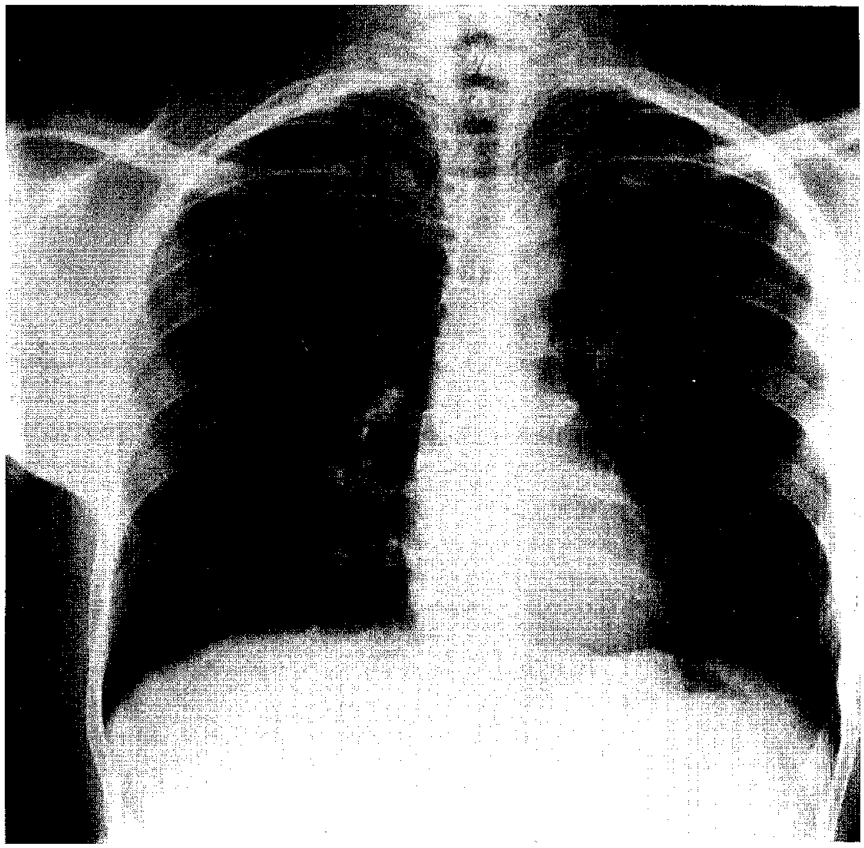


Figure 3A. Valsalva effect. The patient holds the breath too long and "squeezes" air out against a closed glottis. The heart is compressed and its true size is not measured. The blood is squeezed out from the small vessels and the lungs appear falsely "emphysematous".

oblique position (Figure 12). (2) Center the midsagittal plane to the midline of the cassette holder. (3) Adjust the patient's right arm with the elbow flexed and the hand resting on the hip. (4) Rotate the patient approximately 45 degrees (a template cut from cardboard is helpful in providing an accurate 45 degree angulation between the patient and the cassette). (5) Be certain that the patient's right shoulder is in close proximity with the film. (6) Elevate the left arm of the patient with the left hand resting on top of the head. (7) Adjust the shoulders to lie in the same transverse plane; the head is faced forward without rotation. (8) Be certain the long axis of the film is parallel with the long axis of the body. (9) Adjust the central ray until it is perpendicular to the film. (10) In addition, adjust the central ray until it is directed horizontally to the midsagittal plane at approximately the level of the fourth thoracic vertebra. (11) Center the film to the central ray. (12) Instruct the patient to hold the breath at the completion of the second full inspiration and make the exposure immediately to prevent the Valsalva effect (i.e., tell the patient to take a deep breath, blow it all out, take another deep breath, and hold it).

After the radiograph is processed, it should be examined for the following features: (1) the anterior margin of the heart and the posterior surface of the sternum should form an angular clear space. (2) The ascending and descending aortas should be

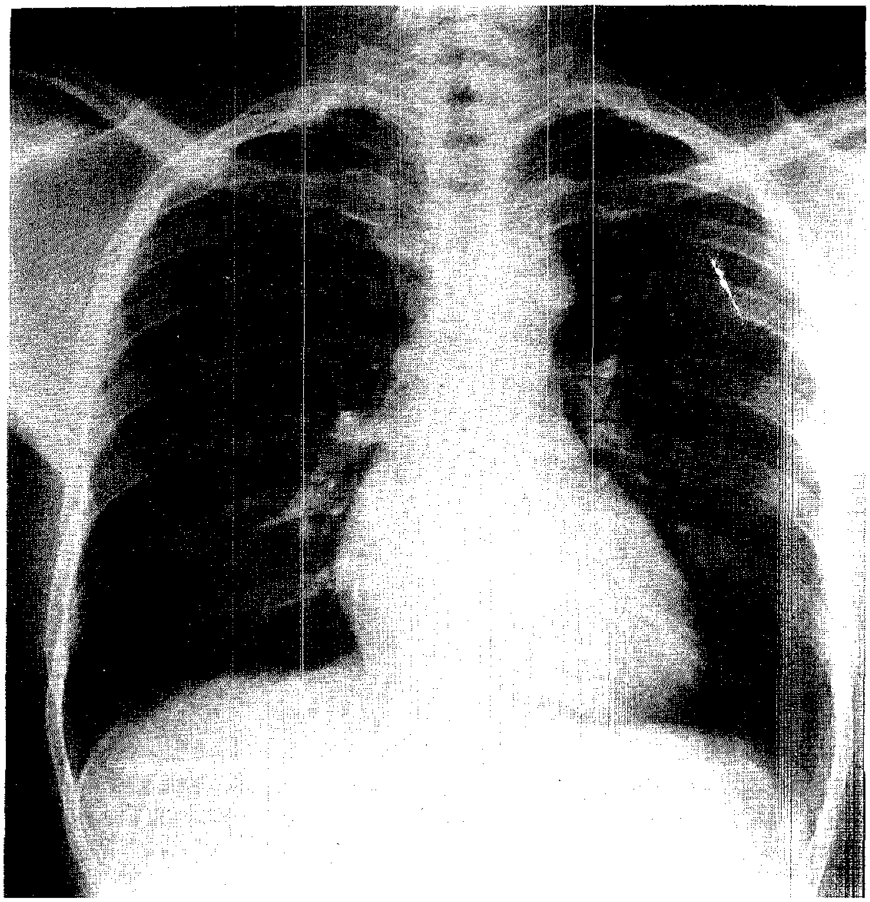


Figure 3B. Normal without Valsalva effect (same patient).

superimposed. (3) The patient's rotation should approximate 45 degrees and should not be excessive (i.e., not approaching a lateral projection) (Figure 13).

Proper positioning is critical in the diagnosis of pneumoconiosis. By following the step-by-step format and paying attention to every detail, the radiographer can produce an optimal diagnostic radiograph.

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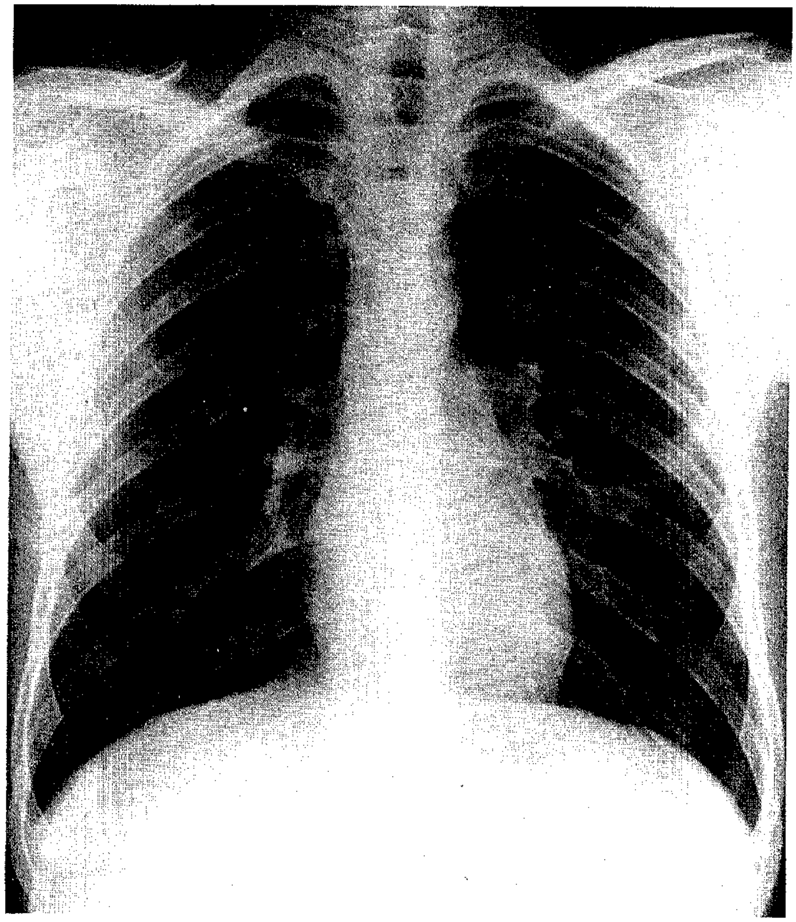


Figure 4. Correct position for a posteroanterior chest radiograph.

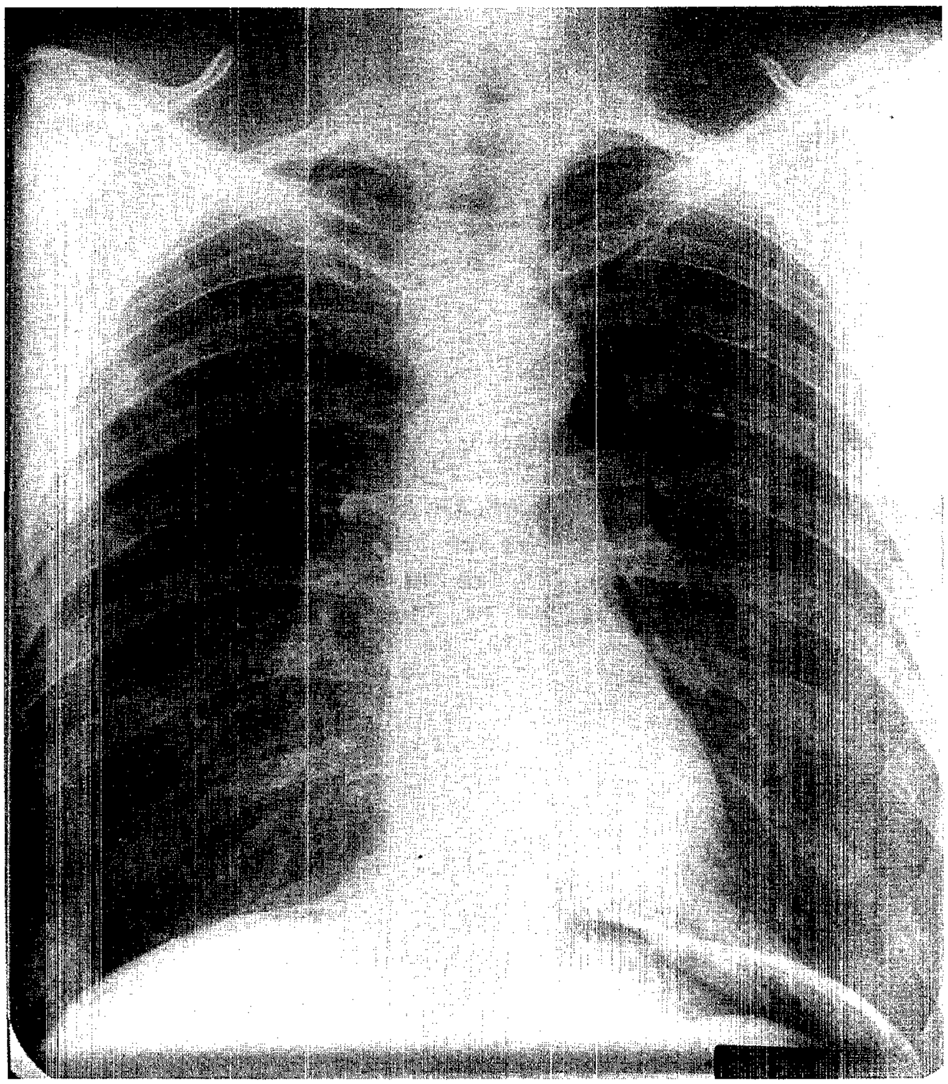


Figure 5. Incorrect position, posteroanterior chest radiograph, with the costophrenic angles cut off.

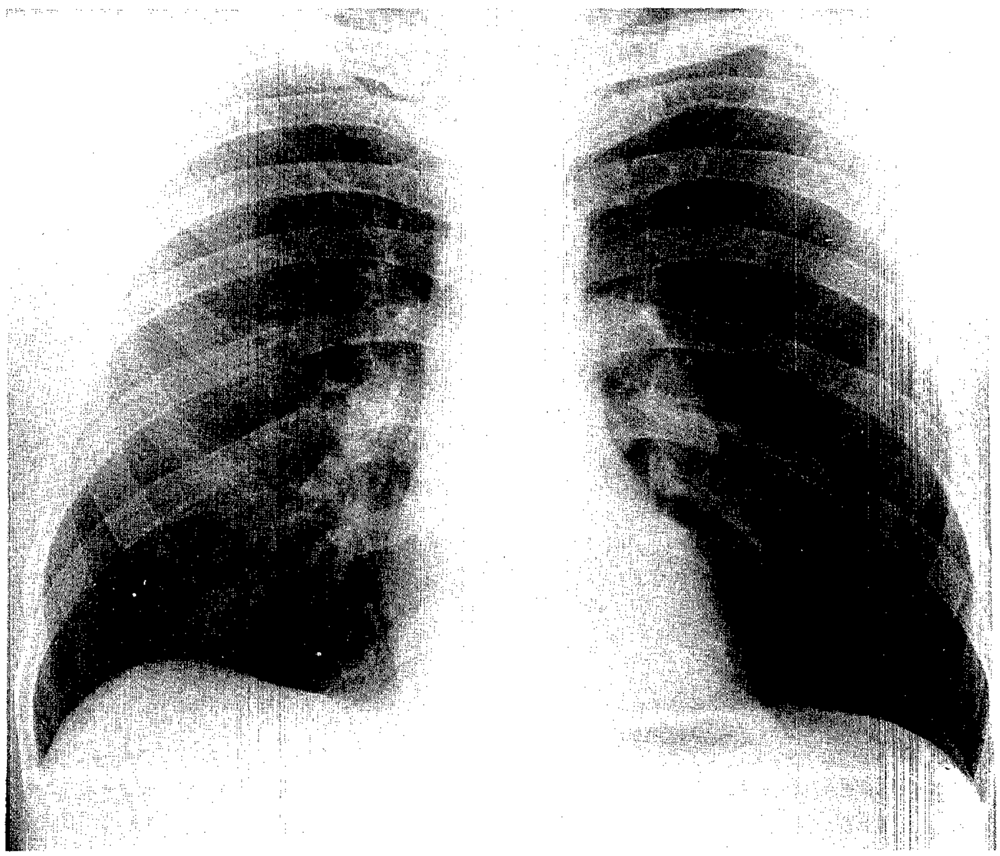
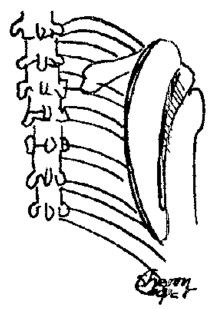


Figure 6. Incorrect position, posteroanterior chest radiograph, with the apices cut off.



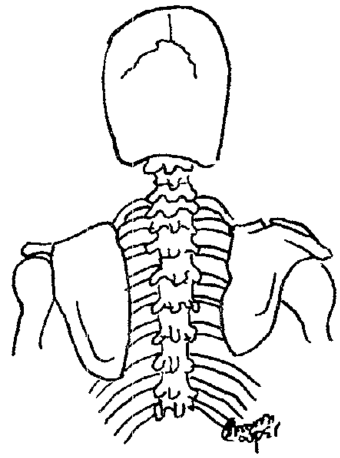


Figure 7A (left). The scapula is rotated to the side of the lung field.

Figure 7B (right). The scapula lies over the lung field.

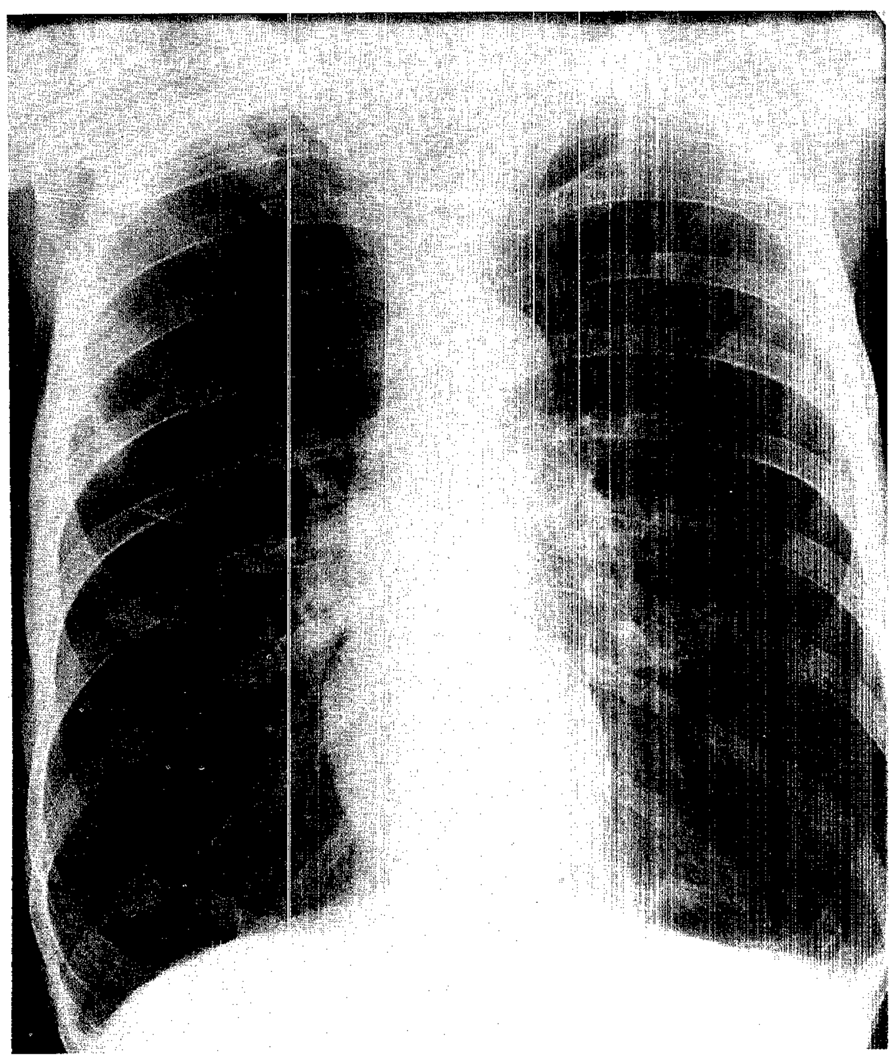


Figure 7C. Incorrect position, posteroanterior chest radiograph, with the scapula overlying the lung field.

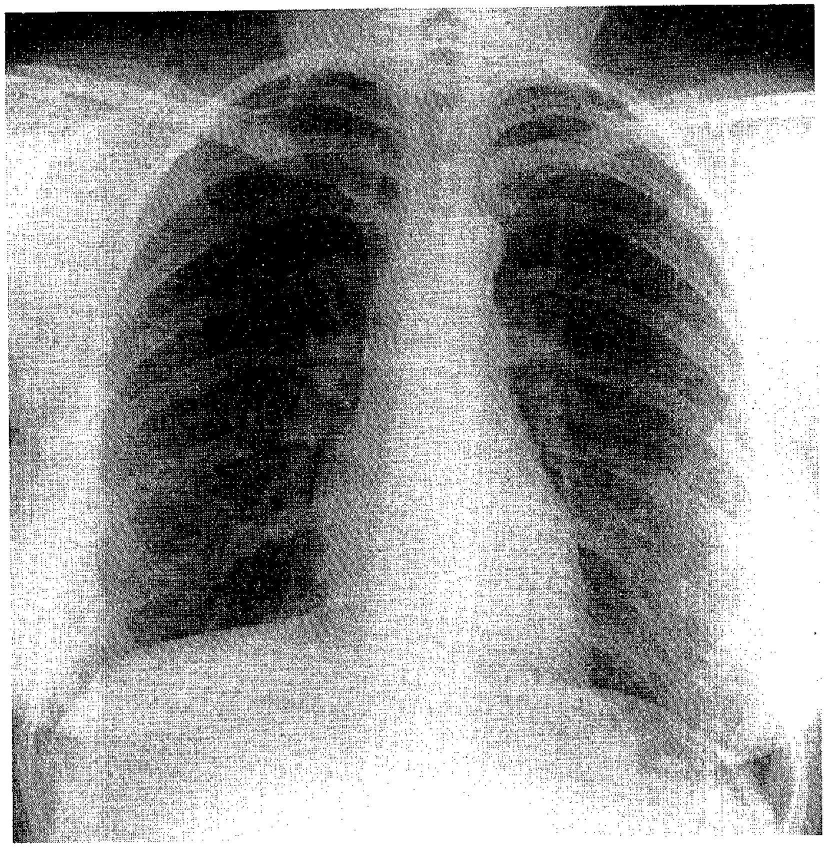


Figure 8A. Correct position, posteroanterior chest radiograph, full inspiration.

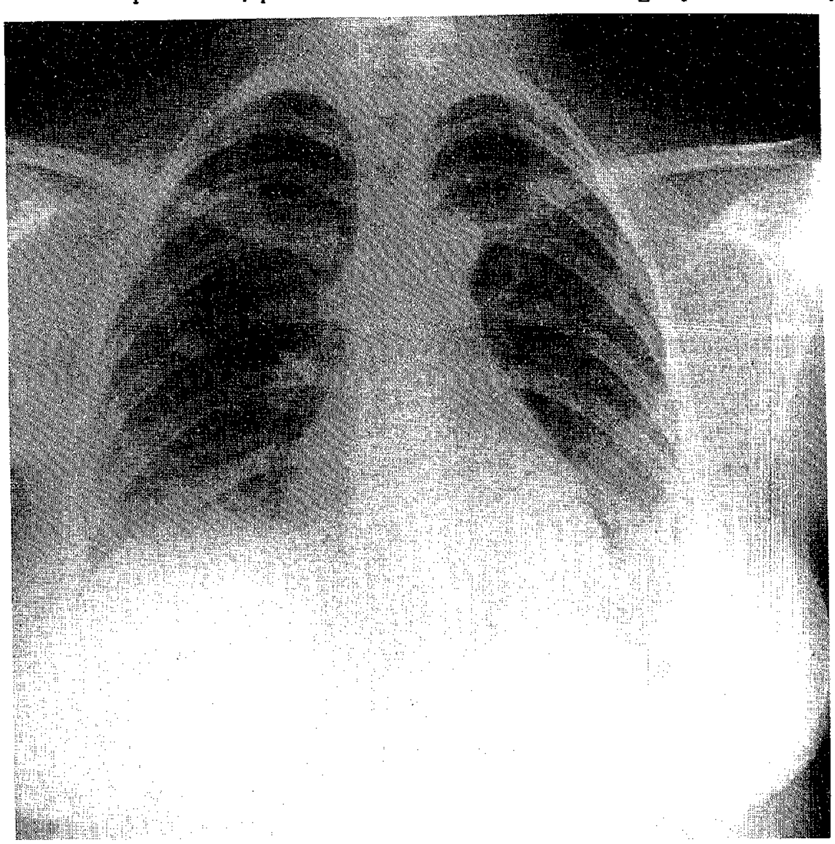


Figure 8B. Incorrect position, posteroanterior chest radiograph, lungs in expiration.

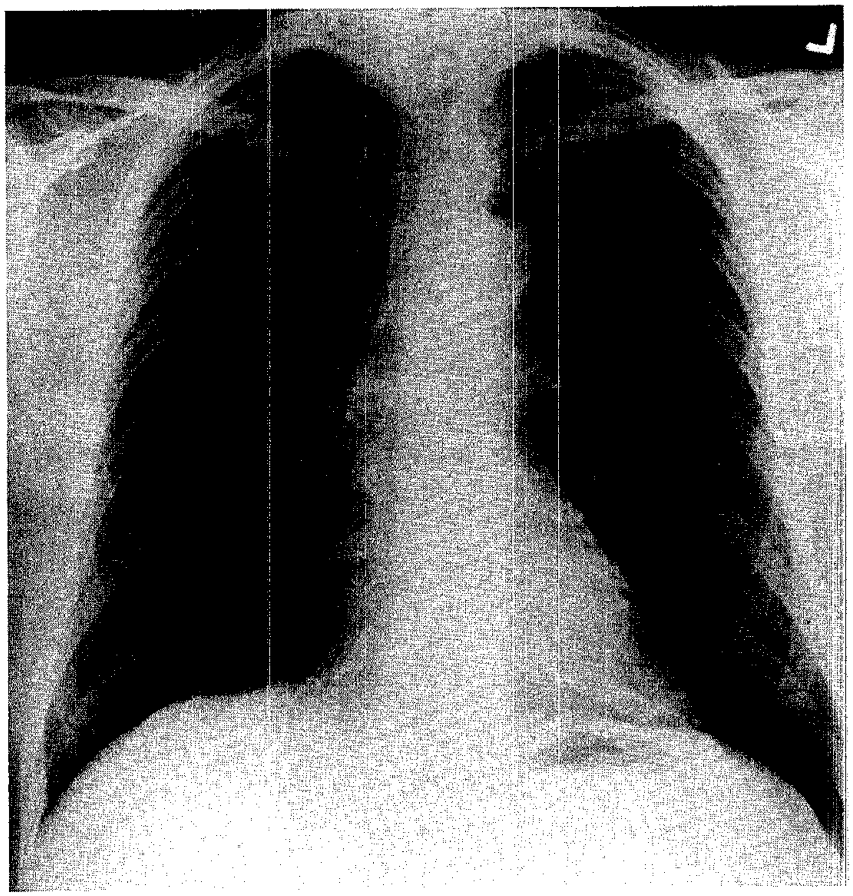


Figure 9. Patient rotated, the sternal end of right clavicle further away from midline than the sternal end of the left clavicle.

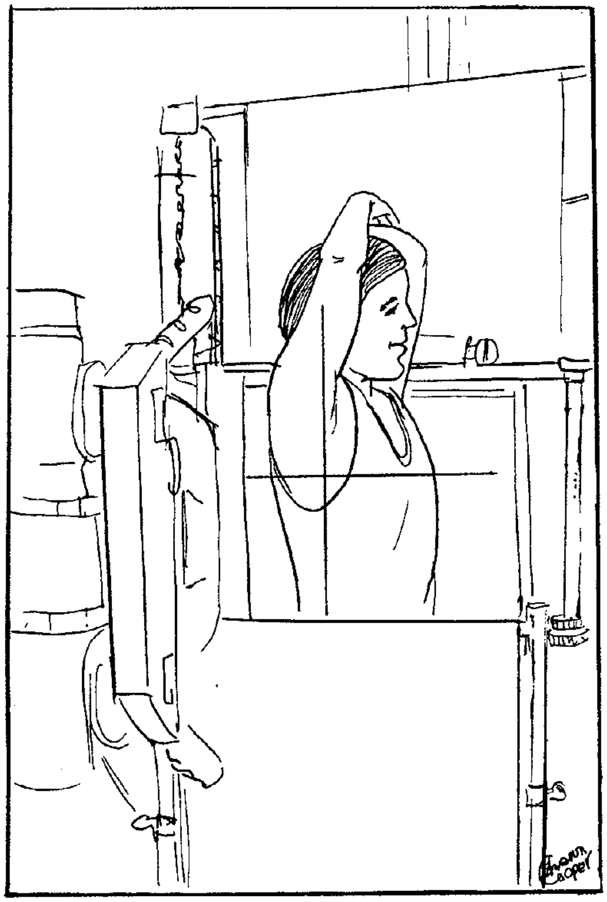


Figure 10. The correct position for an upright lateral chest radiogaph.

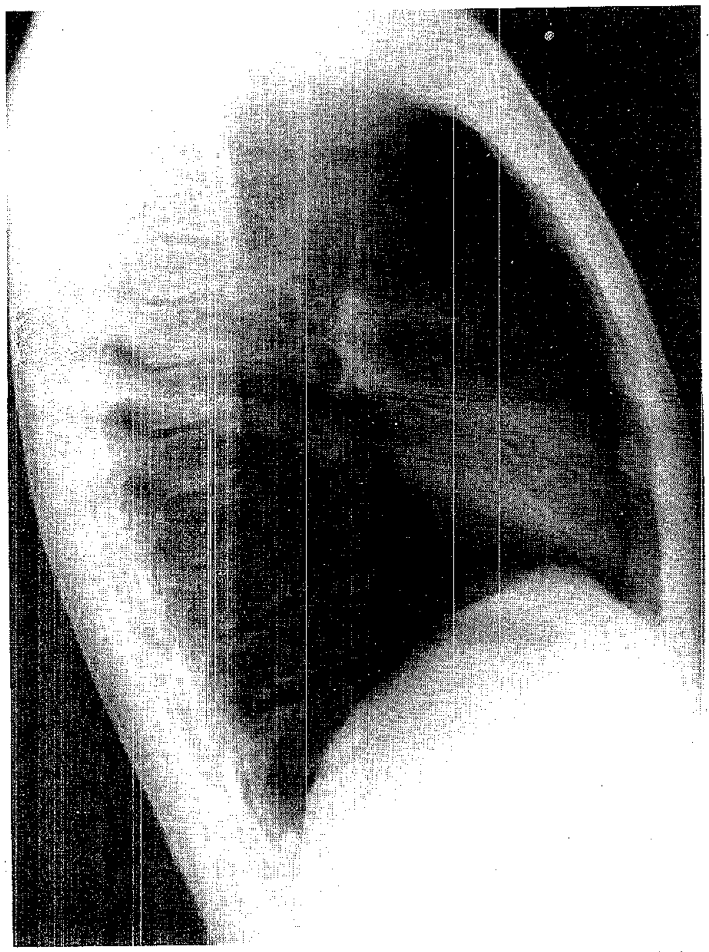


Figure 11. Lateral chest radiograph correctly positioned.

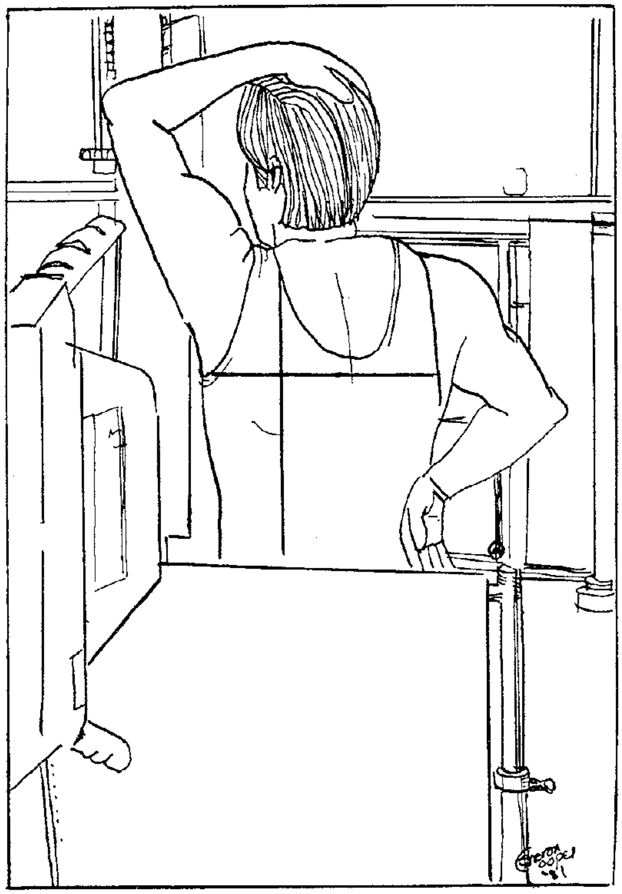


Figure 12. The correct position for an upright anterior oblique chest radiograph. For obese patients both arms should be elevated above the head with the elbows flexed (as for a lateral view) with both forearms resting on top of the head (in order to avoid the overlapping of the soft tissues of the arms over the costopleural margins).

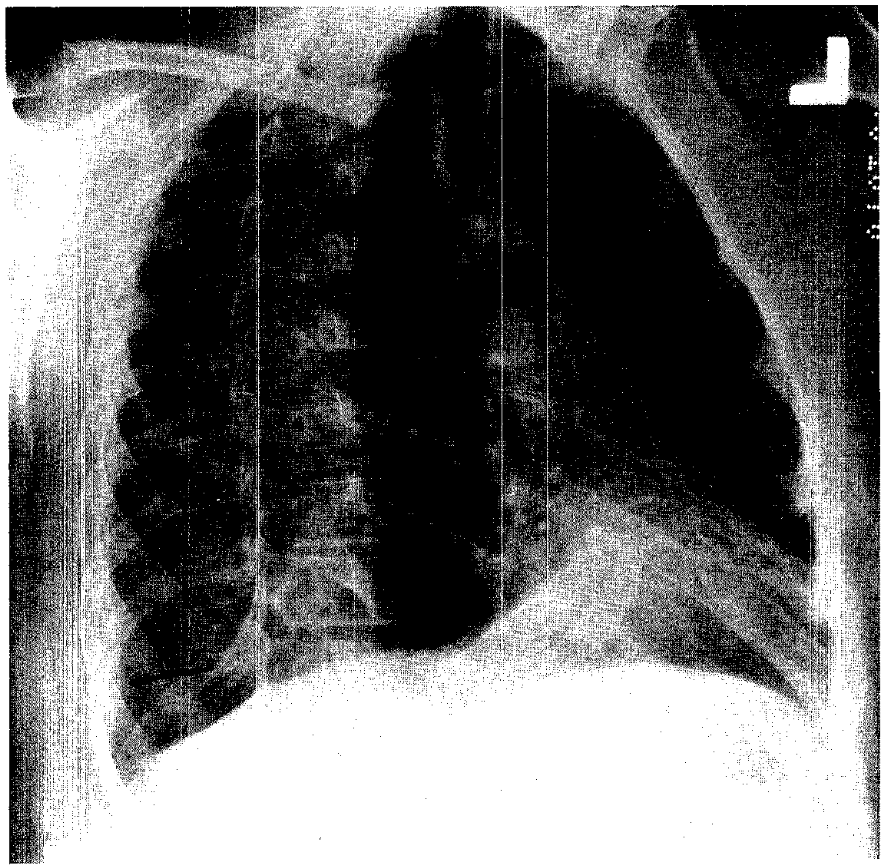


Figure 13. Right anterior oblique chest radiograph, correctly positioned. Arrow points to pleural plaque seen in profile.

Chapter IV

Technique Guides for Consistently Good Radiographic Quality

C. T. McDaniel, R. T., FASRT
E. Nicholas Sargent, M.D.

The radiographer is a vital part of the health care team. Though his duties are varied, none are more important than mastering radiographic techniques. The radiographer who masters radiographic techniques produces consistently high quality radiographs for the radiologist's interpretation. Today's radiologic equipment is sophisticated and versatile and it allows the technologist many options in choosing techniques. Whereas older equipment limited technique selection by inadequate timers, generators, and tubes, today the production of high quality radiographs is limited only by our knowledge and mastery of technical factors. The formulation and application of technique guides is perhaps the single most distinguishing factor between earlier pioneers in radiologic science and today's professional radiographer.

In order to use a technique guide, centimeter measurements for each projection, for every patient, must be obtained at all times. It may seem very time-consuming, but it is the easiest and fastest way to consistently produce good radiographs. It is impossible to look at a patient and guess the correct centimeter measurement of the chest. The use of centimeter graduated calipers to measure every patient for each projection results in correct tissue measurements. Only when correct tissue measurements are obtained, can further compensation for variables, such as pathologic conditions (e.g., emphysema) be introduced.

Equipment Considerations

There is some fundamental information that must be obtained before developing a technique guide. Determine the type of equipment with which you must work. Is it half-wave or full-wave rectified? Does it have a single-phase or a three-phase generator? Determine the maximum mA and kV for the available equipment. Establish the accuracy of the timer and the minimum exposure times that can be utilized in order to cut down on involuntary motion in the chest. A rotating anode tube with a large focal spot no greater than 2 mm. is required. The total filtration should be 2.5 mm. of aluminum.

Quality of Radiographs

The most important quality that radiologists and radiographers seek in a radiograph is the greatest possible detail. For pneumoconiosis studies, the greatest lung detail possible is a requirement. Determine whether the film is properly penetrated. We must differentiate between penetration and density. Sufficient penetration is utilized to visualize the most dense structures adequately. Density refers to the degree of blackness of a radiograph. A radiograph can have adequate penetration yet not have sufficient density (it can also be adequately penetrated and have too much density). The radiograph is made darker by increasing the mAs. The kV need not be changed when the penetration is adequate (kV controls penetration and contrast).

Pathologically, bear in mind both destructive and additive diseases and how they affect penetration. Additive diseases, such as pneumoconiosis, are more difficult to penetrate. Destructive diseases, such as emphysema, which increase the amount of retained air in the lungs are easier to penetrate.

Generally speaking, the kV required to penetrate the various projections of the average normal chest are about 80 for posteroanterior projections, 85 for oblique views, and at least 90 for lateral projections. Lower kV may not totally penetrate adequately. When chest radiographs are properly penetrated, for the posteroanterior projection, vertebral bodies and blood vessels are faintly visible through the shadow of the heart. When striving for consistently reproducible good contrast, this can be obtained by using a fixed kilovoltage. When variable kV is used to alter density, it may alter contrast, resulting in lesser quality radiographs when kV ranges are wide on different radiographs. Proper density is necessary to tie all this together (see Chapter VI) and this can be obtained by varying the mAs. The advantage of using a variable mAs technique is not changing contrast, only the density. Contrast is not changed unless the kV is increased or decreased.

When comparing previous chest radiographs on the same patients, radiographs of different densities are often found. Density variations make it difficult for the radiologist to make an accurate comparison between present and previous chest radiographs.

Low kV Disadvantages

Low kV (60 to 80) does not permit short exposure time. Exposure time should be at least 1/30 second in order to avoid involuntary motion in the chest. If variable kV is used to alter density, larger patients will require additional kV and the scale of contrast will be changed. Inadequate penetration can be a result of using low kV to reduce film density for small patients.

High kV Advantages

The advantage of high kilovoltage is that high kV produces long scale contrast and eliminates many problems. It permits a much wider exposure latitude thereby decreasing the effects of technical errors, such as wrong exposure factors and drops in the line voltage. It utilizes the shortest possible time to avoid involuntary motion. It decreases the radiation dose to the skin. High constant kV keeps radiographic contrast consistent for varying tissue thickness while achieving adequate penetration. Constant high kV minimizes variations in density, thereby reducing the number of repeat examinations. It produces consistently high quality radiographs and this is probably the most outstanding feature of using high kVp for chest radiography.

High kV Problems

High kilovoltage does create one major problem; i.e., secondary radiation fog. Methods of eliminating secondary radiation fog include collimation, grids, or air-gap techniques (Chapter VII). Collimating to the exact film size reduces the radiation hazard and improves detail by cutting out secondary radiation fog.

Grids will clean up secondary radiation fog which is produced by high kV. Although the use of the grid on chest radiographs produces excellent results, the air-gap technique can also reduce secondary radiation fog. Basically, this technique uses a separation between the patient and the film, and a longer target film distance to reduce magnification. This method can be adopted by any department using available materials requiring no additional expense for the purchase of a grid. The air-gap technique which consists of an 8- or 10-foot target film distance and an 8- or 10-inch patient film distance successfully controls secondary radiation. There are many devices that may be used to separate the patient from the film. A radiolucent substance such as plexiglass or radiolucent sponges may be used to separate the patient from the film. Stabilization of the patient minimizes motion. Exposure factors employed are similar to grid radiography of the chest. A fixed kV (125) usually yields optimum results. The mAs is varied according to patient thickness. The high kV, low mAs factor incorporates the use of shorter exposure times and minimizes involuntary motion. If a single-phase generator is used, the exposure time may be short enough on small patients; however, a three-phase generator insures millisecond exposure on larger patients who may otherwise require long exposure times. Secondary radiation, which could fog a film, is reduced by the increased object film distance. The principle is easily understood if one recalls the inverse square law which states that the intensity of radiation from any given source varies inversely with the square of the distance. With the object film distance increased, magnification will exist but the cardiothoracic relationship will remain the same, particularly since the target film distance is also increased.

Either air-gap or grid techniques serve the same purpose in reducing secondary radiation. Choosing either of these methods may be influenced by materials available in the department or the preference of the radiologist.

Screens, Films, and Processing

When selecting screens, par speed is the best compromise between sharp definition and the shortest possible exposure time. The loss of detail from using high speed screens is too much to sacrifice for the resulting decrease in the time.

Automatic processing can remove about 90% of processing problems. Particularly if a technique guide is used and the patient measured for tissue thickness, automatic processing removes an additional variable factor that might influence film quality.

Actual Preparation of Technique Guide

When preparing a technique guide the following steps are required: (1) determine the type of equipment; (2) determine the availability of the accessories; (3) select the kV (a fixed kV technique is quite applicable to chest radiography); and (4) determine the mAs.

Measure the part to obtain tissue thickness because a guide is based on the fact that every 4 cm. of tissue thickness will absorb about one half the amount of radiation. This is the most important single concept in developing and understanding radiographic techniques. To repeat, 4 cm. of tissue thickness absorbs about one half of the amount of radiation (accurately, this is somewhere around 3.6 or 3.8, but for all practical purposes we can use the rounded number of 4).

A practical example of the absorption theory is radiographing a shoulder that measures 10 cm. requiring 10 mAs. If a shoulder measures 14 cm., doubling the mAs (20) will produce a consistently good density, because 4 cm. will absorb one half the amount of radiation. By using fixed kV, the penetrating power of kV remains the same. Therefore, you can work out a technique easily by doubling the mAs when the tissue thickness increases 4 cm. Conversely, divide the mAs in half when the tissue thickness is reduced 4 cm. Always use a centimeter caliper to measure the patient for each projection and measure the tissue "firmly". Always measure through the "line of travel" of the x-ray beam before making the exposure. Correct the exposure factors when necessary. If the radiograph is too dark, cut the mAs in half. If it is too light, double the mAs. Cutting, or doubling, the mAs to compensate for density changes should correct the exposure, unless there have been gross miscalculations. If so, repeat the correction process again.

Suggested Guides

Four guides are presented (see charts labeled Technique 1, 2, 3, and 4) which should be adaptable to your department. These include both fixed and variable kV and mA techniques with different types of equipment available. All of these techniques can produce consistently good quality radiographs.

Important Technique Conversions

Screen Conversions. When converting from par speed to high speed screens at a 60 kVp range, the exposure should be reduced nearly 50%. When converting from par speed to high speed screens at 125 kVp range, the exposure may be reduced about 25%.

Grid Conversion. When changing to grid techniques from non-grid techniques, remember that higher grid ratios absorb greater amounts of primary and secondary radiation. Parallel grids are not optimum, but are not critical for focusing. Focused grids require accurate centering to avoid grid cut-off. A grid of 100 lines per inch shows the fewest grid lines on the film.

mAs Compensation from Non-grid to Grid Techniques. The 6:1 grid uses three times the mAs when converting from non-grid to grid. The 8:1 grid uses four times the mAs when converting from non-grid to grid. The 12:1 grid uses five times the mAs when converting from non-grid to grid.

kVp Compensation from Nongrid Technique. From table top to 6:1 grid, add 15 kVp. From table top to 8:1 grid, add 18 kVp. From table top to 12:1 grid, add 20 kVp.

Cone Conversion. Never radiate any area larger than the film size. Always restrict the field. At 125 kVp, the restricted beam due to collimation or extended cylinder cone requires at least 6 additional kVp, or if compensating with mAs change, add at least 40% in mAs.

Target Film Distance Conversions. The density of the x-radiation reaching the film varies inversely as the square of the focal film distance. For example, changing from 36- to 72-inch distance would require changing from 5 mAs to 20 mAs to maintain the same density. Students beginning in x-ray technology do not easily recognize this. If the distance is doubled, the mAs is not doubled, but, rather, is increased four times the original.

An easy method of finding the new mAs required is as follows: (1) divide the old distance into the new distance; (2) square the answer; and (3) multiply the above answer by the original mAs to find the new mAs. Rules of thumb that work well for distance conversion: (1) when the distance is doubled, use four times the mAs; and (2)

Technique 1. Recommended Guide for Use with Three-Phase Equipment*

	Anteroposterior Diameter	mA	Time	mAs	kV
Small chest	18-19 cm.				
Posteroanterior		300	1/60	5	120 to 125
Oblique		300	1/40	7.5	130 to 135
Lateral		300	1/24	12.5	125 to 130
Medium chest	20-24 cm.				
Posteroanterior		300	1/60	5	125 to 135
Oblique		300	1/40	7.5	135 to 140
Lateral		300	1/24	12.5	130 to 145
Large chest	25-27 cm.				
Posteroanterior		300	1/60	5	135 to 145
Oblique		300	1/30	10	135 to 145
Lateral		300	1/20	15	135 to 145
Extra large chest	28 cm.				
Posteroanterior		300	1/40	7.5	140 to 145
Oblique		300	1/24	12.5	140 to 145
Lateral		300	1/20	15	140 to 145

Distance: 6 feet; grid: 10:1 ratio, 100 lines per inch focused at 5 to 6 feet; screens: par speed; and equipment: three-phase.

* Technique chart for chest radiography in use at the Los Angeles County-University of Southern California Medical Center illustrates constant milliampere seconds, variable high kilovoltage technique. In each projection, posteroanterior, oblique, and lateral, the milliamperage is increased only when the kilovoltage required, by the thickness of the chest, to produce a radiograph of satisfactory density approaches the limit of the radiographic tube.

when the distance is halved, use one fourth the mAs. When using distances between 20 and 40 inches and 72 inches distance, add or subtract ½ kVp for every inch of increase or decrease.

Changing the Scale of Contrast. kVp controls penetration and contrast. High kVp results in long-scale contrast and low kVp results in short-scale contrast. Rules of thumb for changing contrast: (1) to obtain longer contrast, divide the mAs in half and increase kilovoltage by 20%; and (2) to obtain shorter scale contrast, double your mAs and decrease kilovoltage by 15%. Remember, kVp changes need not be as great with low kV as may be required when using high kV.

If a film is too light or if it is too dark, make a change of at least 30% of the mAs. It takes at least a 30% change in mAs in order to produce a noticeable change in radiographic density. If the radiograph is too light, it is probably light enough to repeat; therefore, double your mAs (if unaccustomed to this, the change might seem too drastic, but it will give good results). If a radiograph is too dark, and dark enough that it needs repeating, cut the mAs in half to produce a high quality radiograph.

Technique 2. Suggested Guide for Full Wave Rectified Equipment Limited to 200 mA at 100 kV*

Projection	Cm.	mAs	kV	Grid	Distance
Posteroanterior	17-18	5	90	No	72 inches
Posteroanterior	19-20	7.5	90	No	72 inches
Posteroanterior	21-22	10	90	No	72 inches
Posteroanterior	23-24	15	90	No	72 inches
Posteroanterior	25-26	20	90	No	72 inches
Posteroanterior	27-28	30	90	No	72 inches
Oblique	22-23	10	96	No	72 inches
Oblique	24-25	15	96	No	72 inches
Oblique	26-27	20	96	No	72 inches
Oblique	28-29	30	96	No	72 inches
Oblique	30-31	40	96	No	72 inches
Lateral	27-28	10	100	Yes	48 inches
Lateral	29-30	15	100	Yes	48 inches
Lateral	31-32	20	100	Yes	48 inches
Lateral	33-34	30	100	Yes	48 inches

* For equipment limited to 200 mA or more than 100 kV, this technique is satisfactory. The kilovoltage is high enough to penetrate the lungs. The 72-inch target film distance reduces magnification. On lateral views, since one cannot increase kV, the distance is reduced to 48 inches so that the exposure time can be reduced. The technique is marginal, but it is the best available for limited equipment.

Compensations for Techniques when Changing from Single- to Three-Phase Generators. It is a misconception among some technologists that kV values are not the same on single-phase and three- phase equipment. For example, 70 kV has the same penetrating value and the same effect on contrast whether it is used on a three-phase or a single-phase generator. The difference is in effective radiation time. When using a single-phase generator, radiation is being used only during half of the exposure time. The reason is that only the peak kV is used. Therefore, during half the exposure time, the kV is below the usable peak. However, a three-phase generator does not have this drop in kilovoltage peak and, therefore, the effective radiation occurs during the full exposure time. Thus, the effective radiation time is twice as long for a three-phase generator as compared to a single-phase generator when the same exposure time is used.

Reemphasizing, the techniques are different between three-phase and single-phase equipment because of effective radiation time and not the quality of kilovoltage. To convert techniques from single-phase generators to three-phase generators use half the

Technique 3. Suggested Guide Using Grid, Single Phase, Full Wave Rectified Equipment Rated at 300 mA at 125 kV*

Projection	Cm.	mAs	kV	Grid	Distance
Posteroanterior	17-18	3.75	125	Yes	72 inches
Posteroanterior	19-20	5	125	Yes	72 inches
Posteroanterior	21-22	7.5	125	Yes	72 inches
Posteroanterior	23-24	10	125	Yes	72 inches
Posteroanterior	25-26	15	125	Yes	72 inches
Posteroanterior	27-28	20	125	Yes	72 inches
Posteroanterior	29-30	30	125	Yes	72 inches
Oblique	22-23	7.5	125	Yes	72 inches
Oblique	24-25	10	125	Yes	72 inches
Oblique	26-27	15	125	Yes	72 inches
Oblique	28-29	20	125	Yes	72 inches
Oblique	30-31	30	125	Yes	72 inches
Lateral	27-28	20	125	Yes	72 inches
Lateral	29-30	30	125	Yes	72 inches
Lateral	31-32	40	125	Yes	72 inches
Lateral	33-34	60	125	Yes	72 inches

* This guide is suggested for use with the grid, single-phase, full wave rectified equipment, rated at 300 mA and 125 kV (i.e., the "average" type of equipment found in most departments). This technique uses a fixed 125 kVp. It uses a grid for every projection at 72-inch distance. The variable mAs is based on the principles mentioned previously: 4 cm. of tissue thickness absorbs one half the amount of radiation.

mAs. All other factors should remain unchanged. This conversion will equalize densities when a standardized technique guide is used throughout the department.

Summary

In order to consistently produce high quality radiographs a technique guide must be used. Formulating technique guides is not difficult. High kilovoltage techniques result in consistently good quality radiographs with adequate penetration of tissues. Density may be altered by changed mAs and keeping the kV constant, using the theory that 4 cm. of tissue thickness absorbs half the amount of radiation. This requires the measurement of every patient in order to obtain the tissue thickness. Radiographers have the responsibility of mastering radiographic techniques to produce consistently high quality radiographs for the study of the pneumoconioses.

Technique 4. Air-Gap Technique Suggested for Use with Single-Phase, Full Wave Rectified Equipment Rated at 300 mA 125 kV

Projection	Cm.	mAs	kV	Grid	Distance
Posteroanterior	17-18	5	125	No	8 feet
Posteroanterior	19-20	7.5	125	No	8 feet
Posteroanterior	21-22	10	125	No	8 feet
Posteroanterior	23-24	15	125	No	8 feet
Posteroanterior	25-26	20	125	No	8 feet
Posteroanterior	27-28	30	125	No	8 feet
Posteroanterior	29-30	40	125	No	8 feet
Oblique	22-23	10	125	No	8 feet
Oblique	24-25	15	125	No	8 feet
Oblique	26-27	20	125	No	8 feet
Oblique	28-29	30	125	No	8 feet
Oblique	30-31	40	125	No	8 feet
Lateral	27-28	20	125	No	8 feet
Lateral	29-30	30	125	No	8 feet
Lateral	31-32	40	125	No	8 feet
Lateral	33-34	60	125	No	8 feet

Chapter V

Good Radiographs are Born in the Darkroom

Terry R. Eastman, R.T.

A correctly positioned and exposed chest radiograph brings to the professional technologist a deep fulfillment of purpose in realizing that the patient has been well served. It is recognized that optimal development of film is a major factor in obtaining desired results. Indeed, many believe that good radiography begins and ends in the darkroom.

The use of radiographic technique charts are premised on optimal development of film. A well operated and monitored darkroom results in no loss of service to patients, avoidance of repeat studies due to artifacts or incorrect processing, and control of unnecessary exposure to ionizing radiation.*

Manual Processing

X-ray films are still processed by manual techniques in some locations, either by choice or by necessity. In any event, it is a good place to begin the discussion of processing variables.

Development obviously comes first, for here the exposed silver halide is converted to image-forming metallic silver. Time of development and temperature of the developer solution are two of the most important variables so far as quality of the finished radiograph is concerned. The temperature of the solution must be kept within a narrow range, and the time of development must be adjusted according to the temperature so that development remains constant. Guesswork as to time of development or temperature of the developer does not lead to quality radiographs on the viewbox.

The temperature of the developing solutions is usually controlled by a water bath. The temperature of the water bath and the temperature of the wash water is controlled by a mixing valve attached to the hot and cold water lines.

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* Here reference is made to "underdevelopment", which then requires overexposure to maintain density.

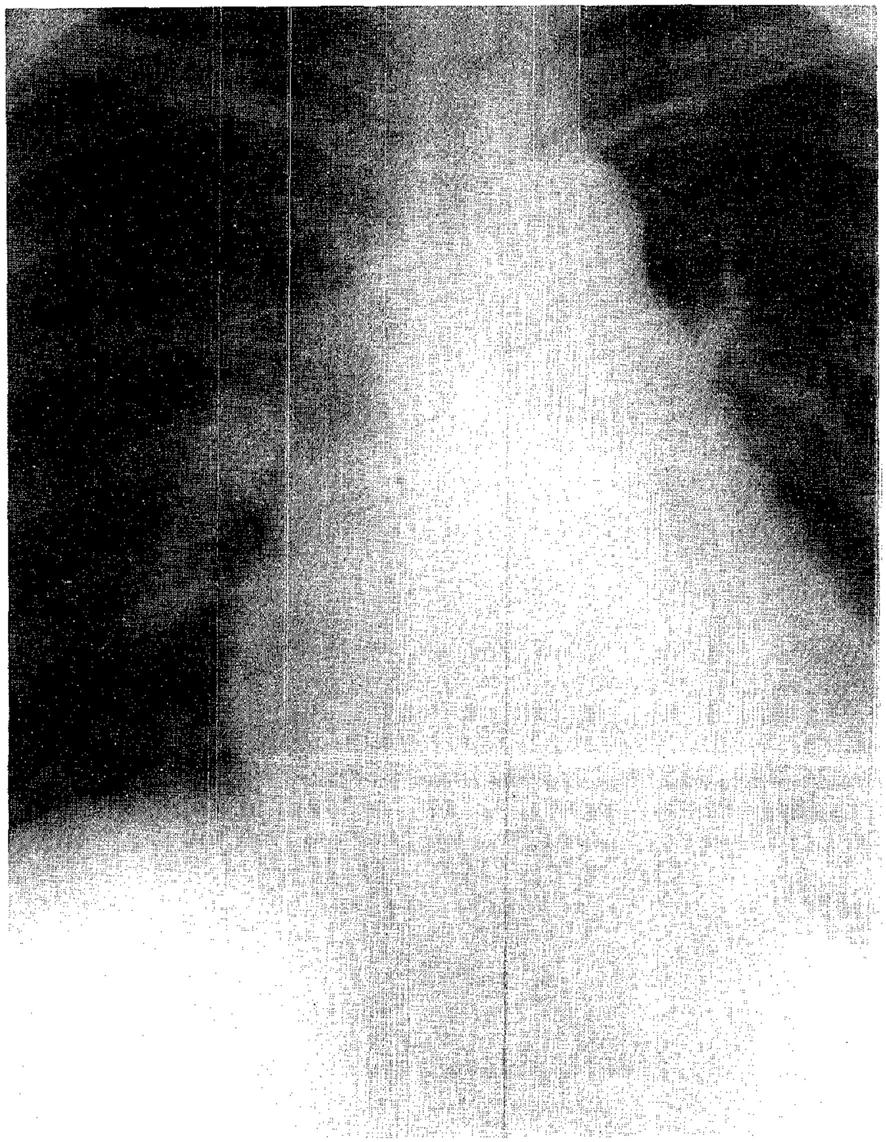

Figure 1. Fog caused by white light exposure.

Sight development should never be used as this can cause both fog and streaks (Figure 1), and the appearance of an unfixed film is not an accurate indication of what the film will look like when processing and drying are completed.

Streaks can be caused by the use of contaminated, improperly washed hangers. Failure to agitate film while in the developer or fixer can also cause streaks. The film should be immersed in the developer quickly and the hanger moved up and down two or three times to dislodge any air bubbles from the surface of the film which may cause spots. Agitation in the developer also brings about uniform development over the entire film surface. This should be repeated once each minute during development.

At the end of the development time, the film should be removed from the developer quickly and allowed to drain into the rinse tank, not back into the developer. A certain

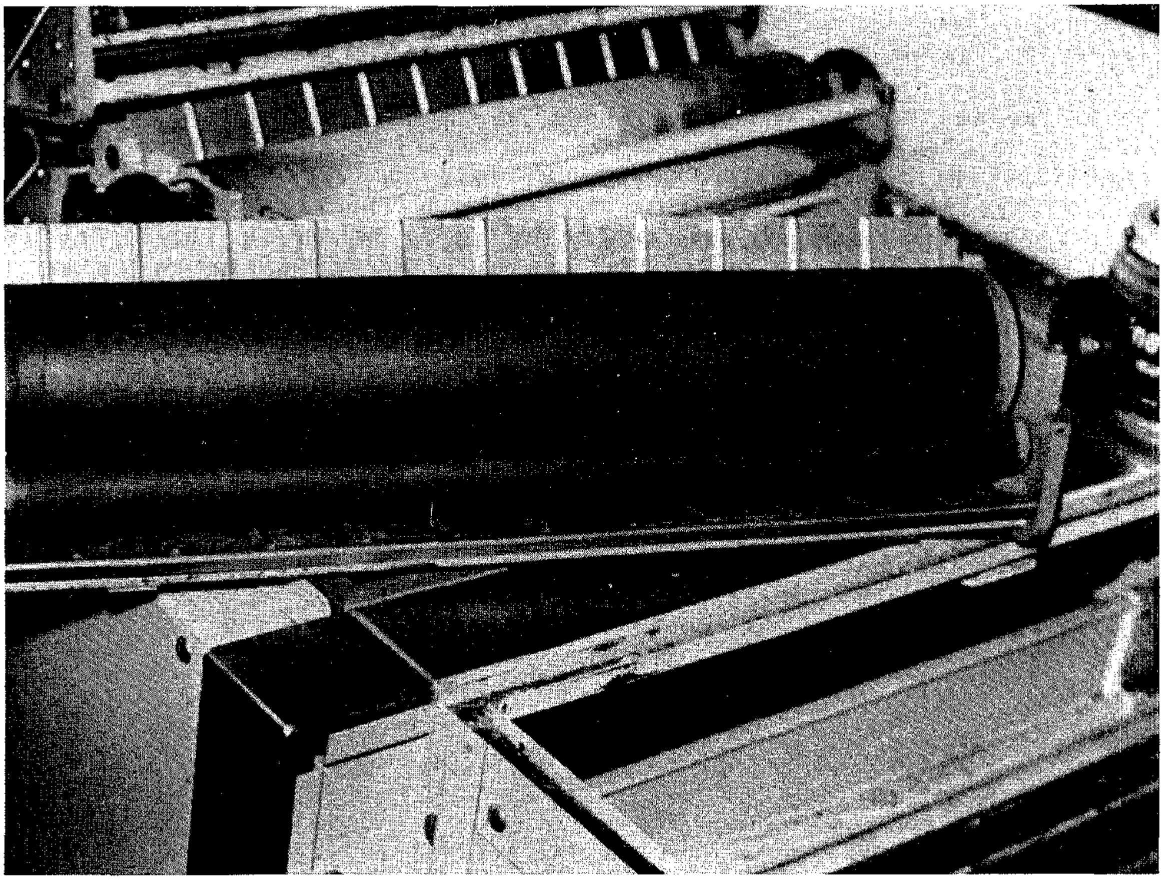

Figure 2. Dirty rollers.

amount of developer will be removed from the tank with each film that is developed; the tank should be "topped off" each day, or more often, with replenisher solution.

Every manufacturer of processing chemicals provides mixing instructions. Take the time to study them. Be sure to mix the solution thoroughly whenever replenisher is added to the developer tank. Failure to do so may be another cause of streaks because of localized overdevelopment by the unmixed extra strong replenisher.

Cleanliness is extremely important in both manual and automatic processing. (Film transport rollers must be cleaned regularly to remove any accumulated chemical deposits (Figure 2).)

Liquid chemicals must be properly mixed. They must be poured slowly and evenly into the mixing tank with constant stirring, paying close attention to the mixing instructions. Currently, automatic mixers are available which enhance not only accuracy, but ease and cleanliness of use as well.

Summary of the Processing Cycle

The basic processing cycle for radiographic film consists of four steps: development, fixing, washing, and drying.

In developing the radiographic image, the essential factors which must be controlled are:

(1) Time of development. In manual processing, this is under the technologist's direct control and requires a timer for repeatable results. In automatic processors, this factor requires no attention from the operator.

(2) Temperature of the developer. In both manual and automatic processors, the temperature of the water usually controls the temperature of the developer. Follow the chemical manufacturer's recommendations.

(3) Activity of the developer. The activity of the developer solution depends upon proper mixing of the concentrated chemicals, whether in manual processing tanks or in automatic replenisher tanks. The activity of the developer in both manual and automatic processing is a function of proper replenishment of the chemicals. Contamination of the developer is one of the major causes of poor radiographic quality and, unfortunately, is more prevalent with automatic processors than in manual processing. Care must be exercised when removing or installing the fixer rack to avoid splashing fixer chemical into the adjoining developer tank.

Replenishment by "topping off" the tank cannot continue forever; the working solution should be discarded when the replenisher added equals about two times the original quantity of developer. Developer in the tank should never be kept for more than 1 month because of oxidation of the developing agent and other impurities. Oxidation, contamination, and evaporation of the developer can be considerably retarded by making sure that the developer tank is covered when not in use.

When film development is complete, it is always desirable to stop the developing activity as quickly as possible. If development is not stopped, it will continue (unevenly) until the film is placed in the fixer and the fixer penetrates the emulsion. Any developer carried into the fixer will reduce its working life.

An acid "stop bath" provides the quickest and surest way to stop development. An acid stop bath is made by mixing glacial acetic acid in the proportion of 4½ ounces to a gallon of water. Caution: Always add the acid to the water with good stirring. The acid stop bath halts development quickly and uniformly. It prevents streaks due to uneven development, prevents contamination of the fixer, and prolongs the life of the fixer solution. If the developer is not removed completely from the film before it is placed in the fixer, the alkali in the developer will neutralize the acid in the fixer upsetting the chemical balance, impairing the hardening action, and possibly resulting in stains on the radiograph. If a stop bath is not used, the film should be rinsed for 30 seconds in rapidly running water.

After development is halted by a "stop bath" or by rinsing, the film is transferred to the fixing solution or "hypo". Fixing must be adequate but should not be allowed to continue too long. A film that has not been fixed long enough has a "milky" appearance because some unexposed silver halide is still in the emulsion. The film must remain in the fixer until this milkiness disappears and the transparent areas of the film are clear. An easy rule of thumb to remember is: fix a film for twice the time it takes to clear, but not more than three times its clearing time, and never less than 3 minutes.

Washing after fixing is essential to remove the fixer and insure the permanence of the radiograph. The film should be washed for at least 20 minutes in water between 60° and 70°F. The water should flow rapidly enough so that motion is apparent. The water must cover the top bar of the hangers to prevent contaminating carry-over of the fixer on the hangers the next time they go into the developer.

Before washing, the use of a wetting agent is optimal, but desirable. Immersing the film for 30 seconds in this solution lowers the surface tension of the water so that it runs off smoothly, minimizing streaks and water spots, and significantly reduces drying time.

Automatic Processing

Automatic processing is, of course, easier because all of the variables are controlled automatically. It is certainly the most desirable way of processing radiographic film wherever the volume justifies the purchase of an automatic processor.

The equipment is compact and self-contained, but it is not just a mechanization of hand processing. Hand processing may take as much as one hour. With automatic processing, because of the elimination of film hangers and hand transport from tank to tank, and also because of greater activity in each processing step, it is possible to go from an exposed film to a dry radiograph in as little as 90 seconds. The variables that the operator must control are reduced to a minimum.

The first of these variables is water temperature, which is controlled by a mixing valve equipped with a thermometer. Developer temperature, which is automatically maintained at a preset level, must be checked regularly. At the higher temperatures used in automatic processing (80° to 95°F), the control is more critical.

Replenishment of both developer and fixer solutions is automatic. Each sheet of film entering the processor triggers a sensing device which causes metering pumps to add predetermined amounts of developer and fixer solutions to replace depleted chemicals used in processing that sheet of film. Gauges indicate how much replenishment is taking place. An important point about automatic processors to remember: the fewer the number of films that are processed in a day's time, the more replenisher that must be added. From the standpoint of radiographic quality, it is best to operate the processor at its maximum capacity. Follow the replenishment recommendations published by the manufacturer of the chemicals being used. One of the most common causes of poor development in an automatic processor is contamination of the developer by small amounts of fixer splashed into the developer tank when the fixer rack is removed for cleaning or service. A half ounce of fixer in the developer can cause a noticeable problem.

The fixing phase in the processing cycle is less critical than development, but the same factors are important: time of fixing, temperature of the fixer, activity of the fixer chemicals as a function of proper mixing, and proper replenishment of the solution. Remember there is silver as a byproduct of clearing in the fixer. This awareness lends itself to ecologic and economic benefits. There are many inexpensive ways to reclaim silver from fixer, and your film representative is in a good position to advise you on this matter.

Washing the films in both manual and automatic processing requires the proper water

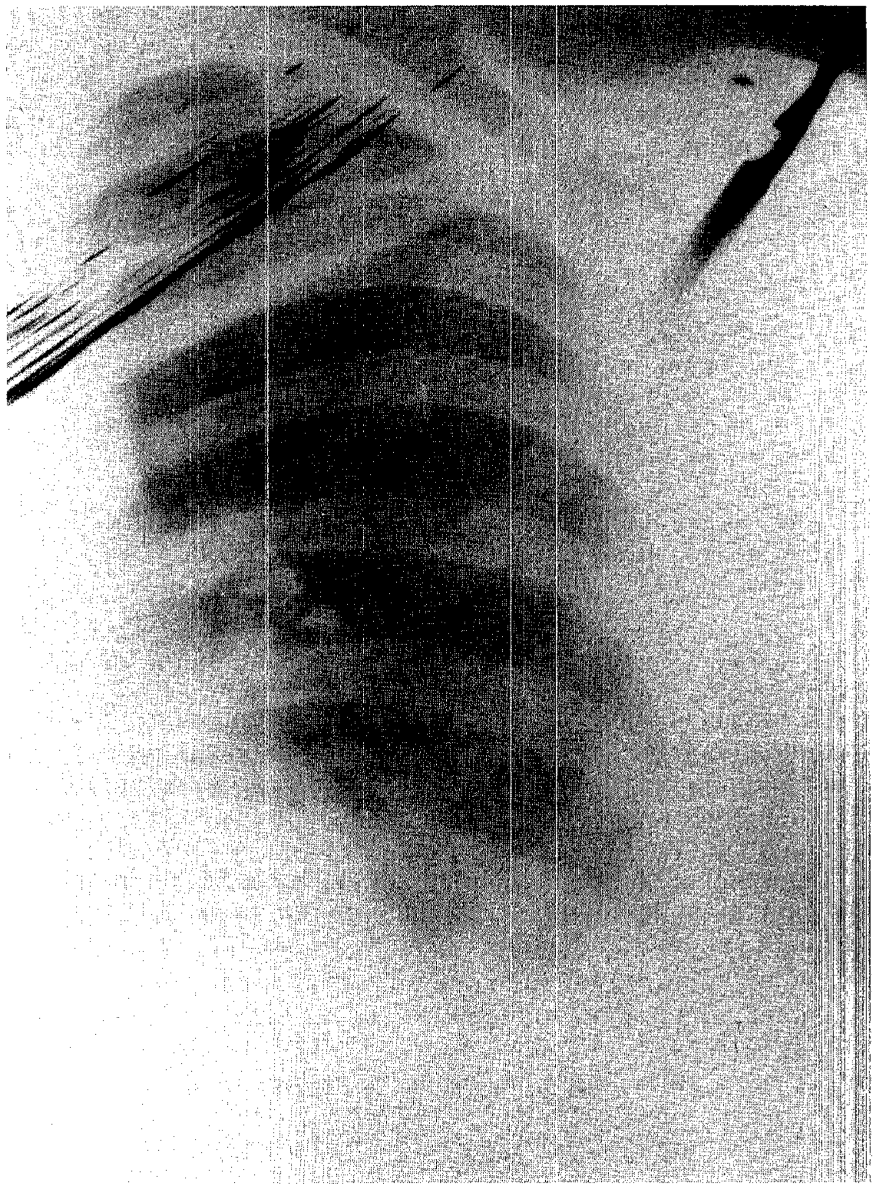

Figure 3. Light fog from a cracked safelight.

flow rate for adequate removal of the fixer from the films. This is a place where cleanliness can pay dividends. Scrubbing the water tanks in either manual or automatic processors to remove algae buildup and sediment will result in cleaner radiographs of higher diagnostic value.

How much can be said about drying the radiograph? In manual processing, keep the dryer temperature at about 120°F. In automatic processors, use only sufficient heat to dry the films. The lower the temperature, the better the film surface will look. Occasionally clean the lint out of the dryer tubes to prevent streaks on the surface of the radiographs when viewed by reflected light.

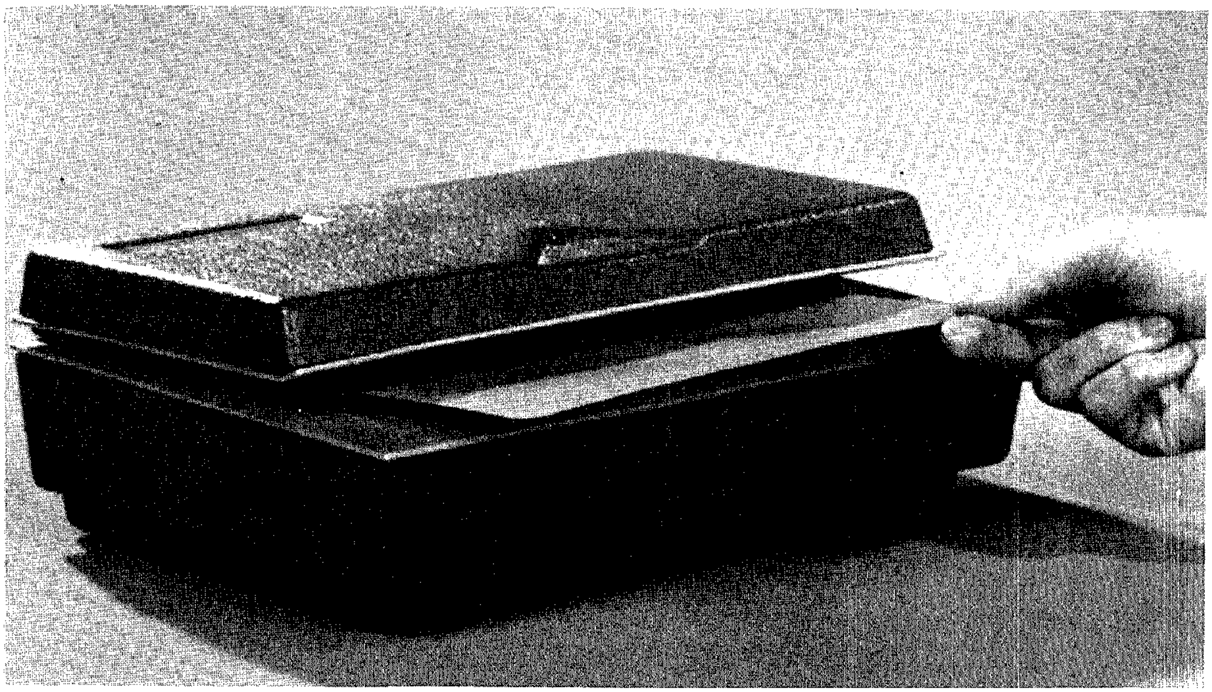

Figure 4A. Sensitometric control strip.

Film Storage

Whether they are to be processed by hand or automatically, storage of the film supply is important. Boxes must be kept in a clean, dry place, fully protected against x- or gamma-radiation.

Boxes should be stored on edge, both for easy availability and to prevent excess pressure on those on the bottom of the stack. When boxes are stored on edge, it is easy to pick the required size without having to shift the others. The oldest film should always be used first and preferably stored toward the front where it will be most readily available. Film should be stored at room temperature or below. If the storage room is too warm for your comfort, it is too warm for the film. A light-proof film storage bin offers a convenient way to store film in the darkroom so that it will always be easily available.

As a final precaution, always handle the film gently. It should never be pulled rapidly from the cassette or from the box because the friction can cause static marks or scratches. Bending, buckling, or snapping the film can also cause serious problems. Careless handling of film prior to its exposure can create abnormal density artifacts. In the lung field, such artifacts could easily be confused with pathologic changes.

Figure 4B. Processed film strip compared with a standard either visually or with a densitometer.

Safelights

Much could be said on this subject since improper safelighting (Figure 3) in a darkroom is such an insidious cause of poor quality radiographs. There is no such thing as a safe light. Any safelight will eventually fog a film. Therefore, the term safelight merely indicates a safety factor. Your film representative can show you how to determine the safety of the illumination. The safelight test checks the effect of safelight exposure on a film after it has been exposed because exposed film has a much lower safety margin than unexposed film.

Process Control

Since over 90% of all radiographs are processed with the aid of an automatic processor, the recommended controls will preclude sensitometric problems and bring about better darkroom organization. In all cases, the preventive maintenance schedule recommended by the manufacturer of the processor should be scrupulously followed. The chemistry, replenishment rates, and developer temperature recommended for the film in use should be ascertained and this recommendation rigidly adhered to. A responsible person should be delegated to check the following throughout the day: water flow rate and temperature; developer temperature; dryer temperature; check to see if the replenisher pumps are working; and check the level of chemicals in the replenisher tank.

A log sheet should be filled in with the above considerations checked four times a day. After the daily cleaning and inspection of the processor and darkroom, the log sheet should be submitted to the chief technologist. A sensitometric control strip should be run daily through each processor (Figure 4A). The processed film strip is then carefully compared to a standard, either visually or with the aid of a densitometer, to ascertain that density and contrast are unchanged (Figure 4B)(see Chapter XI). The chief technologist should keep a maintenance checklist in the office, for each processor in the hospital.

Maintenance checklist

Automatic processor number: ______________________

Machine information: ________ (Make) ________ (Model) ________ (Serial no.)

Present chemistry: Started __/__/__ Drain and change __/__/__

Filters

Water filter: Installed __/__/__ Change __/__/__

Developer filter: Installed __/__/__ Change __/__/__

Replenishment (check cycle every ________ (Day of week))

Developer ________ ml (cc) Fixer ________ ml (cc)

Temperatures (check daily): Developer __°F Dryer __°F Water __°F

For optimum performance, follow the manufacturer's maintenance manual for machine operation.

Film representative	*Machine representative*
______________________	______________________
Address: ______________	Address: ______________
Phone: ______________	Phone: ______________

If the preventive maintenance is delegated by the chief technologist to a responsible person, or if it is carried out by a commercial solution service, signed reports should be submitted to the chief technologist confirming that the preventive maintenance schedule chosen by the x-ray department has been complied with satisfactorily.

The radiographic quality will be determined by the physician who studies the radiograph on the viewbox. By following the darkroom procedures outlined above, the technologists can be assured that their part is well done in justifying our claim that good radiographs are born in the darkroom.

Chapter VI

The Physical Basis for Optimum Chest Radiography

Russell H. Morgan, M.D.

The universal enthusiasm with which radiologic methods have been accepted in medicine stems largely from the wealth of diagnostic information these methods provide. Nowhere is this more evident than in radiography of the chest where the information is of such fundamental importance that the chest radiograph has become an essential element in the clinical investigation of almost every patient and an epidemiologic tool of great value in the study of dust-related occupational disease.

In many respects, x-rays are similar to light. They travel in straight lines with a speed of 300,000 kilometers per second. They blacken photographic film and cause certain crystalline materials to fluoresce. They tend to scatter when interacting with matter. They are composed of myriads of discreet bundles of energy, called photons. However, unlike light, whose photons contain only a small amount of energy (a few electron volts), x-rays are very energetic (tens of thousands of electron volts per photon). This difference causes x-rays to exhibit a number of properties quite distinct from light.

Image Formation. Although x-rays have the ability to penetrate matter, only a fraction of the radiation falling on an object emerges on the opposite side. The remaining radiation is either absorbed in, or scattered by the object. As previously noted, the fractions of radiation transmitted, absorbed, or scattered by an object, such as an anatomic structure, depend on the density and thickness of the structure, its elemental composition, and the energy of the photons comprising the x-ray beam. Consequently, the x-rays transmitted by an object bear an image of the object's internal components.

When x-rays are projected through a person's chest, the amount transmitted in the regions of the lungs is relatively large because only small fractions of the incident radiation are absorbed or scattered by the air-containing pulmonary tissues. On the other hand, the amount of radiation transmitted in the region of the heart is relatively small because the heart and its contents are quite dense. Moreover, the radiation transmitted by the ribs is smaller still because the ribs contain calcium salts which absorb the incident radiation to a much greater degree than the surrounding tissues.

If the radiation transmitted by the chest falls on a photographic film, a visible image is created when the film is processed, with the areas of the film under the lungs being relatively dark and the area under the heart much lighter. The images of ribs superimposed upon the lung fields and heart, are quite light by comparison.

In addition to the gross outlines of the lungs, heart, and ribs, a great deal of fine detail within these structures can also be recorded if the x-ray tube has a small target area from which x-rays are emitted (i.e., a small focal spot), is operated with a short exposure time, and is placed a long distance (e.g., 6 feet) from the patient and film. Under these circumstances, images of the branching blood vessels within the lungs can be recorded quite well, appearing as relatively light structural patterns against the dark background of the pulmonary tissues.

Interestingly, no images of the bronchi and of their branches are seen under normal circumstances. Because these structures are air-containing, they transmit the same amount of x-rays as the lungs' air sacs, and, hence, no images of them are produced. However, if the air sacs contain fluid, as in pneumonia, and consequently are quite dense, the air-containing bronchi then create images that stand out in sharp contrast to those of the surrounding consolidated lung.

Recording Media. Photographic films, including those developed specifically for the recording of x-ray images, absorb very little of the x-radiation projected on them (about 2%). Consequently, large amounts of radiation are needed to produce satisfactory radiographic images unless some means is provided to make greater use of the available x-ray energy. Intensifying screens constitute just such a means. They are thin, yet rigid, sheets of radiolucent material, the size of an x-ray film, which are coated with a thin layer of fluorescent material composed of heavy-element crystalline salts whose x-ray absorption is relatively high (30% or more).

Intensifying screens are normally produced in pairs with one screen placed in opposition to the front surface of an x-ray film and the other in opposition to the film's rear surface. When exposed to x-rays, the intensifying screens fluoresce, converting the absorbed x-rays to light. The light then exposes the film.

A wide variety of films and intensifying screens are available to the radiologist, ranging in sensitivity or speed from very slow, and, hence, requiring the delivery of a relatively large radiation dose to a patient, to very fast, requiring the delivery of a relatively small dose. In general, a film-screen combination's resolution or ability to record fine detail varies inversely with its sensitivity or speed. In radiography of the chest, particularly when pneumoconiosis is a possible diagnosis, it is usually advisable to employ medium-speed films and screens. Such a combination may be expected to record the images of small pneumoconiotic lesions with sufficient detail to assure their easy recognition and yet not cause the delivery of large doses of radiation to patients.

Table I lists a number of film-screen combinations of the midspeed class that are suitable for radiography of the chest (1). Many physicians and technologists prefer combinations using class A and B films because of the greater number from which to choose. Moreover, these films are sensitive only to blue light, in contrast to the green-sensitive class C and D films; darkroom fogging tends to be encountered less frequently with such films.

Table II lists the gradient and latitude characteristics of the several films included in Table I. The gradient of a film is a measure of its contrast-recording capability. Latitude is a measure of the extent to which technical errors of exposure may be made without causing deterioration of image quality. It will be noted that these two parameters vary inversely with one another; that is, films with high gradients generally exhibit less latitude than those with low gradients, and vice versa.

In Table III are listed resolution and absorption characteristics of the intensifying screens included in Table I. Resolution is a measure of a screen's ability to record detail and absorption a measure of the amount of radiation available for image production. It is wise to use screens with a high percentage absorption, if in doing so resolution is not sacrificed, because the radiation dose delivered to a subject during radiography is inversely related to the amount of radiation absorbed by the intensifying screens.

Table I

Representative Film-Screen Combinations of the Mid-Speed Class
Suitable for Radiography of the Chest

Film	Screens	Relative Speed*	QMI+
Class A	DuPont Par Speed	0.40	2.8
Class A	G.E. Blue Max I	1.00	4.2
Class A	Kodak X-Omatic Regular	0.80	4.2
Class A	USR Rarex BG Detail	0.50	2.7
Class B	DuPont Par Speed	0.80	3.9
Class B	G.E. Blue Max I	2.00	6.0
Class B	USR Rarex BG Detail	1.00	3.8
Class C	Kodak Lanex Fine	1.00	5.5
Class C	3M Alpha-4	1.50	4.9
Class D	Kodak Lanex Fine	1.30	6.3
Class D	3M Alpha-4	2.00	5.7

* Measured as the reciprocal of the radiation exposure in milliroentgens required to produce an optical density of 1.0 in the processed film.

\+ Quantum mottle index, a measure of film granularity due to the discreet nature of x-ray photons (the index is a measure of noise contrast under standard conditions (Rao et al. (1)).

Class A Films: DuPont Cronex 7; Kodak XG
Class B Films: DuPont Cronex 4; DuPont Cronex 6 plus; Kodak XRP; 3M Type R
Class C Film: Kodak Ortho G
Class D Film: 3M Type XD

Generally speaking, it is desirable to use film-screen combinations with relative speeds ranging from 1.0 to 2.0, with quantum mottle indices of 5.0 or less and with screen absorption values of 30% or more. Under these conditions, the clarity of the recorded images may be expected to be excellent and subject exposure small.

Image Quality

Image quality is the attribute of a radiographic film which denotes the clarity with which the recorded images are perceived. Image quality is governed by a large number of factors including the characteristics of the structure under examination, a number of physical factors associated with the exposure, processing, and visualization of the radiographic film, and the educational background and psychologic state of the observer. Although many of these factors can be measured objectively, image quality is a parameter only amenable to subjective measurement due to the psychologic element involved in its evaluation. Hence, the image quality of a particular radiograph may be perceived quite differently from one observer to another. This obviously creates problems for the technologist who serves a group of physicians or who makes films that may be reviewed by a number of observers. Situations are not infrequently encountered where a film may be found to be of acceptable quality by one physician only to be rejected as unreadable by another. Interestingly, image quality appears to bear a strong inverse relationship to the difficulty a physician experiences in interpreting the pathologic changes recorded in a film. Quite often, films of excellent quality on purely technical grounds are rejected as being "unreadable" when the films contain patterns that are difficult to evaluate clinically.

It is clear from the foregoing that image quality is a parameter of enormous

Table II

Characteristics of Representative Films of the Mid-Speed Class

Film	Gradient	Latitude*
DuPont Cronex 4	3.0	0.58
DuPont Cronex 6 plus	2.6	0.67
DuPont Cronex 7	3.0	0.58
Kodak XG	3.0	0.58
Kodak XRP	2.8	0.62
Kodak Ortho G+	2.4	0.73
3M Type R	2.4	0.73
3M Type XD+	2.9	0.60

* Latitude is the difference in log exposure to produce film densities of 0.3 and 1.7.
+ Green sensitive, for use with green emitting screens.

complexity. Notwithstanding this, let us examine some of its more important aspects in order that a better understanding may be gained of the way in which radiographic technique may be used to enhance the quality of the images seen in radiography of the chest.

Image Detail and Contrast. Two of the principal factors controlling image quality are the detail and contrast with which the images are recorded. For purposes of this discussion, image detail is defined as the minimum limit of image size perceptible in a film. For radiographic films made with medium-speed intensifying screens, this limit is a diameter of 0.1 to 0.2 mm. when the images are of high contrast and when the films are made under ideal technical conditions. Image detail is considerably poorer when the images are blurred by movement of the anatomic structures under examination or by the use of an x-ray tube whose focal spot is excessively large. Image blurring and degradation also occur if the intensifying screens of a film-screen combination are not in uniformly firm contact with the film.

Image detail is also affected by image contrast, decreasing as contrast diminishes. In radiography, it is convenient to recognize two types of contrast: specific and gross. Specific image contrast is the difference between the blackness or optical density of the image of a given anatomic structure (or lesion) and the blackness or optical density of the immediate surrounding field. Gross image contrast, on the other hand, is the difference between the blackness or optical density of the darkest image of diagnostic interest in a film and the blackness or optical density of the lightest image of diagnostic interest.

Parenthetically, optical density is a quantitative measure of a film's blackness. Speci-

Table III

Characteristics of Representative Intensifying Screens of the Mid-Screen Class

Screens	Relative Resolution*	% Absorption+
DuPont Par Speed	1.4	21
G.E. Blue Max I**	1.5	32
Kodak Lanex Fine ++	2.1	34
Kodak X-Omatic Regular	1.5	37
3M Alpha-4++	1.7	42
USR Rarex BG Detail **	1.4	34

* The number of line pairs recorded at 50% of maximum resolution.
\+ The numbers in this column indicate the incident radiation that is absorbed by the various screens.
**Rare earth screens; green emitting screens.
++These values apply to conditions in which an 80 kVp x-ray beam filtered with 3.5 cm. of aluminum is used.

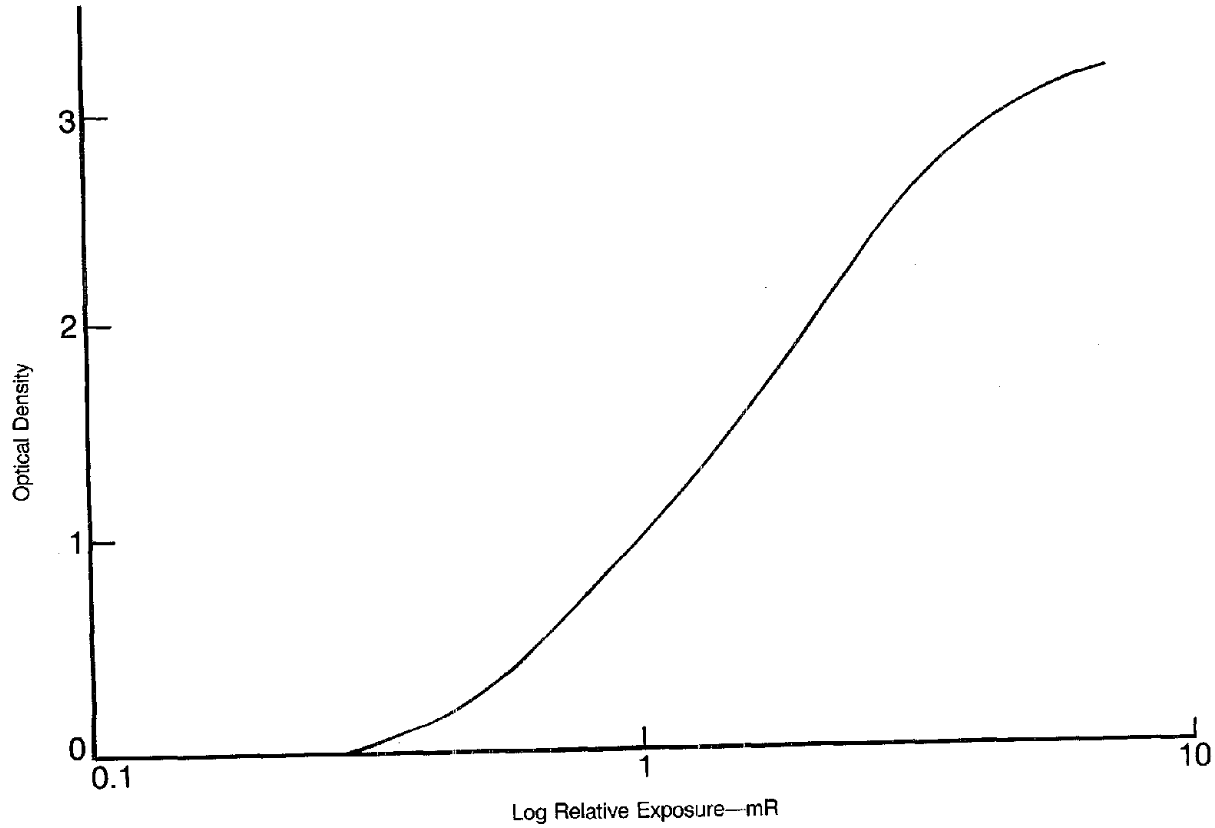

Figure 1. Relationship between the exposure received by a typical film-screen combination and the optical density or blackness of the processed film.

fically, optical density at a given point in a film is the negative logarithm of the film's fractional light transmission. For example, a film which transmits one tenth of the light incident on it has an optical density of 1.0; a film which transmits one hundredth of the light has an optical density of 2.0.

Radiographic Exposure and Film Density

A radiographic film's blackness or optical density is a function of the x-ray exposure received by the film, rising from a value of zero when no exposure is given to values in excess of 3.0 when exposures are large (see Figure 1). This range of blackness or optical density, however, is not useful in its entirety for clinical radiographic purposes. To illustrate this, consider the situation in which the exposure, received by the film, whose characteristics are shown in Figure 1, is 1 mR directly under a pneumoconiotic lesion of a subject under examination. Let us imagine further that the exposure received by the film from the region immediately adjacent to the lesion is 25% greater or 1.25 mR. From Figure 2, it will be evident that the contrast between the lesion's recorded image and its surrounding field will be 0.3 units of optical density.

Consider now, the case when the film under the lesion receives an exposure of 0.4 mR. As before, the surrounding field receives 25% more or 0.5 mR. Again from Figure 2, it

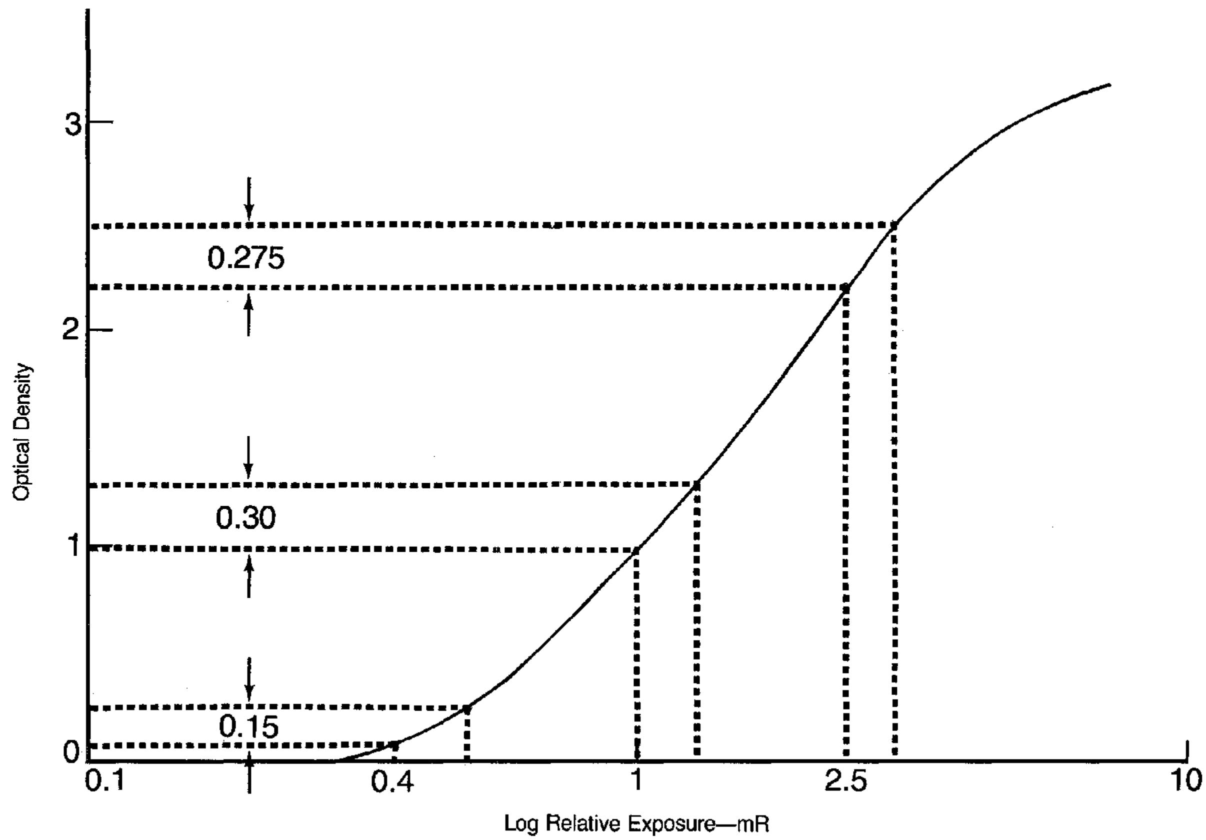

Figure 2. Illustration of the effect of optical density on the contrast exhibited by an image recorded by a radiographic film.

will be evident that the contrast of the lesion's image under these circumstances will be only 0.15 units of optical density due to the shallowness of the film's density vs. log exposure curve at low exposure levels. This loss of contrast is detrimental to image clarity and, hence, should be avoided. In practice, therefore, image contrast is usually judged to be unacceptable when a film's optical density is less than 0.2.

Let us now turn to the case when the film under the lesion receives an exposure of 2.5 mR and the surrounding area 25% more or 3.125 mR. From Figure 2, the image contrast will now be 0.275 units of optical density or closely the same as that when the exposure was 1 mR. Under these circumstances, one might assume image clarity to be good. Such, however, is not the case under conventional viewing conditions. Although image contrast in the film is good, it is sharply reduced when the image is projected on an observer's retina. When a film's optical density is 1.7 or 1.8 and greater, the radiographic images are so dark that ambient light in the viewing room, entering the observer's eyes and diffused by particulate material in the eyes, fogs the visual images and reduces their contrast to unacceptable levels. Indeed, it is important that ambient light in the viewing area be maintained as low as possible. Otherwise, image contrast at the retina may fall to unacceptable levels at optical densities well below 1.8.

Useful Range of Optical Density. It is evident from the foregoing, that there exists a useful range of film blackness for radiographic purposes, extending from an optical density of about 0.2 at its lower limit to a density of 1.8 at its upper limit. Such a range would be more than adequate for all radiographic purposes if, in practice, physicians were interested only in seeing the images of simple anatomic structures, recorded one at a time. Under these circumstances, the technologist would merely expose the film to a point where a desired image produces in the processed film a density somewhere in the middle of the useful range and a good film would a priori be produced.

However, the chest is not a simple structure but an extremely complex one, and its radiographic images must be recorded all at once. Moreover, these images produce optical densities within the film that extend through wide limits. Hence, depending on what structures a physician wishes to see, a film's useful density range is often more than filled. For example, some physicians feel it would be desirable if, on a single film, one could record with excellent detail and contrast the images of the peripheral lung fields, the hilar blood vessels and lymph nodes, the heart and other mediastinal tissues, all of the osseous structures of the thorax, and more. Unfortunately, this ideal cannot be reached because it is quite impossible to crowd the images of all of these structures into the limited range of optical density available and still retain levels of image contrast sufficiently high to permit these images to be seen well. Consequently, physicians must be satisfied with much less. In fact, most find it quite acceptable if little more than the images of the lung fields and hilar regions are included within the useful range of film density.

Because image contrast and clarity are closely related, it might seem important that as much of a film's useful range of optical density as possible be filled by images of diagnostic interest, for under these circumstances, both specific and gross image contrast levels approach their maxima. This is generally true. However, such a rule fails to recognize that when the useful range is fully occupied, the technologist is left with little latitude in estimating the proper exposures to be given when radiographic films are made. Small errors of over- or underexposure will yield unacceptable films. Therefore, it is usually wise to limit gross image contrast to a level moderately below its maximum (i.e., moderately less than 1.6 units of optical density). Figure 3 illustrates the amount of latitude available to the technologist when the gross image contrast is 1.6 units of optical density. It is clear that even under these conditions, the technologist has a relatively little latitude for error.

Scattered Radiation Effects. Under some circumstances, the optical densities of the images of diagnostic interest fall far short of filling the useful range of film density due to the presence of one or more factors impairing image contrast. The most serious of these is scattered radiation which, when excessive, fogs the film and sharply impairs image quality.

Scattered radiation increases rapidly as patient size and thickness increase. To a lesser extent, scattered radiation levels become greater when the electrical potential (kilovoltage) of the x-ray tube is raised.

The amount of scattered radiation reaching a radiographic film can usually be reduced to acceptable levels by the use of a grid, a device, composed of alternating sections of radiolucent and radiopaque materials, which attenuates the scattered radiation while allowing the image-bearing x-rays to pass through. Scattered radiation can also be reduced by increasing the distance between patient and film, but this may cause loss of image detail and a disproportionate increase in the radiation exposure of the patient.

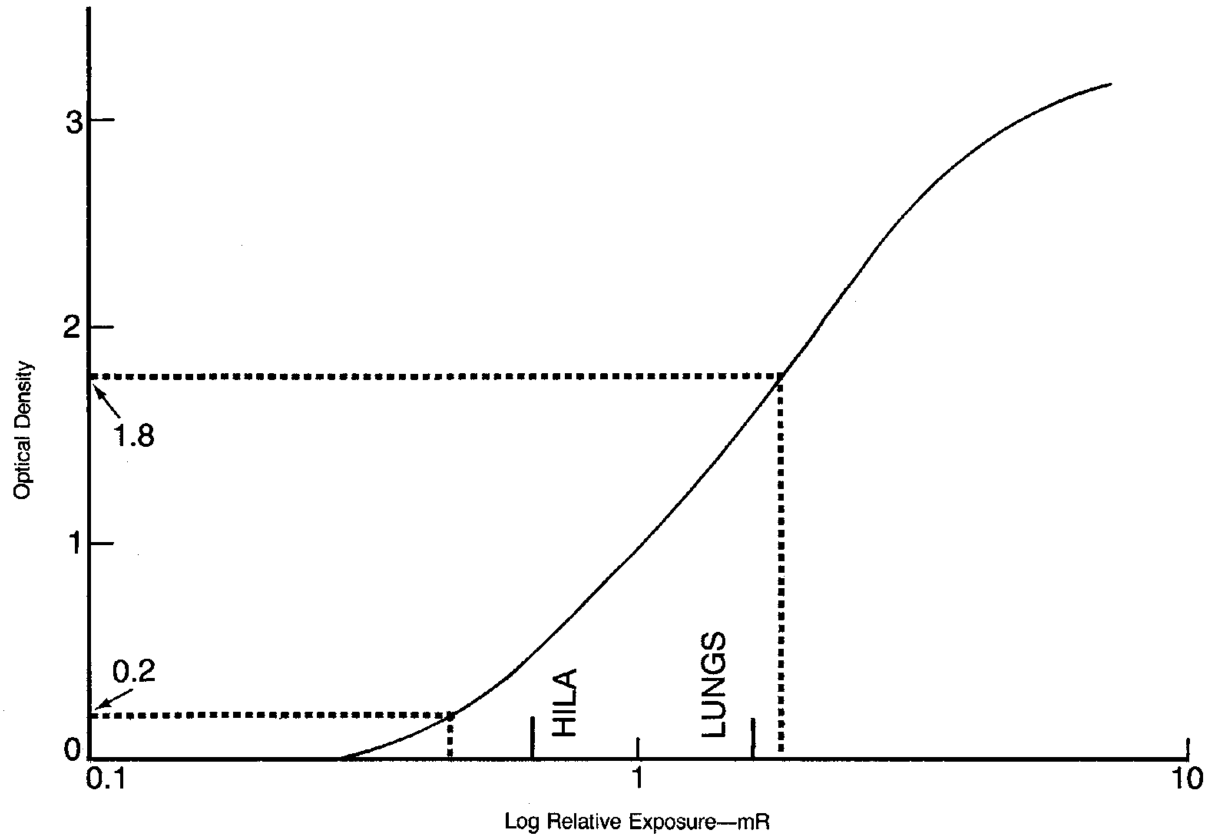

Figure 3. Graphic illustration of how the latitude of a technologist in estimating the exposure to be given during radiography of the chest diminishes as the useful range of optical density becomes increasingly filled by images of diagnostic interest.

High Kilovoltage Techniques. In recent years, the electrical potentials or kilovoltages applied to x-ray tubes during chest radiography have been raised substantially to improve the image quality of pulmonary and other nonosseous structures. By the use of potentials of 300 kVp and more, in contrast to conventional voltages of 80 to 125 kVp, the x-ray absorption of the ribs is sufficiently reduced that the tendency of these structures to obscure the underlying pulmonary tissues is almost wholly alleviated. This trend may be expected to continue.

Major Problems in Radiographic Technique

Experience gained from the pneumoconiosis programs of the National Institute of Occupational Safety and Health and of the Department of Labor indicates that the most serious problem found by physicians and their technologists in producing satisfactory films of the chest is the estimation of proper radiographic exposure. As pointed out earlier, there is little room for error when such estimates are made and, hence, overexposure or underexposure, with resultant loss of image quality, occurs frequently.

The correction of this problem lies in improved training programs for both physicians and technologists. The need for professional excellence in radiographic technology cannot be overemphasized. Unfortunately, many of radiology's practitioners currently fail to recognize its importance.

Another technical problem, almost as serious as that pertaining to radiographic exposure, is the inadequate control of scattered radiation, particularly in large patients. Since satisfactory methods of control are readily available, this problem's correction seems to be a matter of improved training and supervision of radiographic professionals. When scattered radiation is not controlled properly, image contrast falls quickly to unacceptable levels.

Three other technical problems also reflect inadequate radiographic skills and/or lack of professional discipline and supervision among physicians and their technologists. These include unsatisfactory patient positioning, failure to correct radiographic cassettes in which there is poor film-screen contact, and failure to maintain minimum standards of cleanliness in the darkroom.

Major Problems in Interpretation of Radiographs

In advanced cases of pneumoconiosis, there is usually no question, radiographically, regarding the diagnosis of the disease. However, when only small opacities are present and their profusion is limited, interpretation can be quite difficult (2). This is because small opacities can occur in a wide variety of situations, both normal and abnormal, as well as in pneumoconiosis. For example, as individuals become older, periodic respiratory infections often leave them with pulmonary fibrotic changes that appear radiographically as small irregular opacities. These changes are particularly prevalent in cigarette smokers. Also, individuals who suffer from congestive heart disease, in time, develop extensive fibrotic findings in the lungs that may be confused with the early stages of pneumoconiosis. Finally, many pathologic conditions quite unrelated to dust (e.g., sarcoidosis) at various times in their courses manifest themselves radiographically by the appearance of small opacities.

From the foregoing, it is evident that the radiographic findings in early pneumoconiosis are not so characteristic that their interpretation can be counted on to be unequivocal. This has led to the suggestion that chest radiographs always be evaluated with the assistance of the clinical information provided in the patient's history. Superficially, the suggestion appears to have merit. However, it must be recognized that such clinical data usually exhibit as many uncertainties as the radiographic findings. Hence, it is wise in most instances to evaluate history and radiography independently of one another and only afterward bring the two bodies of information together for a clinical judgment. Such a process tends to maximize clinical objectivity and minimize error in the interpretation of both the history and the radiographic information.

Because of the difficulties that exist in the interpretation of chest radiographs, it is perhaps not surprising that inconsistencies arise when a number of physicians independently evaluate a series of radiographs or when an individual physician evaluates the series a number of times. Such inconsistency is unavoidable and indeed is characteristic not only of radiographic procedures, but all clinical testing (including history taking, physical examinations, and physiologic tests) due to uncertainties inherent in all methodologies in which human judgment is a factor (3, 4).

To illustrate graphically the manner in which interfering patterns affect the decision

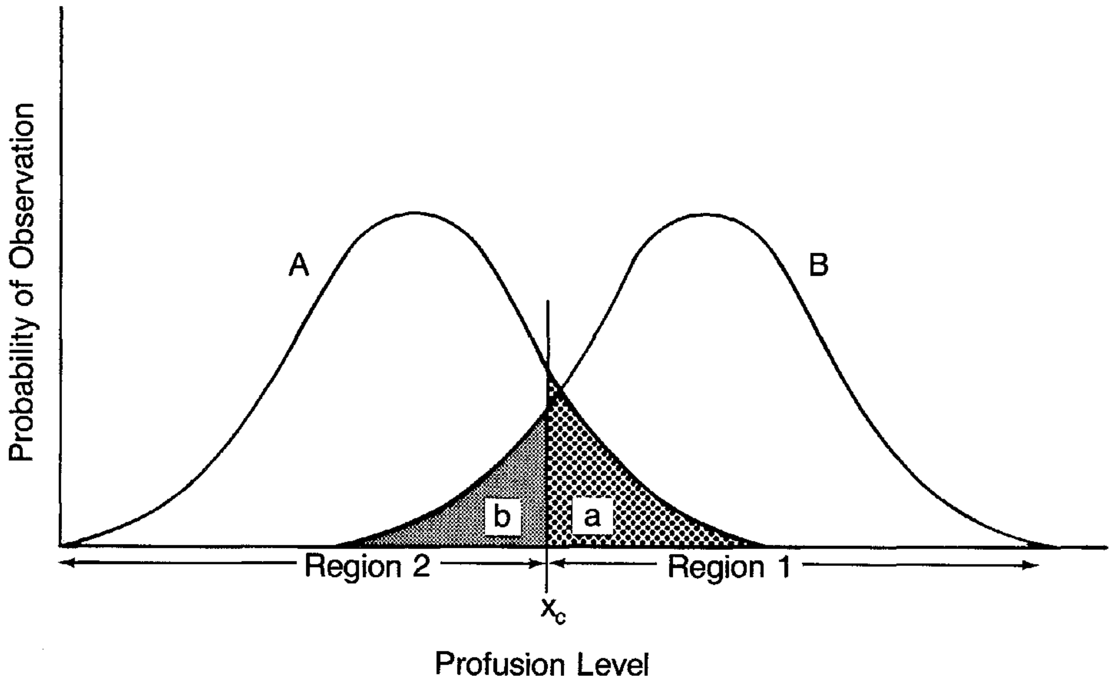

Figure 4. Representation of the decision problem in pneumoconiosis. Hypothetical population distributions in which the ordinate depicts the probability of one's observing a given profusion level in a population free of pneumoconiosis (curve A) and in a population with pneumoconiosis (curve B).

processes and observer error in the interpretation of chest radiographs for pneumoconiosis, let us consider the profusion of small rounded or irregular opacities (i.e., the number of opacities per $cm.^2$) that might be observed in the films of a representative sample of individuals who are free of the disease. Curve A in Figure 4, plotting the number of films prevailing at each profusion level, depicts the data that might result from such a study. Let us now consider the profusion of similar opacities in the radiographs of individuals who have pneumoconiosis. Because profusion levels are higher in such cases, the corresponding probability distribution generated by these cases might be characterized by curve B. It will be observed that the two curves overlap, and quite clearly uncertainty of diagnosis will prevail for those cases included in the region of overlapping. For example, consider an interpreter who selects a profusion level of x_c as his operating point, separating cases he will call positive for pneumoconiosis from those he will call negative. The cases to the right of x_c in region 1 will be called positive for the disease. Of these, the cases under the unshaded portion of curve B will be correctly diagnosed; that is, they will be true positives. However, those cases included under the shaded portion of curve A (a) will also be called positive in spite of the fact that they actually are free of the disease; such cases will therefore be false positives.

The cases to the left of x_c in region 2 will be interpreted as normal. Of these, the cases under the unshaded portion of curve A will be correctly diagnosed and, hence, will be true negatives, whereas those under the shaded portion of curve B (b) must represent false negative interpretations, since the disease is actually present in these cases.

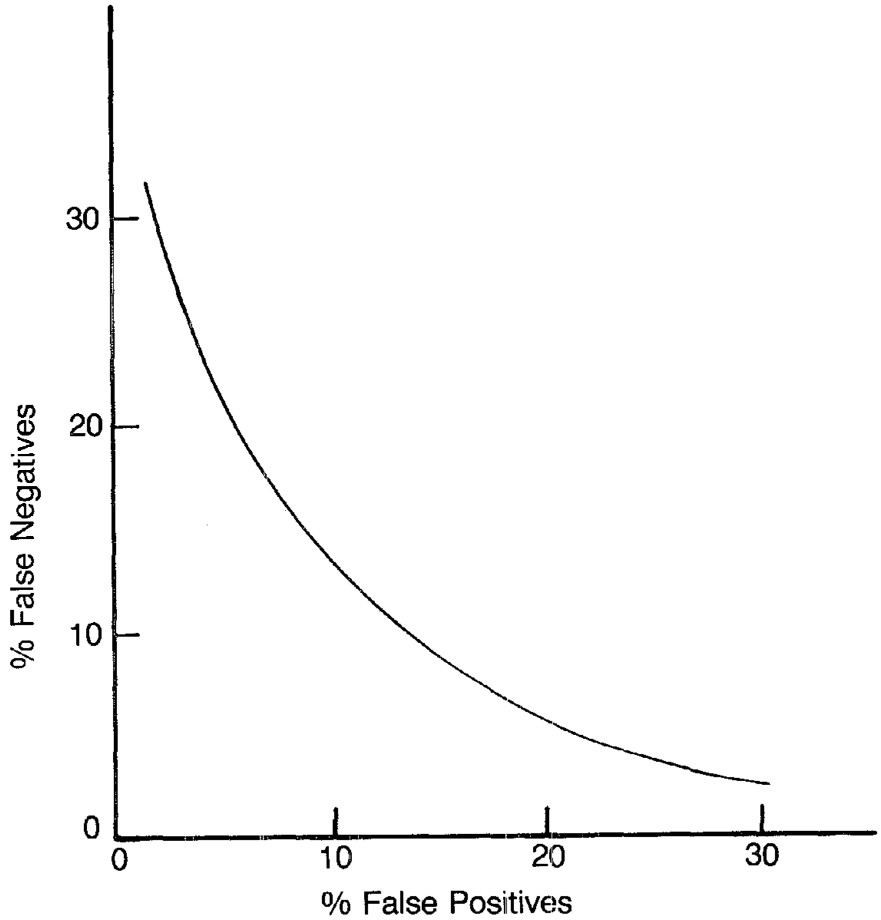

Figure 5. Curve illustrating the reciprocal relationship between percentage of false negative and false positive interpretations of chest radiographs for pneumoconiosis (derived from data given in Figure 4).

It will be evident from an examination of Figure 4 that the percentages of false positive and false negative interpretations will depend upon where the operating point, $\underline{x}_c$ is placed. If it is placed to the left of the position shown, the number of false negatives will diminish but at the expense of an increasing number of false positives. On the other hand, if the operating point is moved to the right, the number of false positives will diminish but at the expense of an increasing number of false negatives. The reciprocal relationship between the percentage of false positive and false negative interpretations as one moves the operating point, $\underline{x}_c$, along the profusion axis is illustrated graphically in Figure 5.

There is evidence to believe that inconsistencies in radiographic interpretation can be reduced by multiple readings carried out independently by a number of physicians and the results examined for concensus (5). Inconsistency can also be minimized by training programs in which physicians are taught to recognize subtle differences between the normal and abnormal radiograph. Finally, it is important that physicians having responsibility for interpreting chest radiographs in national pneumoconiosis programs have an opportunity to apply their knowledge sufficiently often to maintain their diagnostic acuity at a high level of acceptability. If these criteria are carefully observed, the chest radiograph can be relied upon to be of great value in the evaluation of any individual suspected of having dust-related disease.

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Chapter VII

Control of Scattered Radiation by Means of Collimation, Grids, or Air Gap

John E. Cullinan, R.T.R., F.A.S.R.T.

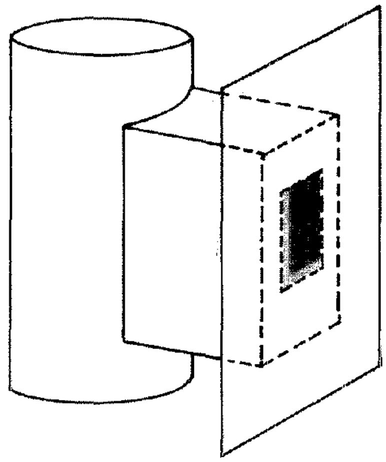
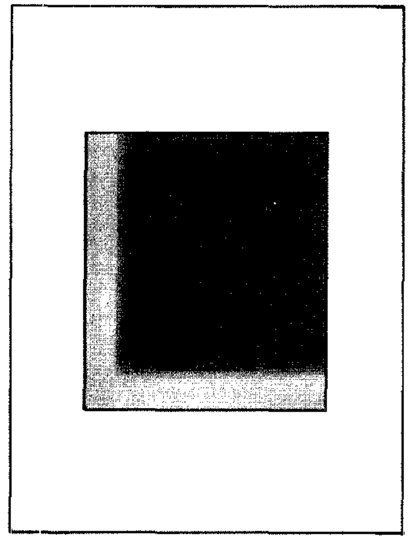
When evaluating a radiographic image, the term "fog" is often encountered. The word "fog" is synonymous with "haziness", or a general obscuration or clouding of the image. Fog may be caused by light, heat, aging of the film, base film fog, and also by improper processing. However, the most common cause of fogging of a film is scattered radiation. This chapter deals not only with control of primary radiation or proper collimation, but also the the proper use of a grid or an air gap to clean up secondary radiation fog. The recognition and correction of difficulties that may be encountered for the control of primary and secondary radiation by these methods is extremely important, in order to produce optimum chest radiographs.

As the primary ray is absorbed producing a roentgen shadow, it might be implied that all of the rays that exit from the object under study originate straight from the focal spot (primary beam), have traveled through the chest to form a well-defined clear-cut image, and that all of the rays that did not penetrate the chest were absorbed by the chest and could be ignored. Unfortunately, this is not the case. Some of the radiation is scattered in all directions as it strikes the atoms of the object, very much as light is dispersed by fog. This nonimage-forming radiation is known as scattered radiation (1).

Scattered radiation does not damage the entire chest radiograph proportionally. It is not uniform throughout the entire image. Wilsey found a variation of 40 to 75% in segments of the chest radiograph. In the average chest radiograph, scattered radiation forms more than half of the radiation striking the screen/film detector and can reach proportions of 60 to 75% (2).

All supplemental densities cannot be blamed on scattered radiation. Many conditions produce a fog-like image on the processed radiograph. Careless handling of the film under improper safelights, difficulties with film processors, improper storage conditions, etc., all produce supplemental densities similar to the effect of scattered radiation (3).

"Tight coning" or beam collimation contributes to a high quality radiograph. Many radiographers believe that small fields are exposed only with the radiation dosage hazard in mind. While this is true, it is important to remember that even if x-radiation

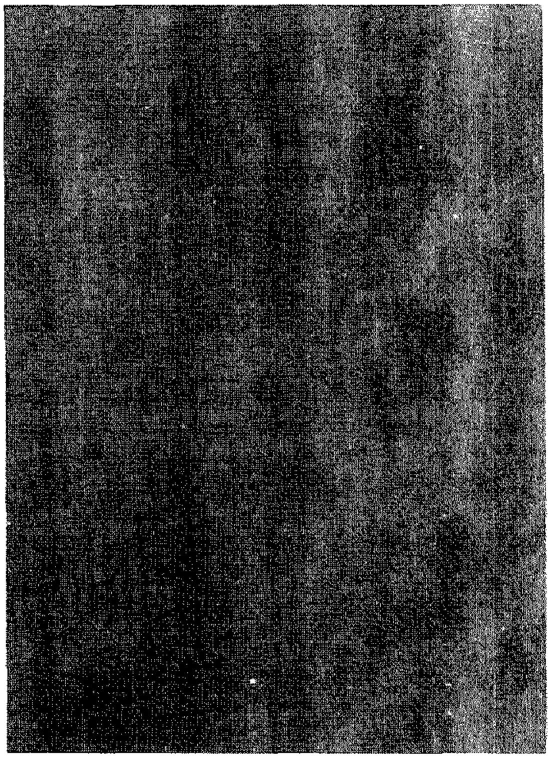
 

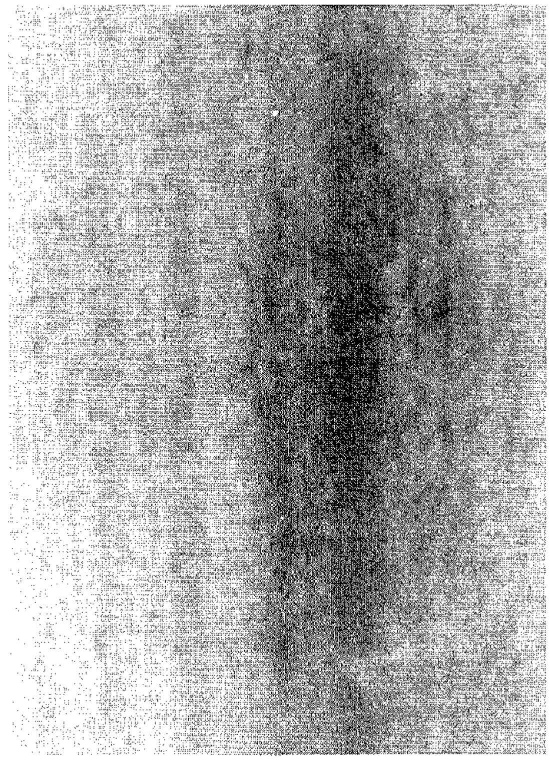
Figures 1A (left) and 1B (right). A simple test to demonstrate the improper position of the primary diaphragm or improper alignment of the primary shutters of the collimator. Often the placement of a diaphragm at the source or the improper alignment of the primary shutters of the collimator can damage the radiographic image (see Figure 3C). To test for this difficulty, a direct exposure film holder is taped to the front of the collimator after the shutters have been restricted to the exact size (14 by 17 inches) required for chest radiography (Figure 1A). An exposure is made using a relatively low kilovoltage (50 kVp) at approximately 25 or 50 mAs. The resulting radiograph (Figure 1B) will exhibit a black rectangular area demonstrating the exit port of the collimator. The exit shutters will be sharply etched. If the upper shutters or the port diaphragm is misaligned, a hazy, poorly defined edge, or edges, will occur. A minor misalignment near the source of radiation can produce major damage to the radiographic image (see Figure 3C).

were completely harmless, it would still be necessary to restrict the primary beam size to improve the radiographic image. The most important way to reduce scattered radiation is to limit the area being exposed to primary radiation. In addition, an adjustable radiation shield for the abdomen should be available for all chest radiography (4).

Off-Focus Radiation

Ter-Pogossian suggests that off-focus radiation may represent up to 25% of the on-focus radiation (5). There is actually an increase in patient exposure due to off-focus radiation. All radiation does not emerge from the actual focal spot of the x-ray tube; e.g., there is additional metal available in the tube for a "rebounding effect". Electrons rebound from the target and strike areas other than the actual focal spot, often producing off-focus radiation. The placement of a lead diaphragm in intimate contact with the tube window reduces this effect to a reasonable level. Wilkinson and Fraser feel that this generally improves the radiographic image (6). The placement of this diaphragm in an improper position or the improper alignment of the upper shutters of the collimator can severely damage the radiographic image (Figures 1A and 1B).





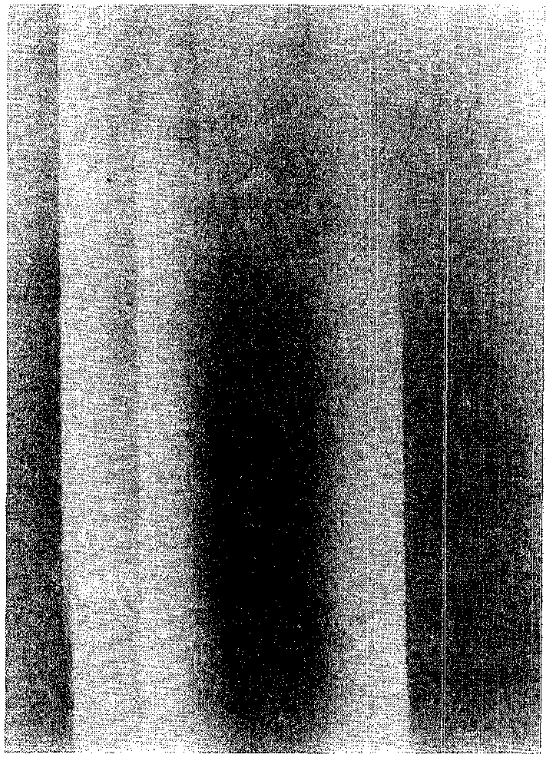
Figures 2A (left) and 2B (right). Grid damage or mechanical difficulties. A Bucky grid "captured" in motion. Erratic movement of the grid or short exposure times can capture a grid during an exposure (Figure 2A). This is a radiograph made using very short exposure to demonstrate this effect. Grid mottle, as demonstrated in Figure 2B, is often superimposed on the radiolucent lung field. This pattern is sometimes difficult to separate from the radiographic image of the chest.

When a dedicated chest radiographic unit is used, Wilkinson and Fraser suggest the installation of a special cone with a predictable constant focal film distance, a constant size of the film, an automatic alignment of the x-ray tube to the film, and the use of various diaphragm sizes for smaller patients (6).

The Use of a Grid or Bucky for Scatter Control

The use of a grid during chest radiography has gained wide acceptance. It is not necessary, however, to use a grid with all patients, particularly smaller individuals or when using lower kilovoltage values. A good quality grid is necessary to avoid the loss of information by the "masking" of the pathologic conditions (7) (Figures 2A, 2B, 2C, and 2D). Milne and Gillan feel that when using high kilovoltages (for example, 125 kVp) the use of a grid with a ratio greater than 10:1 is of no appreciable value (8).

A grid is a device composed of alternating strips of lead and spacer material. The spacer material (fiber or aluminum) is chosen for low x-ray absorption. These strips are encased in a protective cover to provide strength and durability. The lead strips absorb a considerable amount of scattered radiation; i.e., radiation not traveling in the



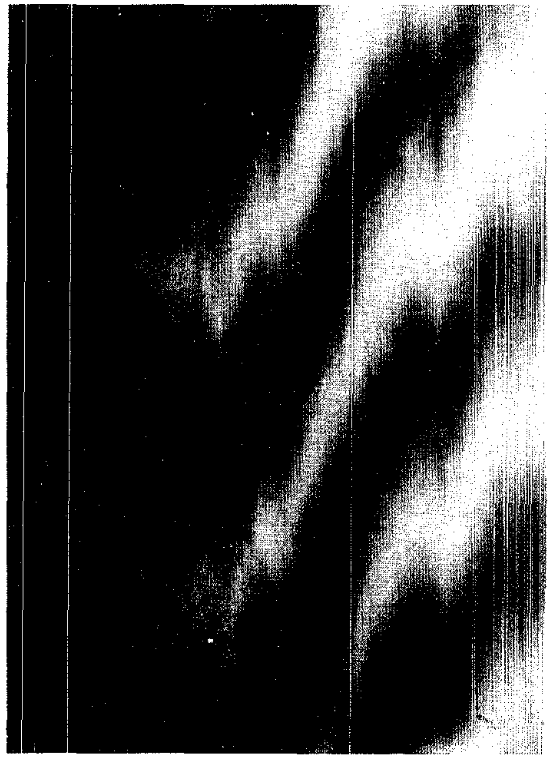


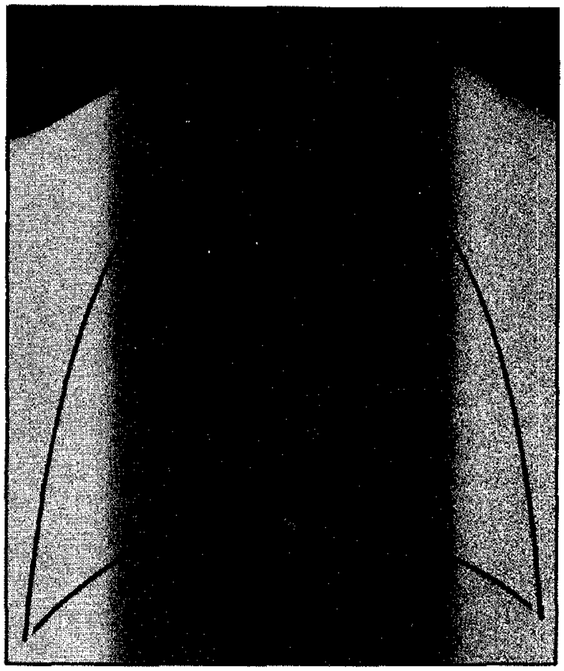
Figure 2C (left). Damage to an aluminum interspaced grid. Note the low-density (white) banding throughout the entire grid. This grid would be difficult to ignore on a chest radiograph. Unfortunately, if a grid damaged in this manner were used in a moving Bucky, this banding would be obliterated and the radiographic image would be of poor quality.

A simple test can show the presence of damage to a grid whether fiber or aluminum interspaced. The grid should be perfectly centered to the x-ray tube at a distance of 72 inches and a radiograph made using the screen-film combination customarily employed. Suggested technical factors to use as a starting point are 50 to 60 kVp and 1 to 5 mAs, depending on the screen-film combination. Be sure to adjust the exposure to produce a density on the film similar to that shown. In order to obtain a 72-inch distance from tube to cassette, it may be necessary to place the cassette with grid on the floor under the tube instead of on the table.

Figure 2D (right). "Moire" grid artifact. An unusual grid artifact is produced by the use of two grids with both grids positioned so that their lines and interspacing material are nearly superimposed. This moire artifact was caused by the use of a grid cassette in combination with a stationary grid. On occasion, a grid cassette is accidentally used for a chest radiograph in a cassette holder already containing a stationary grid. The moire pattern results because it is virtually impossible to accurately line up both grids. If conventional factors are used, the radiograph will be considerably underexposed.

direction of the primary beam. The x-ray transparent spacers allow most of the primary rays to pass through to the screen/film combination.

The relationship of the depth of the lead strips to the width of the radiotransparent



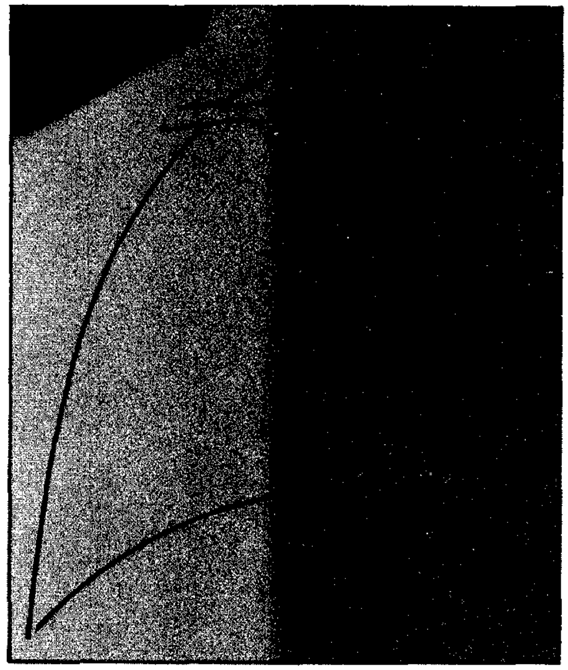
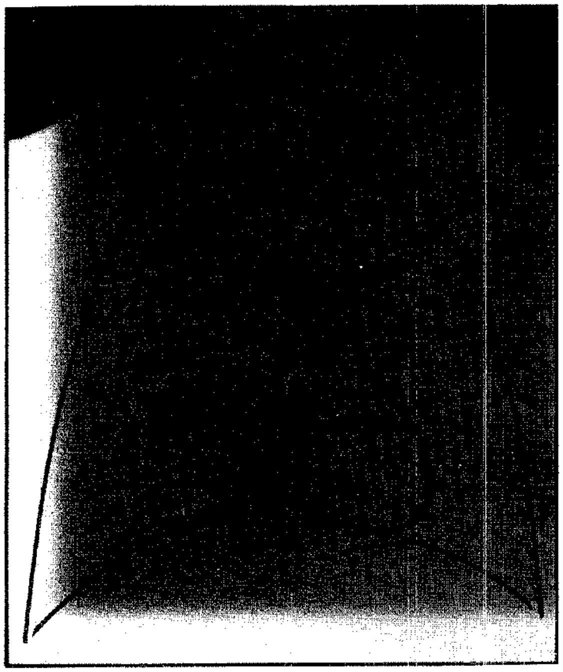


Figure 3A (left). Some common difficulties associated with the use of a Bucky or grid: improper grid focal range. If a 40-inch focal film distance is used instead of a 72-inch, a bilateral cutoff occurs on both lateral aspects of the grid. Often an upright Bucky is used for high kilovoltage chest radiography. In general, the upright Bucky of older radiographic rooms contains a grid focused for conventional radiography as opposed to teleroentgenography (72-inch focal film distance or greater). It is relatively easy to remove the grid and check the manufacturer's label regarding grid focal range and grid ratio.

Figure 3B (right). Nonuniform distribution of x-ray intensity under the grid. If an x-ray tube is rotated in its mount or miscentered to one side of the grid, a unilateral decrease in density will occur. Although there is an overall decrease in radiographic density, one side of the radiograph is considerably lighter. The tube is off-center to the lighter side of the radiograph.

spacers is known as the "grid ratio". For example, if the depth of the lead strips is eight times the width of the interspacing material, the grid ratio is 8:1.

Grid Focus or Cut-off. Focused grids usually have a focal range specified by the manufacturer; i.e., a range of distances throughout in which the grid can be satisfactorily used. If used at a reduced focal range (for example, 40 inches instead of 72 inches) a grid cut-off is observed. There is a progressive decrease in transmitted x-ray intensity on both sides of the radiograph (Figure 3A). If the tube is tilted laterally across the lead strips or not centered to the x-ray tube, there is also a nonuniform distribution of x-ray intensity beneath the grid. The tube can be improperly rotated in its mounting or miscentered to one side of the grid, producing a unilateral decrease in density (Figure 3B). Stationary grids must be handled carefully for they are easily damaged (see Figure 2C).



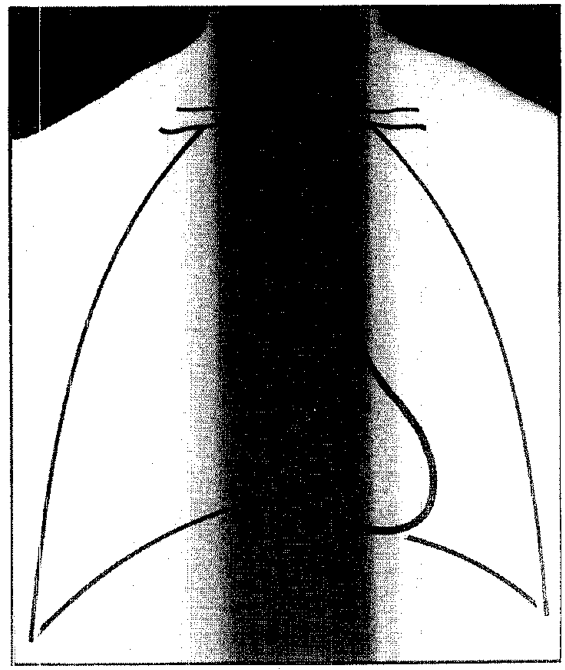


Figure 3C (left). Improper position of a primary diaphragm or improper alignment of the exit shutters of the collimator (see Figures 1A and 1B).

Figure 3D (right). Reversed grid. When a grid or a Bucky is placed in the reverse position, only the x-rays parallel to the center of the grid reach the detector. The higher the ratio grid, the more damage to the radiograph.

Since a grid is often used in several rooms, some type of grid "stop" is needed to accurately center the x-ray tube to the grid. It is recommended that the grid be inserted from one side of the grid-cassette holder only, moving the grid on its tracks to a given automatic stop, assuring accurate centering of the tube and grid.

A stationary grid when moved during an x-ray exposure to obliterate its lines is known as a Potter-Bucky diaphragm and is often called a "Bucky". The moving of the stationary grid not only blurs out the lead lines but also any defects in the grid or the radiolucent spacer materials.

The availability of the aluminum (inorganic) interspaced grid has resulted in a grid with more lines per inch, often 100 or more. These lines are also separated more evenly making it difficult for the interpreter to see them.

Unwanted Grid Lines on a Radiograph. When using a Potter-Bucky diaphragm with short exposures, it is often easy to "capture" the grid in motion (see Figures 2A and 2B). The use of a lead marker taped to the cassette in the Bucky tray can also produce this "grid mottle" effect, for often the moving grid will touch against the lead marker or its adhesive tape fastener, causing erratic movement of the grid.

Air-Gap Technique

Air gaps of 8 or 12 inches are used respectively with focal film distance settings of 8 or 12 feet (9). One of the problems encountered with an increased focal film distance is that it is often difficult, even in a room with subdued lighting, to see collimator shutter patterns on the surface of the patient. If possible, the control for the overhead room light should be mounted on the tube crane so that the tube is aligned with the patient. It is then possible to momentarily turn off the room lights for maximum beam limitation (7) (a visible low-level laser beam can be used for positioning purposes*).

The reduction of scattered radiation by an air gap should not be compared to the reduction obtained by the use of a grid or a Bucky which absorbs the scattered radiation. When using the air gap, the intensity of the scatter is dependent upon the distance separating the source of the scatter from the detector (1). To reduce backscatter, the cassette frame used for an air-gap technique requires 1/16 inch of lead mounted to plywood on the wall of the radiographic room before the installation of the cassette holder (10). Lead installed behind the back intensifying screen of the cassette (0.015 inch in thickness) helps to reduce backscatter from the room wall, increasing image contrast (6).

Summary

The control of scattered radiation requires "tight coning" or beam collimation in combination with a grid, Bucky, or air gap when reasonably high-level kilovoltage values are used. The short exposures associated with chest radiography can often "capture" a Bucky grid in motion producing grid mottle. A grid must be free of artifacts and used at the manufacturer's suggested focal range.

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* Manufactured by Gammex, Inc., Patient Positioning Systems, Glendale, Wisconsin 53209.

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Chapter VIII

The Screen/Film Combination: Blurring and Quality Assurance

Leland Erickson, M.A.

The reason for requiring a chest radiograph for the detection and classification of the pneumoconioses is to obtain as much information as possible with a reasonable x-ray exposure to the patient. In order to provide a foundation to aid in the understanding of some of the material to be discussed in Chapter IX, let us first take a brief look at how screens and films function as well as why they influence the appearance of radiographs. In keeping with the main purpose of this text there will also be specific recommendations for the use and care of screens and films to produce the best possible radiographic images.

Radiographic blurring has two components: geometric blurring and blurring from light diffusion (i.e., spreading of light in the screen/film combination used to record the image). Geometric blurring results from such factors as focal spot size, source-subject distance, source-image-receptor distance, and motion. The effect of these factors on radiographic image quality is discussed elsewhere in this syllabus. Light diffusion blurring results from the sideways spreading of light in the screen/film combination. It depends on how the screens are constructed, the type of film, and how good the contact is between the screens and films during the exposure.

Let us first examine what happens in a screen/film combination during a radiographic exposure, and understand the components of the screen which result in reduction of required x-ray exposure to a film. One of the factors that makes x-radiation useful is its ability to penetrate substances. When a film is placed in an x-ray beam, a relatively small amount of the x-ray energy is absorbed by the very thin silver halide emulsion layer and most of the beam passes on through. Soon after x-rays were discovered, experimenters realized that x-ray absorbtion could be increased by coating the emulsion on both sides of the film base (inert plastic support) instead of on just one side. Subsequently, it was found that much less exposure was required if certain phosphors were placed next to the film during the exposure. These phosphors were materials which fluoresced (i.e., gave off light when exposed to x-rays).

The use of these screens, known as intensifying screens, then permitted a reduction in x-ray exposure for the following two reasons: (1) they absorbed more x-rays than the film, and (2) they changed some of this x-ray energy into light, which is more effective in exposing the film than x-rays alone. Most medical radiography today uses a

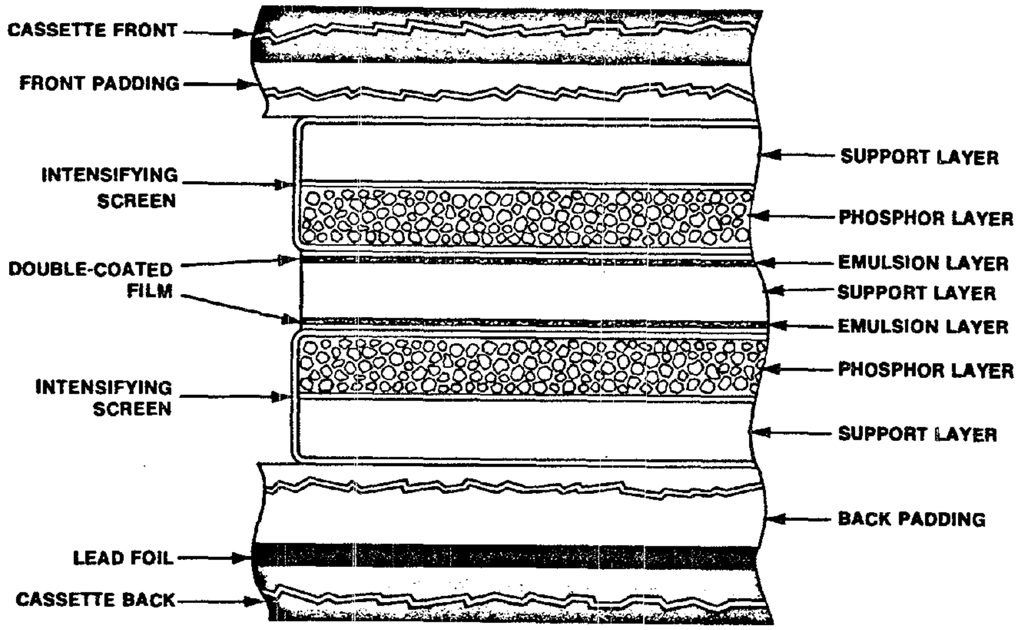

Figure 1. Cross section of a loaded cassette. This shows the screen/film configuration most commonly used in medical radiography enclosed in a lightproof container (cassette). A double-coated film (one with emulsion on both sides of the support) is sandwiched between two intensifying screens and enclosed in the cassette providing good screen/film contact and protection from light and damage. The back of many cassettes is covered on the inside with a sheet of lead foil to prevent backscattered x-radiation from reaching the screen/film combination. Components in this diagram are not drawn to scale.

combination of a double-coated film placed between two fluorescent intensifying screens composed of suitable phosphors. Using fluorescent screens with x-ray film permits exposure to be reduced by a factor of 100 or more relative to that required for direct exposure (film exposed without screens).

Advantages of Reduced Exposure. Some of the advantages offered by the reduction in exposure made possible by use of fluorescent screens are: (1) shorter exposure times, thereby decreasing image blurring from patient motion; (2) reduced dosage to patients and personnel; (3) increased x-ray tube life; (4) increased flexibility in choice of kilovoltage which permits adjustment of subject contrast; and (5) decreased focal-spot size to minimize geometric blurring and to permit direct x-ray enlargement studies.

Without intensifying screens, most radiographic examinations would not be possible.

Screen Construction. Figure 1 shows in schematic form a cross section of a cassette loaded with a screen/film combination as used in medical radiography. The screen consists of a layer of binder material, which contains many small phosphor crystals, coated in a uniform layer on a plastic, paper, or cardboard base or support layer. A protective coating is applied to the outside of these layers to keep moisture out, to prevent staining and damage, and to permit cleaning. Some screens also contain a thin layer between the phosphor and support layers which may contain a reflector or an absorber of light. In other cases, the support layer itself may contain a reflective material, such as titanium dioxide, instead of having a separate reflective layer. Phosphor layers in different screens may differ in thickness and may contain light-absorbing pigments or dyes depending on the type of screen and its intended application.

Phosphors and Film. For many years the phosphor used in most intensifying screens was calcium tungstate. More recently other phosphors have come into use which differ from calcium tungstate (1) in their absorption characteristics, (2) in the efficiency with which they convert x-ray energy to ultraviolet radiation and light, and (3) in the color of the light they produce. Some of these phosphors absorb 50% more x-ray quanta (photons) than a calcium tungstate phosphor layer of the same thickness and also produce more than three times as much light for each quantum absorbed. The light from calcium tungstate is predominantly blue, whereas some of these other phosphors emit, in addition to blue, large amounts of green light or of ultraviolet radiation. All x-ray films are sensitive to ultraviolet radiation and blue light, but in order to make effective use of the green light emitted by some rare-earth screens, an orthochromatic film is needed--one which is also sensitive to green light. It is important to remember that the safelight filters used with orthochromatic films must be designed for the extra sensitivity of these films. Safelight filters intended for use with orthochromatic films will also be safe for most blue-sensitive films.

Screenlight Paths. Consider some of the things that can happen when an x-ray quantum interacts with a phosphor crystal. The absorption of a single x-ray quantum results in the emission of hundreds of light quanta from the crystal. These light quanta travel outward in all directions from this phosphor particle. Some reach the first emulsion layer of the film and are absorbed there to produce a latent image. Others pass on through the first emulsion layer and through the film support layer to the opposite emulsion layer where they are absorbed. Light which crosses over through the film support to the opposite emulsion in this manner is called "crossover" or "punchthrough".

About half of the light quanta which emerge from the phosphor crystal travel in a direction away from the film. Some of these will be absorbed in the phosphor binder, and this absorption will be increased if the binder contains light-absorbing materials, such as yellow or pink dyes. Some of the light will reach the support where it may be absorbed or reflected depending on the characteristics of the screen-support layer. If the support is reflective, some of the light will be redirected back toward the film where it will contribute to the radiographic image. Thus, incorporation of a reflector permits light to be used in image formation which would otherwise be lost and thereby reduces the exposure needed. However, as we shall see, a price must be paid for this benefit.

Screenlight Blurring. Perhaps it is now becoming apparent how the composition and structure of the screen/film combination relate to blurring of the radiographic image. The central fact to remember is that the longer the path the light travels before reaching the film emulsion layer in which it is absorbed, the greater the possibility for it to spread sideways and cause blurring of the image. Thus, crossover light, which is spreading laterally as it passes through the film support, produces more blurring than the light which is absorbed in the emulsion next to the screen. Also, light that travels away from the film spreads as it approaches the screen support layer. If the support layer contains a reflective material, this light will continue to spread even more on its

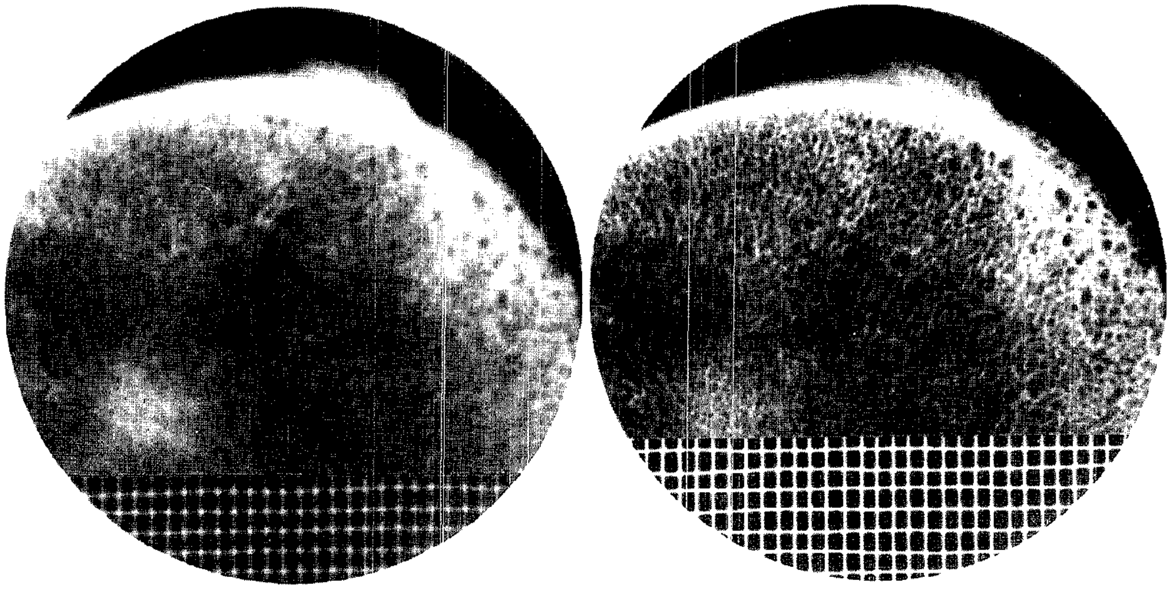

Figure 2. Radiographs showing the effect of poor screen-film contact. Figure 2A (left): Blurring of the image and loss of detail of the wire mesh and adjacent bone caused by poor contact. Figure 2B (right): Good contact between screens and film with sharp outlines of wire mesh and osseous structures.

way back toward the film. Similarly, if contact is poor and there is a space between the screens and film, the light must travel a longer path to reach the film. This, of course, produces increased blurring and decreased radiographic image quality.

In the cases of crossover and the use of reflecting support, the light they prevent from being lost provides a benefit in the form of reducing the exposure needed. In some examinations, the shorter exposure times made possible by the use of reflectors reduces blurring due to patient motion. This improvement in image quality from arrested motion can more than offset the blurring caused by the reflector or by crossover. However, there is no benefit associated with blurring produced by poor screen/film contact, and since it can destroy the quality of the radiographic image, it must be prevented (Figures 2A and 2B).

Reducing Crossover. There are ways of reducing the amount of light which crosses over to the opposite emulsion of the film. One method is to put a light absorber under the emulsion layer. This reduces blurring and also the amount of light available for image formation, thereby necessitating increased exposure. Another way of reducing crossover and the blurring associated with it is to use a phosphor which emits a large proportion of ultraviolet radiation. The silver halide crystals in the film emulsion are efficient absorbers of ultraviolet radiation. For a screen which has much of its emission in the ultraviolet, more of this radiation is absorbed to expose the emulsion in contact with the screen and less is left over to punch through to the emulsion on the opposite side. In this case, blurring is reduced, but the radiation is not wasted because it is taken up by the emulsion and used in image formation.

Effect of Screen Thickness. Not only are screens made of different phosphors but also a given phosphor may be coated at different thicknesses to provide screens which differ in their ability to absorb x-rays. As the phosphor layer increases in thickness, its x-ray absorption increases. Also, other factors remaining the same, its light output increases with thickness so that the same blackening can be produced in the radiograph with less x-ray exposure to the patient.

As mentioned previously, the farther the light has to travel before it reaches the film, the greater the blurring of the image it produces. Thus, if nothing else is changed, the thicker the phosphor layer, the farther the light must travel before reaching the film and the more it spreads out laterally, thereby producing greater blurring of the image (Figures 3A and 3B).

Summary of Blurring from Light Diffusion. The longer the light path to the point of absorption in the film, the greater the lateral spreading of the light and the greater the image blurring. In general, those factors which increase the light output of the screen tend to increase light spreading and image blurring. On the other hand, those factors which tend to reduce light output usually reduce diffusion and blurring. In the following examples of these relationships it is assumed all factors are held constant except the one mentioned in each example.

Increasing phosphor layer thickness--increases light output and blurring.

Using a reflecting underlayer or support--increases light output and blurring.

Using an absorbing underlayer or support--decreases light output and blurring.

Adding a light absorber to the phosphor binder--decreases light output and blurring.

Manufacturers provide a variety of screens having different speeds and imaging characteristics to meet the diagnostic needs of the radiologist. In some examinations, minimal blurring is desired. In others, greater blurring from light diffusion is tolerable because the increased speed associated with it may be used, e.g., to reduce blurring from motion, to increase contrast by reducing kilovoltage, and to reduce geometric blurring by use of a smaller focal spot.

In selecting a screen/film combination suitable for his needs, the radiologist will have determined acceptable limits for blurring resulting from the factors listed above. However, it must be remembered that blurring from poor screen/film contact is never acceptable and that care must be taken to prevent blurring from this source.

Now, having had this introduction, let us move on to see how to guard against poor screen/film contact, and other problems, in the following sections.

Quality Assurance. In addition to selecting a screen/film combination whose characteristics are a suitable compromise for a particular examination, consideration must be given to many other factors which affect the quality of the radiographic image. Among these are exposure conditions and processing. In order to obtain the image quality which the screen/film combination has been designed to produce, exposure and processing systems must be checked regularly to be sure they are performing satisfactorily. This is discussed in Chapters V and XI.

Other factors of importance in a quality assurance program are those relating to the care and handling of the screen/film combination, such as screen/film contact, cleanliness, safelighting, storage, and handling of films and cassettes.

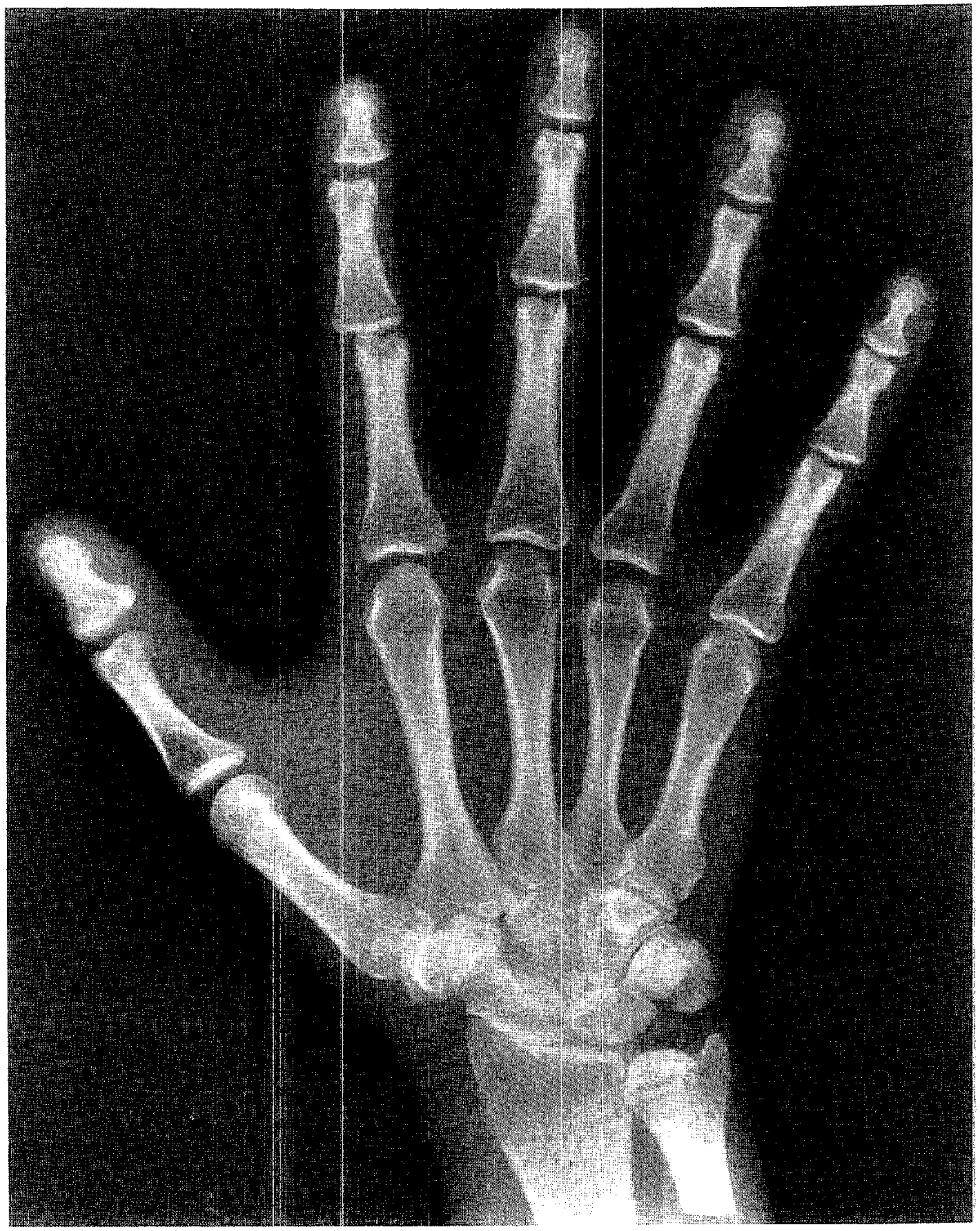

Figure 3. Effect of screen thickness on blurring. Figure 3A: Radiograph of hand phantom made with a thin screen containing a light-absorbing dye. There is excellent detail of bone trabeculae (55 kV, 30 mAs).

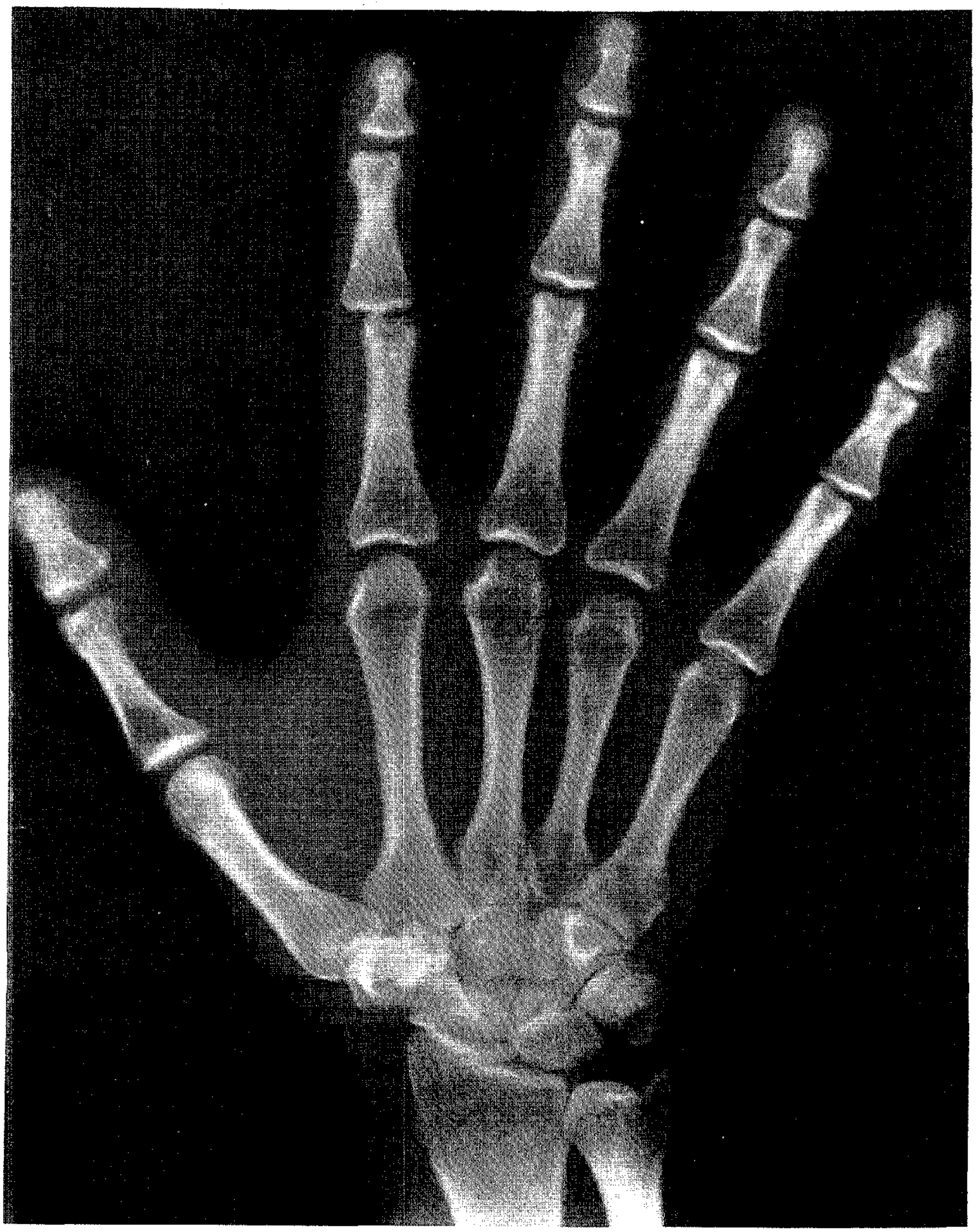

Figure 3B: Radiograph showing blurring resulting from use of a thick screen (55 kV, 3mAs). A hand phantom was used because the trabeculae make it easy to see the effect of screen thickness on image quality. Notice the semicircular low-density artifact over the fingers in Figure 3B. This marking resulted from use of a damaged screen.

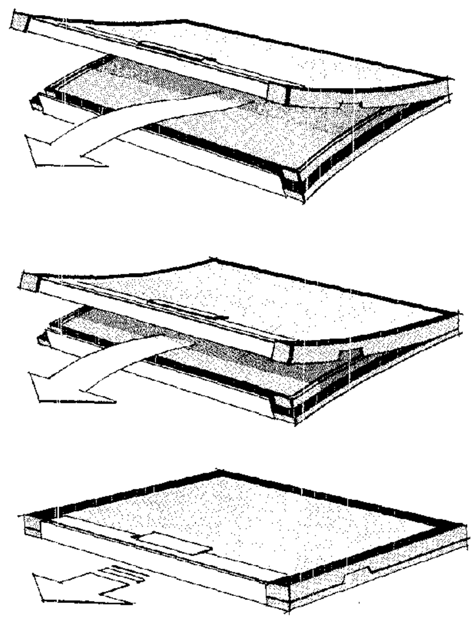

Figure 4. Cassette with curved front and back panels. The drawings illustrate how air (indicated by the arrows) is squeezed out from between screens and film as the two curved panels roll together during closing of the cassette. This cassette design produces good screen/film contact more consistently than traditionally designed cassettes which are more susceptible to trapping of air pockets between screens and film.

Screen/Film Contact. We have spoken of the loss of image quality resulting from poor screen/film contact. Now let us examine some causes of poor contact, a way of testing for it, and remedies. A frequent cause of poor contact in traditional cassettes is the trapping of air in pockets between screens and film as the cassette is closed. Irregularities arising from wear or damage to the cassette oftentimes produce such pockets. Therefore, cassettes should always be handled carefully to prevent damage and mimimize wear. However, even cassettes without irregularities may trap air. This air can leak out after a time, thereby permitting contact to be restored. Thus, when testing for screen/film contact, exposures should be made soon after loading the cassette, as would be the case with ordinary usage.

Cassettes are available which greatly reduce the likelihood of trapping air between screens and film (Figure 4). These cassettes have curved front and back panels which squeeze out the air as the opposite surfaces come together thus helping to assure good contact.

In addition to air trapped between screens and film, poor contact can be caused by dirt or other material on the screen, damaged cassettes and latches, and/or improperly mounted screens. Accordingly, care should be taken to avoid dropping or rough handling, which can cause dents or misalignment of the front and back covers of cassettes with resultant poor contact.

Contact Test. Changes in screen/film contact can be insidious and difficult to detect when imaging clinical subjects. Therefore, it is necessary to select a test object which makes it easy to detect areas in the radiograph where a loss of contact has occurred and to test cassettes for screen/film contact on a regular schedule.

One test method which is simple and effective is the use of a wire mesh screen as a radiographic test object. The screen should be large enough to cover the entire cassette and sufficiently absorbing to provide high contrast. Brass, copper, steel, or nickel wire about 1 mm. in diameter with openings between wires approximately 3 mm. wide, should be satisfactory (aluminum wire of this size will not provide sufficient contrast). An opening about 13 mm. in diameter is desirable in the center of the screen to give an unobstructed area. This area can be used by those who have densitometers to measure the density of the radiograph made in this test. For protection and convenience in handling, a wooden frame of two sheets of cardboard can be used to mount the screen.

Exposure conditions should be chosen to produce a high density (2.6 to 2.8) on the radiograph in the central, open area of the screen. A technique (50 to 60 kV) similar to that used for a hand with the same screen/film combination but at about half the mAs should be satisfactory, using a focal film distance of 40 inches.

For ease in locating areas of poor contact, the test radiographs should be viewed from a distance of about 3 meters or through a reducing lens. Areas of poor contact will appear darker than their surroundings on the radiograph. More important, these regions will appear blurred or fuzzy when examined closely.

Cleanliness. Cleanliness in all its aspects is essential for production of radiographs of high quality, starting with intensifying screens and including work areas, processing, and personnel.

Screens. Frequent inspection and regular cleaning of screens is vital to eliminate dirt and foreign material which can spoil screen/film contact, can scratch and damage the screens, or can produce artifacts that interfere with image visibility. The manufacturer's directions should be followed when cleaning screens to prevent injury to their surfaces. For instance, some cleaning solutions leave a residue on the surface which absorbs the ultraviolet emission of certain screens and produces reduced density patches on the radiograph.

Except for cleaning, the screen surface should be kept dry. Splashes of solutions and other moisture not only may cause the film to stick to the screen, thereby damaging both, but also may cause permanent stains. Frequent causes of soiling are medications, such as nasal sprays, which reach the screens or film as a result of sneezing or coughing, processing solution splashes, damp fingers, nail polish, lipstick, ink and pencil marks, soot, and cigarette ashes. Smoking should never be permitted in darkrooms. Not only can the ashes soil the screens and mar the image but also the glow from a lighted cigarette can fog the film.

Cassettes. Cassettes should be kept closed except when in use to prevent dirt and dust from collecting on the screens. When loading and unloading film, an effort must be made to avoid scratching the screen. The film should not be dug out of the cassette with a fingernail. When opening the cassette to unload it, lay the latch side on the bench and tip the front side toward the latch side so that the film falls free. As the film drops out of the cassette, grasp an edge or corner with the free hand. When loading a cassette, do not slide the film across the screen with one hand. To do so may abrade the screen and cause kink or crimp marks on the film. The film should be held by diagonally opposite corners and placed into the cassette carefully.

Workrooms. Cleanliness and good housekeeping are important in exposure rooms as well as darkrooms. Spills of contrast media, such as barium or iodinated solutions, onto cassettes can appear as artifacts on the radiograph which can interfere with the diagnosis. The workroom itself as well as its contents, such as bench tops and equipment, must be kept clean and free of litter. If the darkroom is used for manual processing, it is desirable to have the cassette loading area on the opposite side of the room from the processing tanks to avoid splashes and spills from reaching screens or films. Splashes and spills should be cleaned up promptly. Not only can the dust from dried-up processing chemicals settle on screens and films to cause defects in the radiograph, but also floors wet from spilled solutions can be slippery and dangerous.

Processing. The necessity for cleanliness applies to processing equipment also. For example, contamination of the developer by fixer solution because of failure to use splash guards or drip trays when removing processor racks can adversely affect the appearance of the radiograph. Tanks, racks, and dryer air tubes in automated processors should be cleaned regularly according to the manufacturer's instructions. A few nonreusable sheets of cleanup film should be sent through the processor after it has been idle for an extended period to remove roller deposits and dirt. In the case of manual processing, hangers should be clean and their clips free of residual gelatin and film particles because such accumulations can cause stains or streaks on radiographs.

Hands. Finally, when handling films and screens, hands must be kept clean, dry, and free of contaminants, such as medication or chemicals. Failure to do so may produce fingerprints as well as soil and stains on screens and films (Figure 5).

Light Fogging. Another important aspect of quality assurance is the prevention of fog, i.e., the unwanted blackening of the film from sources other than the radiation to be imaged. Some common causes of light fog are light leaks, afterglow from fluorescent room lights, and improper safelights (Figure 5).

Light Leaks and Afterglow. After about 10 to 15 minutes in a darkroom in which all lights have been turned off, one's eyes become very sensitive and capable of seeing small light leaks or afterglow from lamps that otherwise would go unnoticed. The film does not require a period of dark adaptation, as the eye does, to become sensitive to small amounts of light. Therefore, small light leaks or afterglow can cause significant fogging of film and loss of radiographic image quality.

Places to look for light leaks are cracks around doors, in walls, or where ceiling partitions join walls. Also, they may arise when the cover on an automated processor is left slightly ajar or, occasionally, when vibration of the processor creates a small opening between the light seal and the processor or the light seal and the adjacent partition. Also, indicator lights on some darkroom equipment may be of a color to which film is sensitive or sufficiently bright to cause fogging.

Fogging from these sources can be eliminated by replacement of the offending room lights with lamps that do not exhibit afterglow, by covering cracks with appropriate sealants and gasketing materials, by anchoring automated processors solidly in place, and by covering or removing troublesome indicator lights. Also, as noted previously, smoking must not be allowed in the darkroom because the glow of a lighted cigarette

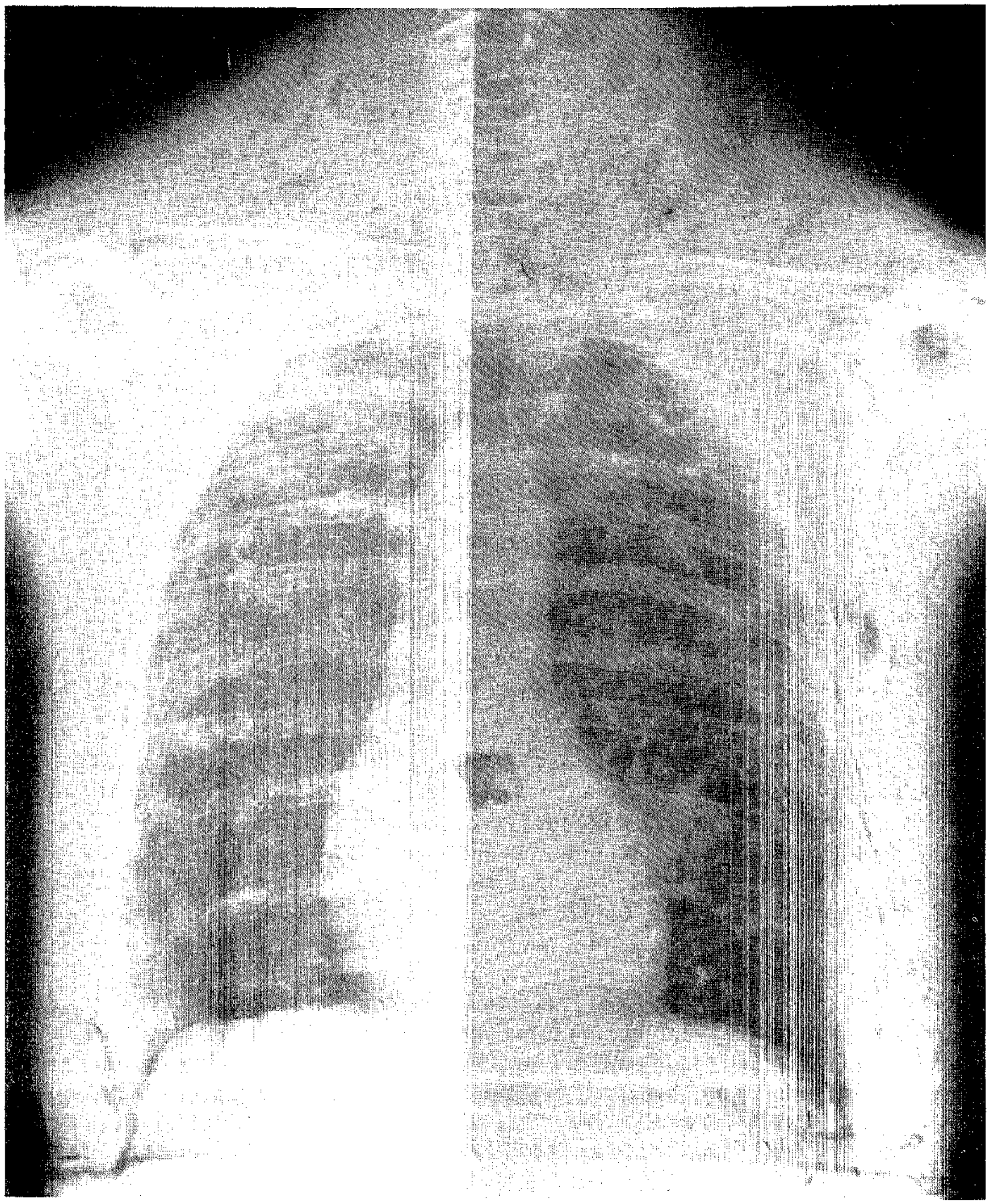

Figure 5. Results of film mishandling. The left side of this radiograph is darker than the other because another sheet of film was placed on top of the right half to protect it as it lay on the loading bench under the safelight before being processed. The glass filter in this safelight was intended for use with blue-sensitive films and this radiograph was made with an orthochromatic film (sensitive to green as well as blue light). Consequently after only a few seconds of exposure to this incorrect safelight, the fog density seen on the left was produced on the uncovered side of the radiograph along with a lowering of contrast in this part of the image. Notice, also, the thumbprint over the heart shadow caused by a wet hand, and the black cresent-shaped crimp marks over the left neck, apex of the left lung and lower left chest resulting from kinking of the film through careless handling.

can cause fogging, and cigarette ashes can cause defects in radiographs.

Safelighting. As was pointed out in the section on phosphors and films, safelight filters should be used which transmit only light of a color for which the film has little sensitivity. It must be recognized that most films have some slight sensitivity even to the colors of light emanating from safelights recommended for them. Therefore, fogging of films can occur even with the correct filter, if the safelight is too bright or if the film is exposed to it for too long a time.

The following are some recommendations to insure proper safelighting:

1. The film manufacturer's instructions should be followed in selecting safelight filters. When properly installed, the identification printing on the filter should be readable when facing the lamp. If installed backwards, heat buildup in the lamp housing may damage the dye layer and cause film fogging.

2. The film manufacturer's recommendations regarding wattage of the lamp should be followed. Use of oversized bulbs not only produces too bright a light but also too much heat so that filter damage can occur.

3. The film manufacturer's recommendation as to the distance between the safelight and film should be followed. If the safelight is too close to the film, fogging can result, even though the proper filter and bulb wattage are used.

4. Exposure of films to safelight should be kept to a minimum. Exposed films should be processed as promptly as possible.

5. Films should not be placed in overlapping positions under the safelight. It is possible for the edge of the upper film to be imaged by the safelight onto the film beneath. Even though the small density difference across the image of this edge may be difficult to measure, the eye is very sensitive to such sharp boundaries and may find it distracting.

6. Safelights should be tested periodically to be sure that filters have not faded and that their performance is satisfactory. Tests should be conducted on films regularly used under conditions typical of daily operations. One method of making such a test is described elsewhere (1).

It should be pointed out that films are more sensitive to light after radiographic exposure, than before. Therefore, during manual processing, films are especially liable to fogging until after they have been fixed, and it is important to maintain proper safelight conditions over the processing area. This, of course, also means that wet films should not be inspected by white viewing lights until after fixation.

Film Storage. In addition to the light fogging just discussed, processing and storage conditions can have a significant effect on fog growth. The effect of processing conditions on film characteristics is discussed in another section of this text. The following section will deal with relations between storage conditions and fog. If they are not carefully controlled, storage conditions can lead to high fog levels with an adverse effect on radiographic image quality.

X-ray film is sensitive to x-rays, gamma rays, and light. It is also sensitive to certain gases and fumes, heat, moisture, pressure, and aging. In order to preserve its sensitivity for the purpose for which it is intended (image recording) it should be protected from substances to which it is sensitive until it is needed for use.

Excessive heat and humidity can promote rapid fog growth in the film emulsion. If possible, unexposed film should be stored at a temperature of 50 to 70° F and at 30 to 50% relative humidity. It should be kept away from heat sources such as steam pipes and radiators. Most films are packaged in moisture-proof wrapping so that humidity is not a concern until the wrapping is opened. However, both sealed and open packages are sensitive to heat.

Some of the substances whose vapors promote fog growth are formalin, hydrogen sulfide, hydrogen peroxide, and ammonia. Therefore, film should not be stored in areas where such gases can leak into the air. Also, film must not be stored in a place where it can be fogged by gamma rays from radioactive materials (such as used in nuclear medicine) or where radiation from x-ray machines can reach it.

Natural Background Radiation. There is one source of ionizing radiation against which it is difficult to protect film, i.e., naturally occurring background radiation. This radiation consists of high-energy cosmic rays which are constantly bombarding us from outer space, and of emissions from naturally occurring radioactive materials in our bodies, in building materials, in the soil, and in the atmosphere. The intensity of background radiation varies considerably with locality. Film is being exposed constantly from this source of radiation, and the fog it produces is often mistakenly attributed to chemical changes in the emulsion as it ages. Frequently, a major portion of the fog growth on x-ray films during storage is due to this natural background radiation. The best protection against it is to rotate film stocks so that the oldest film is used first, and to purchase film in quantities which will assure reasonably rapid turnover and freshness. It is a good idea to store packages on edge so that the date can be seen easily for checking freshness and so that pressure marks from the combined weight of a stack of boxes can be avoided.

After processing, radiographs should be stored at 60 to 80°F and 30 to 50% relative humidity. The storage area should be free of chemical fumes and well ventilated. Film jackets should be made of materials which contain no chemicals capable of reacting with the film over a period of time.

Film Handling. We have noted previously that pressure is one of the things to which film is sensitive. Therefore, it is imperative that film be handled gently and carefully to avoid producing marks in the radiograph which can interfere with the diagnosis or be confused with pathology.

Often it is not realized that what seems like a harmless action can damage the film. For instance, the effort needed to pick up a sheet of film with one hand (thumb on one side of film pressing against forefinger and middle finger on the other side) and to hold it out horizontally is not very great. However, if the stresses are measured at the points being gripped, it will be found that they are very large and sufficient to deform the structure of the silver halide crystals in the emulsion. The result of this deformation will be kink or crimp marks at this location in the radiograph (Figure 5). Therefore, when loading a cassette, it is recommended that two hands be used, as follows. Gently remove the film from the box with the thumb and forefinger of one hand. Being careful not to kink it, grasp the bottom edge with the thumb and

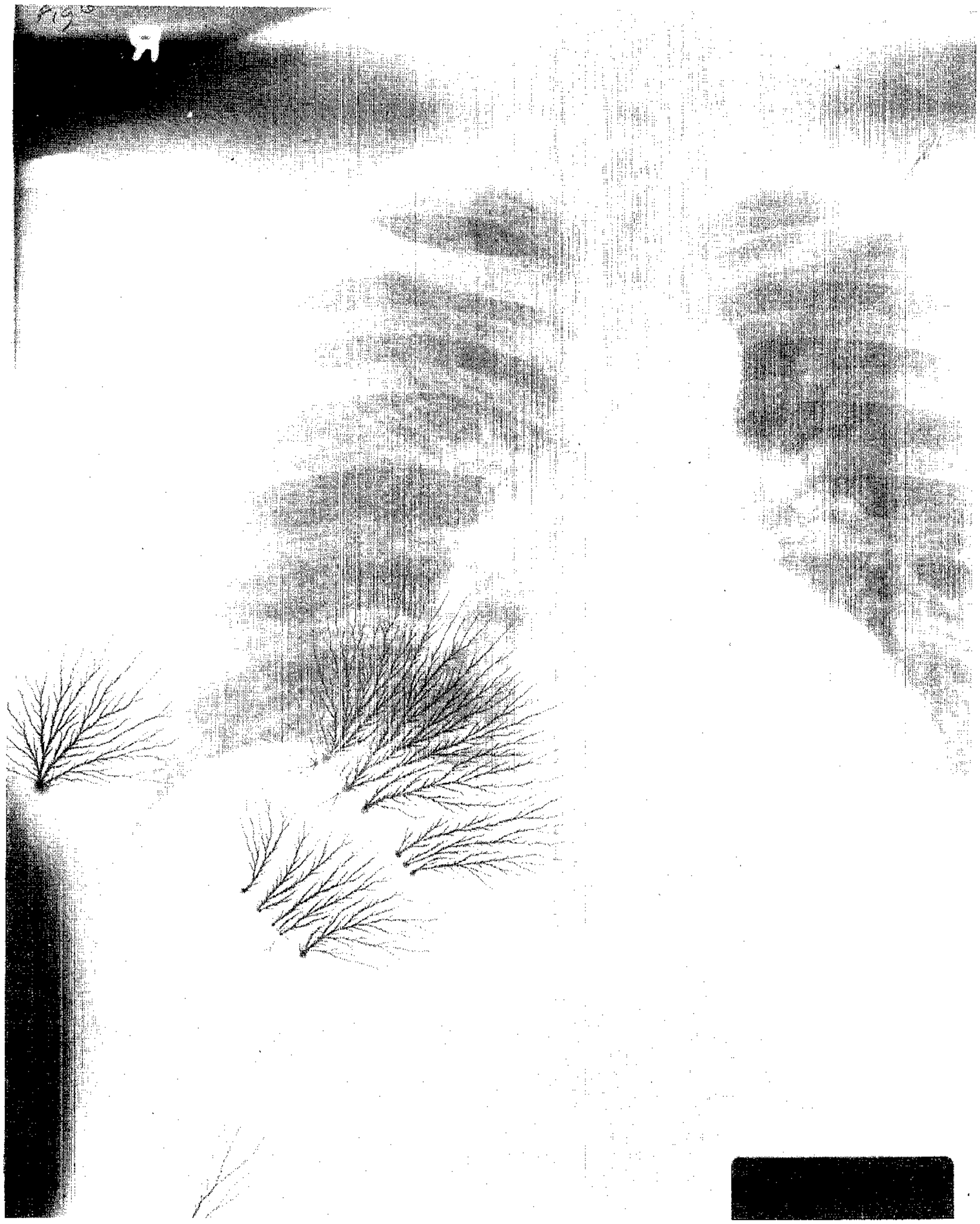

Figure 6. A radiographic catastrophe. This radiograph is unacceptable because (a) the patient was not properly positioned with respect to the film, (b) it is underexposed, therefore, the density is too low, and (c) part of the image is obscured by tree-like markings from an electrostatic discharge.

forefinger of the other hand, and, using both hands, place it carefully into the cassette. Also, two hands should be used when unloading the cassette as described in the section on cassette cleanliness. This kind of handling not only protects the film but also, as noted earlier, prevents abrasion of the screen caused by sliding the film into the cassette with one hand.

The film's sensitivity to pressure also accounts for some of the markings which result when deposits on rollers are pressed against the film as it is transported through automated processors which are not properly maintained.

Static Electricity. Another reason for handling film carefully is to avoid generating static electricity. As anyone who has scuffed his shoes across a carpet on a dry, cold day knows, static electricity attracts dirt and dust particles. Similarly, if a static charge is built up on a sheet of film, it will attract dirt and dust which can produce artifacts on the radiograph. If the charge is sufficiently large, it can produce an electrical discharge or spark. This results in black markings that can make the radiograph useless (Figure 6).

The following are some suggestions to prevent the problems associated with static electricity on screens and film. Static electricity in the darkroom is usually caused by friction. Therefore, avoid sliding the film across the screen. Place it directly into the cassette with two hands. Do not withdraw the film rapidly from the carton, interleaving paper, or exposure holder. Applying an antistatic solution to the screens or use of a screen cleaning solution which contains an antistatic agent may be helpful. In either case, be sure to follow the screen manufacturer's instructions.

The likelihood of problems from static electricity increases when relative humidity is low. It is for this reason that such problems occur more frequently on cold, dry days during the winter. When cold outside air is brought into buildings and warmed, relative humidity drops to very low levels. On such days adding moisture to the air by means of a humidifier, or even by steam from a hot water faucet in the darkroom, may be helpful.

REFERENCE

1. Hurtgen, T.P.: Safelighting in the automated radiographic darkroom. Med. Radiog. & Photog. 54:32, 1978.

Chapter IX

The Screen/Film Combination: Quantum Mottle

Leland Erickson, M.A.

Some introductory information is necessary to show that quantum mottle is the fluctuation of the image itself, not something added to it. First, one must learn why quantum mottle is present in a radiograph made with fluorescent intensifying screens, and how it affects the appearance of the image. Then one has to understand why when selecting a screen/film combination, a compromise has to be made between quantum mottle and sharpness to meet the imaging needs of the radiologist.

Radiographic Noise

In Chapter VIII we discussed blurring and its effect on the radiographic image. Another major factor affecting radiographic image quality is radiographic noise. By radiographic noise is meant unwanted density fluctuations in a radiograph which interfere with the images one is trying to visualize. Radiographic noise can be considered to consist of two components: artifacts and radiographic mottle.

Artifacts. Artifacts are blemishes or unwanted variations in photographic density (film blackening) in the radiograph. Causes of some of these imperfections, such as scratches, crimp marks, fingerprints, static, light fog, dirt, and stains, have been discussed in Chapter VIII. Mention was also made of pressure marks caused by deposits on rollers in automated processors which have not been cleaned regularly, and of streaks from contaminated film hanger clips used in manual processing. There are many kinds of streaks, spots, stains, scratches, and surface deposits which can appear on radiographs if proper processing procedures are not followed and processor cleanliness not maintained. To prevent artifacts it is important to use processing solutions formulated, mixed, and replenished according to recommendations and to be sure that radiographs are developed, fixed, washed, and dried properly. A detailed discussion of processing is given in Chapter V.

It is also possible for radiographs to show a streaked or striped pattern, or a splotchy, mottled pattern caused by grids which have been damaged, were not moved sufficiently during exposure, or were not focused properly. The use of grids to control scattered radiation is covered in Chapter VII.

Radiographic Mottle. Radiographic mottle can be defined as the density variation in a radiograph made with intensifying screens which have been given a uniform x-ray exposure.

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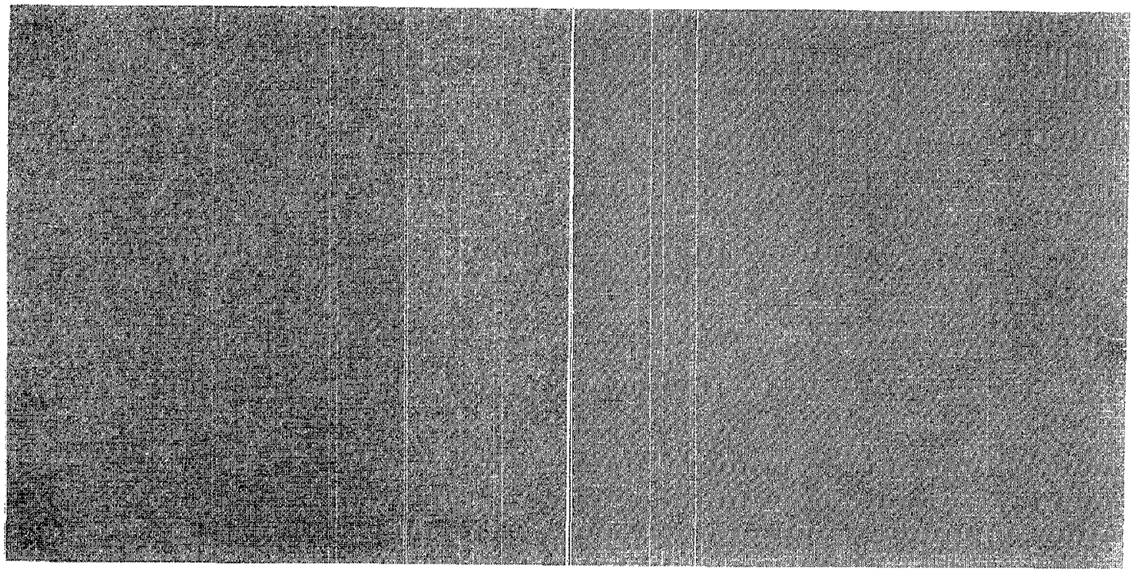

Figure 1. Mottle and graininess. Figure 1A (left): Radiographic mottle. This image was produced by a screen/film combination which was given a uniform x-ray exposure. The mottling or irregular density pattern is due primarily to quantum mottle. Figure 1B (right): Film graininess. This image was produced by uniform exposure of the film to light alone, without intensifying screens.

There are three components to radiographic mottle: (1) quantum mottle, (2) structure mottle, and (3) film graininess. Because it almost always has the greatest influence of the three on the appearance of such uniformly exposed radiographs, most of the ensuing discussion will deal with quantum mottle.

Structure Mottle. Structure mottle is density fluctuation resulting from nonuniformity in structure of the intensifying screens used in making the radiograph. This type of density variation might be caused, for example, by clumping of the phosphor crystals or by unevenness of coating. It is very seldom seen in screens of most manufacturers.

Film Graininess. Film graininess is the visual impression of the density variation in a film uniformly exposed to a light source other than intensifying screens. It arises from the random distribution of the deposits of developed silver. If a radiograph made with intensifying screens that have been given a uniform x-ray exposure is compared with a film exposed to a light source other than screens, it will be seen that the graininess produced by the light exposure is much smoother in appearance than the quantum mottle produced by the screen exposure. Those who have not had an opportunity to make such a comparison often mistakenly refer to the coarse appearance of the screen exposure as "graininess". In actuality the contribution of film graininess, which is always part of this pattern, is negligible. It is overwhelmed by the quantum mottle (Figures 1A and 1B).

Quantum Mottle. Quantum mottle takes its name from the fact that x-rays can be thought of as "bundles" or "packets" of energy referred to as quanta or photons. Quantum mottle is defined as the variation in photographic density of a uniformly exposed radiograph that results from the random spatial distribution of the x-ray quanta absorbed in the screen. This is quite a mouthful, so let us try to make this definition more understandable.

An x-ray beam is composed of many quanta. The number of quanta in a cross section of a "uniform" x-ray beam (i.e., a beam not containing an object to be radiographed) differs randomly from one area to another. In a screen-imaging process, the random distribution of quanta within the x-ray beam produces a random pattern of x-ray absorption in the phosphor. The phosphor emits a pattern of light that fluctuates according to this absorption pattern. This light pattern produces a density pattern in the radiograph which corresponds to the random locations (the spatial distribution) of the x-ray quanta absorbed by the screens. These density fluctuations in the radiograph are quantum mottle.

It is important to remember that it is the x-ray quanta which are absorbed by the screen, not those incident on it, which affect the appearance of quantum mottle, because only absorbed quanta generate light to expose the film.

There are three major factors which affect quantum mottle: (1) the number of quanta used to produce the image, (2) the contrast of the film, and (3) the amount of blurring caused by light diffusion in the screen/film combination.

The number of quanta needed to produce a radiographic image is influenced primarily by film speed, screen conversion efficiency, and screen absorption. For a specific screen and a given blackening of the film, the fewer the x-ray quanta per unit area used to produce the image, the greater the quantum mottle. This is illustrated in Figures 2A and 2B where the radiograph made with many quanta is much smoother in appearance than the one made with relatively few quanta.

As far as film speed is concerned, a fast film requires less exposure (fewer absorbed quanta) to produce a given density than a slow film. Thus, other factors remaining the same, the faster the film, the greater the quantum mottle. Use of a slower film is one way of reducing quantum mottle.

Screen conversion efficiency is defined as the ratio of light energy emitted by the screen to the x-ray energy absorbed in it. As this efficiency increases, fewer quanta are required to produce the same amount of light and corresponding density in the radiograph than for a less efficient phosphor. Since fewer quanta are used, quantum mottle is greater for the more efficient phosphor, other things being equal.

Screen Absorption. Absorption of x-ray quanta in the screen may be changed by changing the thickness of the phosphor layer or by changing to a phosphor with different absorption characteristics. For a particular phosphor, the number of absorbed x-ray quanta required to expose a given film to a given density generally stays about the same, regardless of screen thickness. For example, if one doubles the x-ray absorption by making a screen thicker, and thereby doubles the amount of light emitted, then the x-ray exposure can be cut in half to produce the same density in the radiograph. Thus, we would expect no change in mottle from a change in phosphor thickness if the optical characteristics of the screen/film combination were unaffected. However, we know that as screen thickness increases, blurring of the image increases. Since quantum mottle is the statistical fluctuation of the image itself, not something superimposed on it, reduced sharpness from increasing screen thickness causes a decrease in quantum mottle.

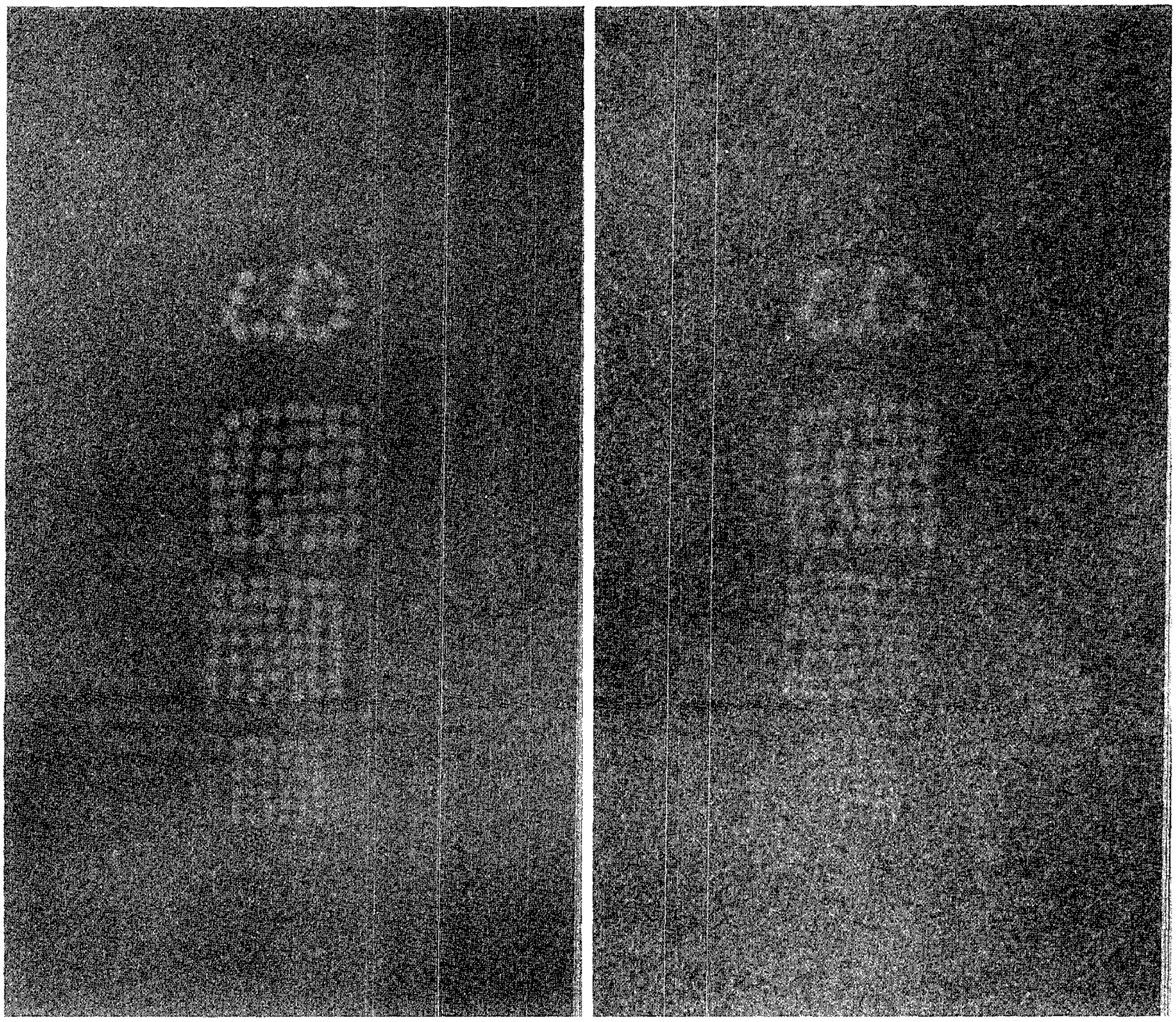

Figure 2. Effect of quantum mottle on image quality. Figure 2A (left): Radiograph of acetate beads made with a slow screen/film combination using many x-ray quanta. Figure 2B (right): Radiograph made with a fast screen/film combination using relatively few x-ray quanta. Note loss of detail and unsharpness of outline of the acetate beads.

On the other hand, if x-ray absorption is increased by changing to a phosphor having greater absorption without a change in screen thickness, then sharpness and quantum mottle will be the same as for the less absorbing screen. Of course, there will be less exposure to the patient when the more absorbing phosphor is used because fewer incident quanta will be needed to produce the same number of absorption events as in the less absorptive screen. That is, fewer x-ray quanta will be wasted in producing a radiograph of a given density (remember that all other factors, including conversion efficiency, are held constant in this instance). This illustrates the statement made earlier that it is the number of absorbed quanta, not incident quanta, which controls the appearance of quantum mottle.

Film contrast is the second major factor affecting quantum mottle as listed earlier. As film contrast increases, quantum mottle increases. For a given difference in brightness between two areas of an intensifying screen, a high contrast film produces a larger density difference in the radiograph than does a low contrast film. This is true whether the brightness differences are the result of differences in absorption by the subject or whether they are the result of the small random differences discussed in this section. Accordingly, a high contrast film will produce more quantum mottle than a low contrast film because of its greater enhancement of brightness differences in the emission patterns of the screens.

Blurring from light diffusion is the third major factor previously mentioned as influencing quantum mottle. An increase in radiographic blurring from light diffusion tends to cause a reduction in the ability to image quantum mottle, just as it reduces the ability to image structures in the subject being radiographed. Conversely, changing phosphor thickness, light absorbing and reflecting characteristics, and crossover so as to reduce light diffusion increases sharpness and tends to make quantum mottle more noticeable. We have already mentioned in the section on screen absorption that increasing screen thickness also increases light spreading and thereby reduces quantum mottle. Similarly, both crossover and use of a reflector in the screen increase light diffusion, but their effect on quantum mottle is not easily predictable since they also increase speed. Adding light-absorbing dyes to the screen reduces light spreading, which tends to increase quantum mottle, but here again, this tendency may be offset by the decrease in speed resulting from these changes.

Effect on Image Quality. As can be seen in Figures 2A and 2B, quantum mottle can affect visibility of structures in a radiograph. The radiograph which was made with a fast screen/film combination using relatively few x-ray quanta has a much higher level of quantum mottle than the radiograph using many quanta. Because of this quantum mottle, bead visibility is degraded.

From experiments similar to this, it can be shown that quantum mottle has a relatively greater effect on perceptibility of low contrast structures, such as these acetate beads, than on high contrast objects, such as wires or needles. These artificial structures may be considered to indicate how the imaging of analogous body structures, for instance gallstones or small rounded opacities in the chest (usually low contrast) or bone trabeculae in an extremity examination (relatively high contrast), would be affected by mottle.

On the basis of these observations, it is important to remember that what we see in a radiograph depends not only on the imaging characteristics, such as sharpness and noise, of the recording system but also on the characteristics of the structures to be imaged.

We have now learned how various factors in the design of screen/film combinations can be adjusted to influence blurring and quantum mottle. It can be seen that there are many compromises possible among these design factors to satisfy the needs and preferences of radiologists for different examinations. For example, with the advent of rare earth screens, it is now possible because of their increased absorption and conversion efficiency relative to those of calcium tungstate to provide the following options: (1) a screen/film combination matching the speed of a medium speed calcium tungstate combination but with significantly higher image quality (similar to that of a slow calcium tungstate combination); (2) a screen/film combination having twice the speed (requiring only one half the exposure) and producing image quality similar to that of a medium speed calcium tungstate combination; and (3) a screen/film combination having twice the speed and producing image quality similar to that of a fast calcium tungstate combination.

This seems an appropriate place to point out that it is meaningless to treat the three components of the screen/film process combination as separate entities. To illustrate, one cannot specify film speed without also specifying how the film was exposed (whether to x-rays directly or to what type of intensifying screen) and how it was processed. For more specific examples, consider the following.

A pair of rare earth screens which emit a high percentage of green light may require twice as much x-ray exposure to produce a given density on a blue-sensitive film as on an orthochromatic film, for the same processing conditions.

One pair of screens may be twice as fast as another at 120 kV, but be only 20% faster at 60 kV, using the same film and process. Also, the speed difference between these screens may vary as the amount of scattered radiation reaching the cassette changes.

For the same screens and film, speed and contrast can change significantly, depending on the temperature of the processing solutions.

Before concluding, it should be noted that even though some of the effects of screen/film design factors can be predicted when considered separately, it is difficult to generalize about their combined effects on radiographic image quality.

For example, based on what has been said before, one might assume that a screen/film combination which minimizes noise and produces a sharp image of a stationary subject because of controlled light diffusion would be most desirable. However, for many examinations, the image given by such a combination may be less useful than one produced with a faster screen/film combination having more quantum mottle and less sharpness. The faster combination may provide more diagnostic information because of its ability to arrest motion by permitting shorter exposure times, to increase subject contrast by allowing use of a lower kV, or to give a magnified image by enabling use of a smaller focal spot and increased distance.

Our understanding of the relationships among the factors affecting radiographic image quality is still evolving. Choices of exposure conditions and recording materials must be based on experience, taking into account the imaging task (the examination to be performed) and the objective and subjective needs of the person involved in interpreting the image. As noted above, such choices require compromises. For instance, the sharpness of a screen/film combination preferred for visualization of trabecular detail in an extremity examination has to be traded for the unsharpness and quantum mottle of a fast system if blurring is to be minimized, when imaging structures such as eggshell calcifications in hilar regions adjacent to the pulsating heart. Regardless of how cooperative a patient may be, involuntary heart motion will be present. Therefore, an increase in quantum mottle and light diffusion resulting from use of a fast screen/film combination may be acceptable because this mottle and light spreading are more than offset by the improvement resulting from the reduction in blurring from motion.

Chapter X

The Choice of Film/Screen Combinations

Norman A. Baily, Ph.D.

The imaging properties of x-ray film and intensifying screens are complex, vary greatly, depend on many physical parameters, and must also be chosen to provide the needed clinical diagnostic properties. In fact, they must be carefully selected to provide the characteristics required for a particular radiologic examination, so that sufficient information will be recorded in the roentgenogram for the desired diagnostic purpose and at the lowest possible dose to the patient.

Two basic types of film/screen systems are available. The traditional film/screen combination uses a calcium tungstate phosphor matched to a film which is highly sensitive to the blue light emitted. Newer phosphors having considerably more x-ray absorption and light photon emission resulting in conversion efficiencies as much as 8 times that of a detail calcium tungstate screen are now available. These are known as rare earth screens since the phosphors contain the rare earths lanthanum, yttrium, and gadolinium. In general, the rare earths emit green light and consequently require a different type of film. There are some exceptions to this requirement resulting from the addition of blue light activators to some of these phosphors in certain screens and/or the acceptance of a reduced speed when using certain film/screen combinations.

When considering the adoption of a new film/screen combination there are certain parameters which are of importance. The most important of these are speed, large area contrast, small area contrast, and spatial resolution.

Speed. The speed of a film/screen combination determines the patient exposure and the resulting organ dose. It also determines, for any operating potential and generator capacity, the minimum exposure time. Although absolute speed is defined, speeds of film/screen combinations are generally referred to that of par speed screens in combination with a medium speed film. If this combination is designated as having a speed of 100, then film/screen combinations are given designations of 100, 200, 300, and 400 speed systems. Some manufacturers assign in-between values (i.e., 330, etc.). This is, of course, a rough classification system and not an actual measurement of a system's speed. Actual speed varies with exposure parameters, screen/film characteristics, and processing conditions. A more rigorous definition of speed is that it is equal to the reciprocal of the exposure in roentgens ($\frac{1}{R}$) at the screen which is required to produce a density of 1.0 above base plus fog on the film.

Large Area Contrast. The contrast attainable on a film is reduced by the magnitude of the base density and the developing fog. The value of the base density plus the developing fog, plus 0.15 density units constitutes an absolute or practical lower limit of the exposure level required to record meaningful diagnostic information. For fast screen/film combinations this value runs between 0.3 to 0.4.

In radiology the large area signal transfer of a film/screen system can be characterized by an H and D curve which relates the optical density of the film to the x-ray exposure. This curve has both a toe and a shoulder where response is poor (small changes in film density for equal increments of exposure). Therefore, patient exposures which would result in densities corresponding to these portions of the H and D curve should be avoided. These curves are, therefore, useful in determining maximum and minimum usable densities. Most film/screen combinations yield H and D curves that have an approximately linear portion in the midrange of densities. It is this range of densities that produce the best image (i.e., contain the most diagnostic information), and also determine both the latitude and contrast scale (gamma) of the film/screen combination.

In general, one wants to use a film/screen system that has an essentially linear Hand D curve in the range of densities extending from about 0.5 to less than 2.0. The combination should have enough latitude so that the range of densities representing the x-ray attenuation of the body part(s) to be imaged fall on a portion of the H and D curve where contrast representing the desired x-ray attenuations will be maintained. The gamma, or the slope of the straight portion of the H and D curve, is a measure of contrast capabilities. For pneumoconiosis radiographs, a long latitude medium contrast film/screen combination is desirable.

The other factor which affects a film's ability to depict small contrast differences and/or to provide image detail is the degree of mottling present in areas of films exposed to produce a density corresponding to the lower or midrange of film density. Screens having a coarse phosphor structure, or combinations having the capability of responding to a very few x-ray events, will produce radiographs having a distinct mottle appearance. All radiographs made with intensifying screens have such patterns, but if the pattern is too prominent then diagnostic information will be obscured and information will be lost in this noise (see Chapters VIII and IX).

There are film/screen combinations in all speed categories that satisfy these requirements and which can be used either for the needs of special procedures or to produce acceptable roentgenograms in the general distribution of clinical examinations.

Detail or Small Area Contrast. This parameter specifies the ability of a film/screen combination to image small objects such as blood vessels. It is a measure of the density produced for the same exposure of small objects, and is dependent on the size of the object, e.g., the diameter of a vessel. A satisfactory combination must not suffer too great a loss in contrast as the diameter is decreased over the range of object sizes one wishes to image. In addition, any loss of contrast must not seriously distort the apparent size of the image. This might happen if the film density changes too rapidly with exposure (high gamma). Here again films of all speeds can be found which will fulfill both specific and general roentgenographic requirements.

Noise. Noise is the variation in density which occurs on a submacroscopic level across an otherwise uniformly exposed portion of a film. It is generated by a number of sources such as: quantum fluctuations due to an insufficient number of x-rays interacting with the screen over a given area, a coarse crystalline phosphor composition, inhomogeneities in the screen phosphor layer, inhomogeneities in light output of the phosphor crystals, inhomogeneities in the film emulsion, and because of deficiencies in the chemistry of processing. In general, fast systems have high mottle, but exceptions do exist. Noisy films obscure the observer's ability to distinguish edges, to depict small changes in contrast, and may even interfere with the radiologist's ability to perceive pathology.

This parameter is important since it affects the signal to noise ratio. It is this ratio which determines which information can be successfully recorded and imaged with consequent transfer of the information to an observer (radiologist). The greater the signal to noise ratio the more diagnostic information that will be contained in the roentgenogram. In addition to the factors discussed above which govern the noise present in a roentgenogram, the quality of the x-ray beam (effective kV) will affect the magnitude of the signal and the transfer of information on the attenuation of the x-rays in their passage through the body part to be imaged. Therefore, operating potentials (kVp) must be properly selected for specific film/screen combinations so that optimal information transfer will be obtained.

Spatial Resolution. All film/screen combinations are limited in their ability to image small objects. In general, as object size decreases, its contrast as depicted on film decreases until it is no longer distinguishable from its neighbor. The ability to produce an image of a certain size object and the contrast of the image is described by a curve known as the modulation transfer function. A more descriptive name might be the contrast transfer characteristic. In general, higher speed film/screen combinations have lower contrast transfer properties. However, some rare earth systems (which are mainly high speed systems) have higher resolution than calcium tungstate systems with comparable speed. This improved imaging capability results from increased x-ray absorption capability and the fact that there is an increased light emission per unit of x-ray energy absorbed. As a result it may be advantageous to use those systems where other requirements are satisfied.

Wavelength Dependence. Wavelength dependence of film/screen combinations reflect the differences in the efficiency with which x-rays of a particular energy interact with the crystals forming the phosphor coatings of the screens. Despite efforts to avoid or minimize this problem it exists in all systems. It is easily seen in test films made to study large and small area contrast. It is for this reason that if underpenetration is not the major symptom on an underexposed film, a change in mA is always preferable to a change in kVp. If no change in contrast is desired, kVp should be held constant, and mA variations should be used to control film density.

The kVp dependence for the newer fast-type screens, those containing gadolinium, lanthanum, and yttrium, is very much more severe than for the traditional calcium-containing screens. A modification of the usual clinical procedures must be initiated after the technician is given the additional instructions required.

Reciprocity Law Failure. The reciprocity law simply put states that when using photographic film the optical density of the film is a function only of the total light exposure incident on the film and is independent of the rate at which the exposure takes place. This law also holds for the direct exposure of film to x-rays. However, it does not hold for film/screen combinations exposed to x-rays. In fact, if exposure time is changed from 0.02 second to 1.0 second and total x-ray exposure is held constant the resulting film density may be decreased by a factor of approximately two. That is, to produce a radiograph having the same density the mAs requirement is doubled. Of course not all film/screen combinations show this strong an effect. The effect is found for types of film both blue- and green-sensitive and for all speeds.

Chapter XI

Sensitometric Monitoring for Film Quality

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Howard R. Elson, Ph.D. and James G. Kereiakes, Ph.D.

Sensitometric Monitoring

Meticulous attention must be paid to film processing, since it is an absolutely essential ingredient if consistently high quality radiographs are to be produced. Many factors affect the quality of a radiographic image during the processing of the film. Variations in chemistry, temperature, and occasionally film transport time, may change slowly and not be observed until a significant decrease in the diagnostic quality of the radiograph occurs. Test procedures using sensitometric monitoring of film development and further processing, fixing, washing and drying, are designed to monitor the results. Daily monitoring of the sensitometric film, including a record on a chart of the results, can provide necessary information to initiate corrective action before the radiographs decrease in diagnostic value.

The sensitometer consists of a stable white light source and an optical stepwedge so that a film can be exposed providing a range of film densities. The light source gives a reproducible light exposure to the film. Any change in the densities from film to film represents, for the most part, a change in the film processing. The use of an aluminum stepwedge which is exposed by a radiographic unit is not recommended since the output of radiographic units may normally vary as much as 10%.

The required equipment for initiation of the sensitometric monitoring program includes the following:

1. Sensitometer
2. Densitometer
3. Thermometer (accurate to within $\pm$ 0.5 degrees F)
4. "Dedicated" box of 8 x 10 inch film

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* No official support or endorsement by the Department of the Navy is intended or should be inferred.

PROCESSOR MAINTENANCE LOG

Processor ____

Developer Temperature ________	Chemicals Changed ________
Dev. Temp. Calibrated ________	Developer Filter Changed ________
Fixer Temperature ________	________
Water Temperature ________	________
Water Temp. Calibrated ________	________
Water Flow Rate ________	________
Developer Replenisher Rate ________	________
Fixer Replenisher Rate ________	________
Developer Replenisher Tanks Filled	Fixer Replenisher Tanks Filled
________	________
________	________
________	________
________	________
Water Filter Changed	Racks Cleaned
________	________
________	________
________	________
________	________
________	________
________	________

Comments ____

Figure 1. Sample processor maintenance log.

The following steps are recommended to begin a sensitometric monitoring program:

1. The processor must be cleaned and set up according to the manufacturer's instructions at least 1 week before starting the program. The processing solutions should be compatable with the type of film being used.
2. A box of "dedicated" film should be reserved for the sensitometric monitoring. The film should be of the same type as the film most commonly used in the facility and should be stored in the darkroom under the same conditions as other film.
3. The calibration of the densitometer should be checked according to the

manufacturer's instructions.

4. The darkroom should be free of light leaks and other sources of light fog.
5. The optimal processing conditions recommended by the manufacturer should be used.
6. Maintenance logs for the processor should be started (Figure 1).
7. A processing control chart for the processor should also be started (Figure 2).

The following procedures are recommended for the program:

1. The processor should be turned on according to the manufacturer's start-up procedures. Sufficient time should be allowed for the solution temperatures to stabilize (approximately 30 minutes).
2. Solution temperatures, replenishment rates, water temperature, and flow rates should be determined. The temperatures should be recorded on the control chart (Figures 1 and 2). Developer temperature should be within $\pm 1^{\circ}$ F of the manufacturer's recommended value. The wash temperature may be lower but not less than 5°F below the developer temperature. Note: Never use a mercury thermometer in a darkroom (a broken mercury thermometer is a hazard; mercury is toxic and fogs films, and mercury droplets cannot be easily picked up or disposed of).
3. A cleanup film (exposed to room or white light before processing) should be processed to remove any residue material from the racks and to check for processor scratching. The transport time for the film should be measured.
4. The control film should now be exposed with the sensitometer following the manufacturer's instructions closely. If dual emulsion film is used, expose both sides of the film.
5. The control film should be processed immediately after exposure. The film must be consistently inserted at the same location of the processor feed shelf with the lighter end of the control film leading.
6. Using the densitometer (Figure 3), the density of the selected steps of the control film are read (Figure 4). The average of the two exposures on dual emulsion film should be used. The base plus fog level should be determined (see paragraph c below).
   a. Steps selected should be chosen so the same step is read each time.
   b. Three steps with low, medium, and high density (densities of about 0.4, 1.0, and 2.0, respectively) should be used.
   c. The density reading of a clear area, at least 2 cm. past the darker step, is used as base plus fog. The value is plotted on the control chart (Figure 2).
   d. The density difference between the high and the low density step is determined and is used as the contrast index. This result is plotted on the control chart (Figure 2). The medium density reading is used as the speed index and plotted on the control chart. Control limits (the allowed variations in these plotted densities) should be determined. Normally, the density should not vary by more than 0.1 density units. Base plus fog density should not exceed 0.3 density units for films with slightly tinted base, and 0.25 for other films.
   e. A series of sensitometric films taken over several days or a week may be used to establish a baseline for the speed index, contrast index, and base plus fog. Variations of these parameters with changes in chemistry or time of week should be noted (Figure 3).

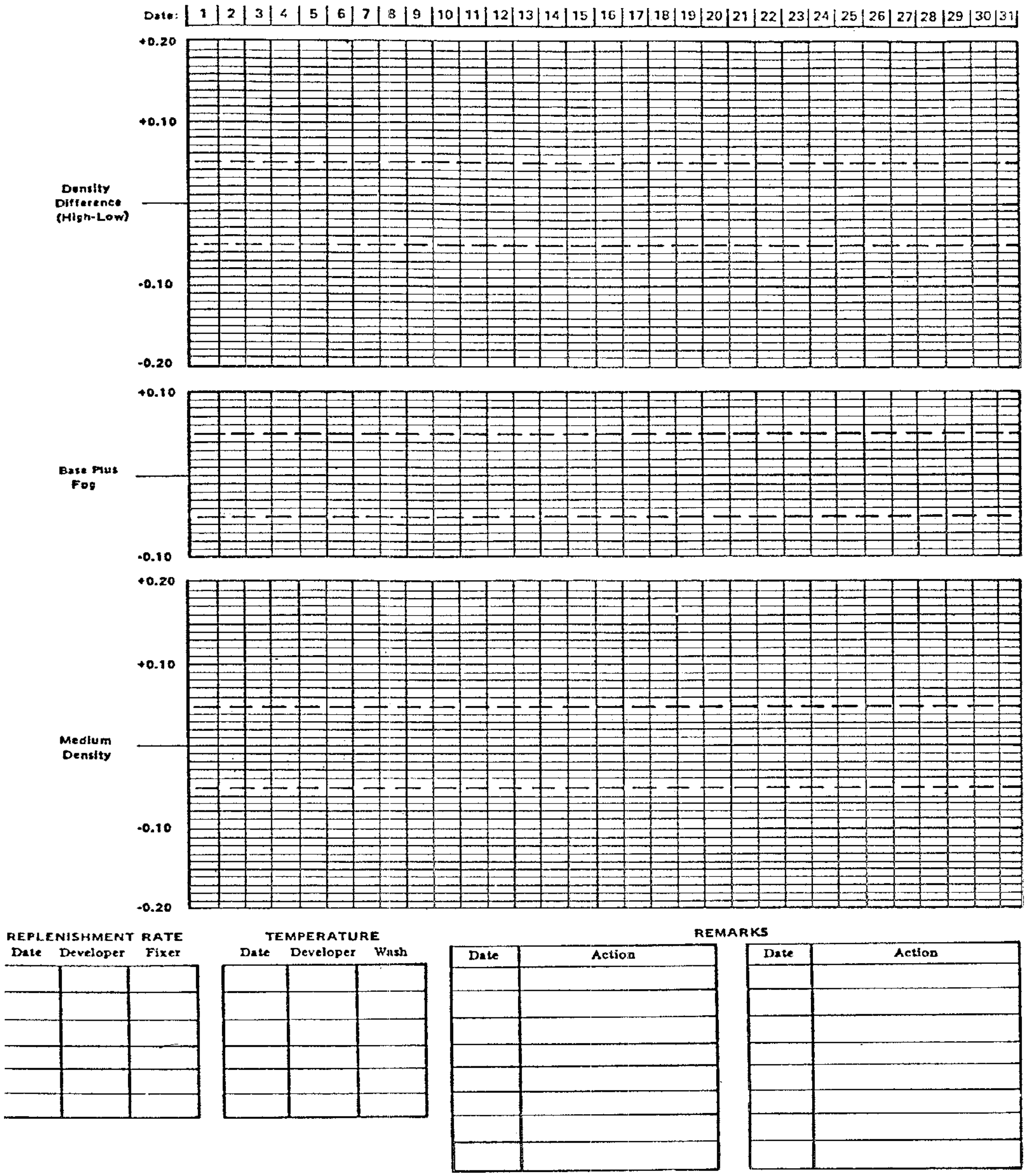

Figure 2. Sample processor control log.

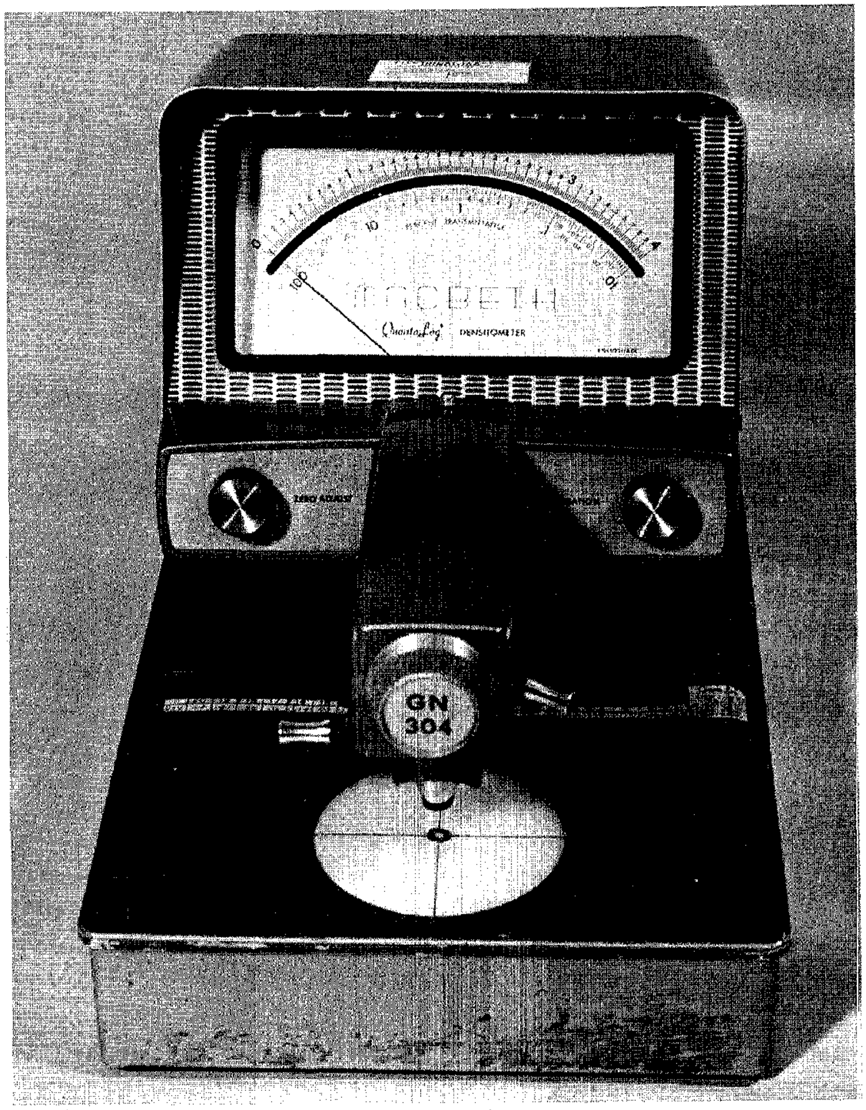

Figure 3. Densitometer.

7. If all data points (base plus fog, speed index, and contrast index) fall between the upper and lower limits and no trend is apparent, the processor is within control limits. Trends must be watched, and if one or more data points fall on or exceed the control limits, proceed as follows:
   a. Repeat steps 1 through 6 above to ensure the apparent change is not due to random variability or procedural error.
   b. If the change is confirmed, the following items should be checked:
      developer temperature,
      replenishment rates,
      water flow,
      water temperature,
      transport time,
      recirculation pumps and filters,
      solution batch mix dates, and

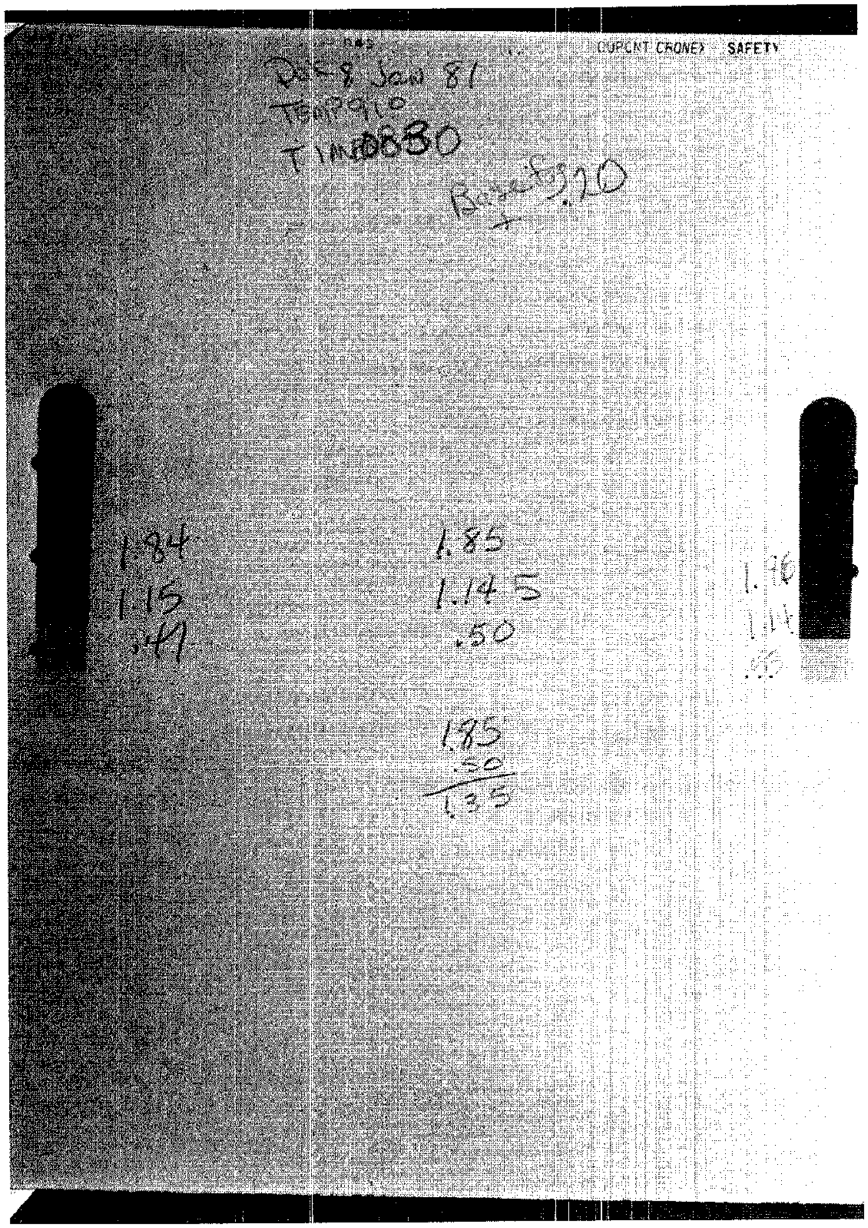

Figure 4. Sensitometric strip.

any possible indication of contaminated chemistry (e.g., cross contamination of fixer into developer).

c. Take indicated corrective action.
d. The sensitometric test should be repeated and the new data points recorded on the control chart along with the "out of control" data points. The corrective action taken should be indicated on the chart.
e. Processors show variations throughout the day. Control films may be repeated two or three times daily at predetermined times.
f. If corrective actions taken do not result in densities within the control limits, it may be necessary to replace the chemistry.

The following weekly procedures are recommended for the program:

1. Processed films should be checked for residual fixer. Chemistry suppliers have kits available for this purpose.
2. Water flow rates should be checked. Filters should be replaced as needed.

Processor Maintenance and Cleaning Requirements include:

1. Preventive maintenance procedures should be followed in accordance with the manufacturers' recommendations.
2. Clean crossover racks daily.
3. Check processor daily for unusual noises or odor.
4. Check processors and darkrooms daily for cleanliness.
5. Clean processor racks weekly with running water, soft cloth, and, if necessary, a soft brush to remove chemical deposits. The internal and external surfaces of the processor should be cleaned with a damp cloth (be sure to avoid using the same cloth for fixer and developer areas).
6. Replace developer and fixer at least monthly. Try to use floating covers to prevent evaporation and oxidation which decrease solution strength.
7. Every 6 months the processing chemicals should be drained and the tanks and racks cleaned to remove all traces of dried chemicals and other material deposits. Check for parts which may be in need of repair. Use cleaning solutions recommended by the manufacturer. System cleaners require specific precautions; instructions for their use must be followed carefully.

The Densitometer is Used to Measure the Degree of Darkening or Optical Density on a Radiograph or Control Film. The following is a general procedure for the use of a densitometer.

1. Always read and follow the manufacturer's specific instructions for the particular densitometer being used.
2. Turn on the densitometer power supply and light source.
3. Allow adequate warmup time (approximately 30 minutes for some models).
4. Zero the densitometer.
5. Read the calibration step tablet to ensure proper response of the densitometer. The calibration readings should be within $\pm$ 0.03 of the step tablet value. If not, adjust the densitometer according to the manufacturer's instructions. If adjustment is not possible a representative of the manufacturer should be contacted for assistance.
6. The densitometer is now ready for use. Read the sensitometric control film density steps. Always use the middle portion of a step when making a reading (Figure 4).

The above discussion for the use of sensitometric monitoring is by design general and somewhat brief. More detailed discussions of quality assurance for processors are available (1-5). Many chemistry suppliers have complete quality assurance packages available with detailed instructions. The need for the radiographers at a particular medical facility to thoroughly review and understand the operation of the facility's processor and associated equipment, and then to apply these general procedures, cannot be overemphasized.

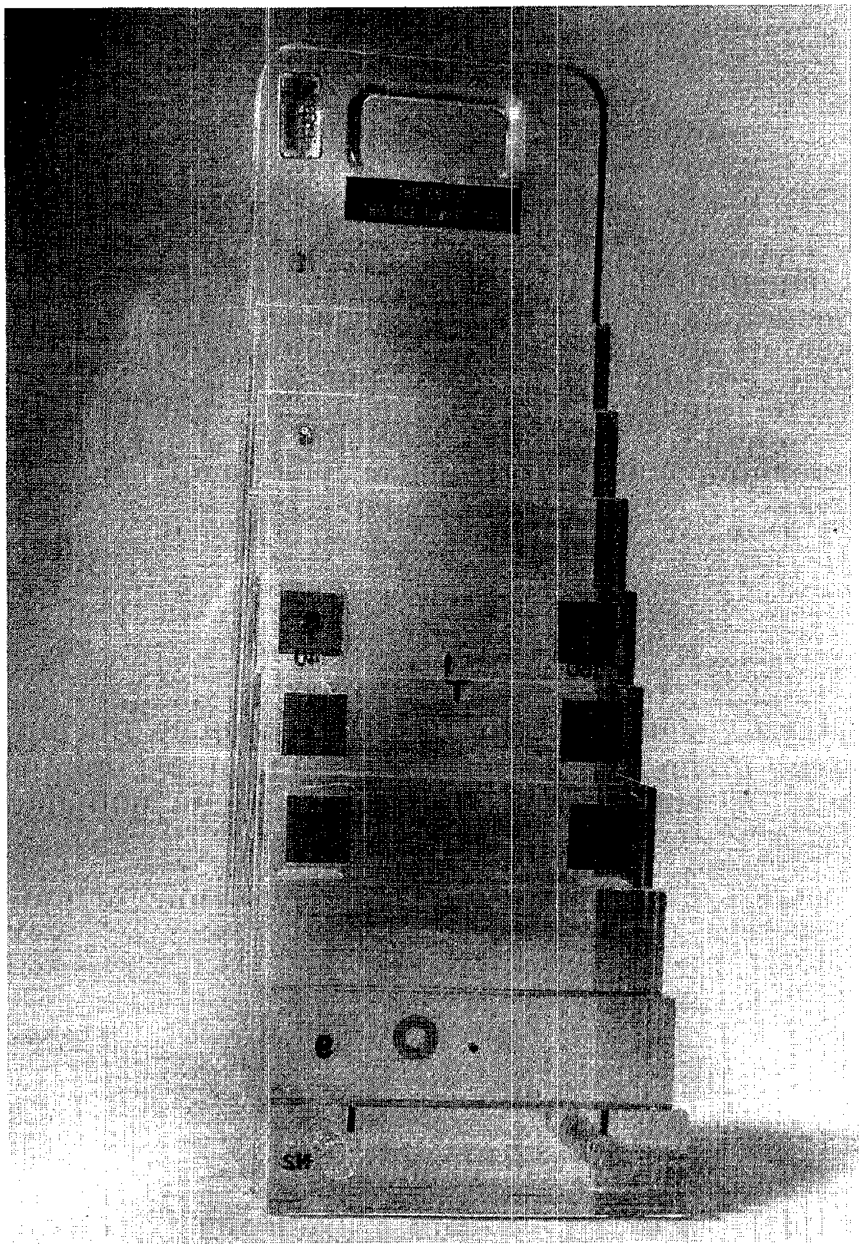

Figure 5. Chest test object, viewed from the front.

Phantoms and Test Objects

Medical facilities must employ radiographic equipment and techniques to produce radiographs of suitable quality which the radiologist can interpret according to an international classification system for the study of the pneumoconioses. Basically a high kilovoltage technique with minimum time and medium speed film/screen combinations is recommended.

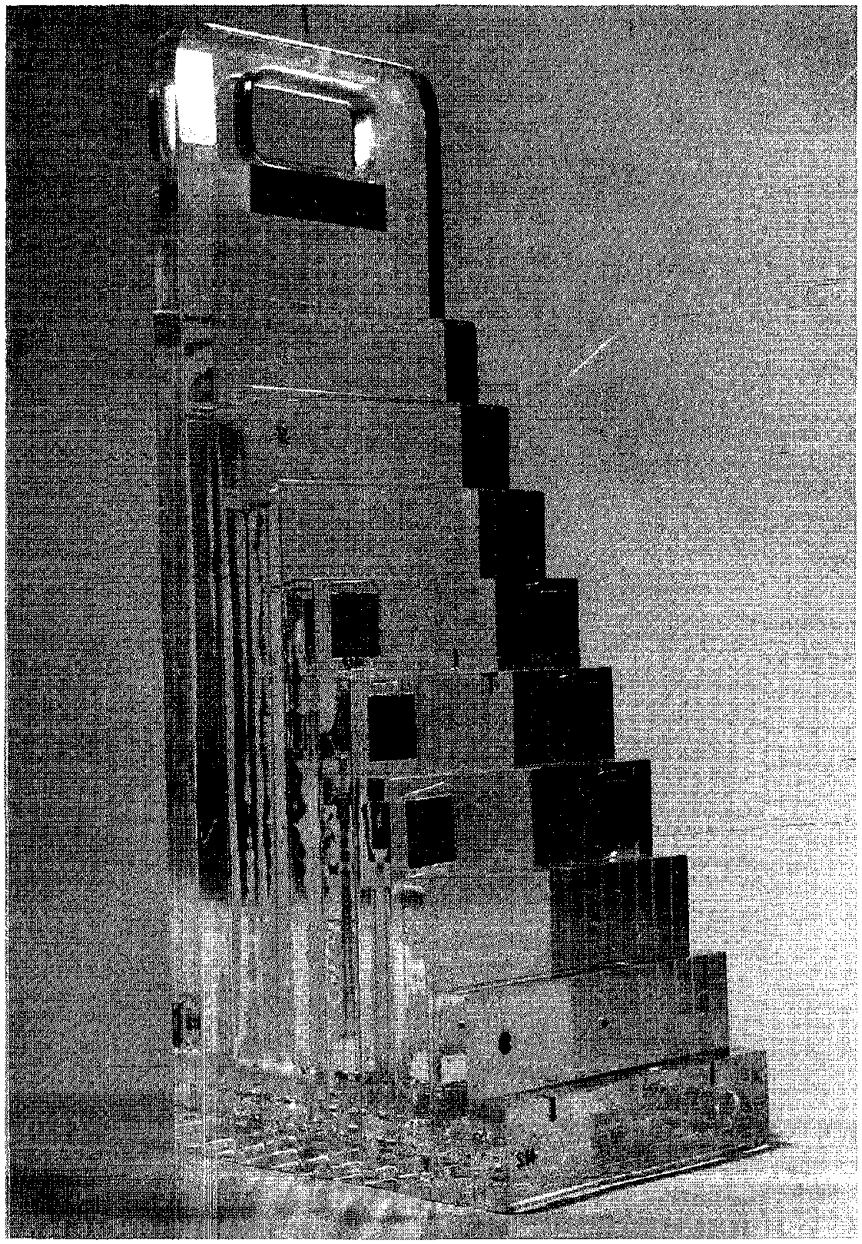

Figure 6. Chest test object, viewed from the side.

Not every facility has the same type of x-ray units, grids, film/screen combinations, and associated imaging equipment to produce chest radiographs. A plexiglass phantom, also known as a chest test object, has been designed to help in evaluation of a particular medical facility's ability to produce acceptable chest radiographs. The phantom is sent to the facility initially, under the auspices of a sponsoring agency such as the National Institute for Occupational Safety and Health, to help establish techniques and to certify the medical facility for participation in a screening or surveillance program for the pneumoconioses. The phantom may later be used for recertification or to help in identification of problems which have resulted in unacceptable radiographs.

The phantom, described in detail by Trout and Kelley (6), consists of 10 sheets of plexiglass formed into a giant stepwedge (Figures 5 and 6). When the phantom is radiographed using the technique factors normally used for a patient measuring 23 cm., the phantom should provide the range of film densities found on a patient's chest radiograph. The densities of the steps can be plotted against the step number to provide a graph for comparison with a similar graph made under known and controlled conditions.

To evaluate the geometry used, a lead pin is embedded in the front of the phantom and a ring is embedded in the back of the thickest step (Figures 5 and 6). The positions of the pin and ring are such that, at a 72-inch source to film distance (SFD) with a 1-inch space between the film and the face of the cassette holder, the image of the pin will be centered in the ring if the x-ray source is centered to the film and at right angles in both planes. The use of correct geometry is very important when grids are used, especially a grid with a high grid ratio.

In the front of the thickest step are two lead bars. When a 72-inch SFD is used the spacing between the inner edges of the bars on the phantom radiograph is 10 cm. A measurement of this distance between the bars can be used to confirm the actual SFD.

Image Detail

To record gross lack of image detail usually associated with poor film/screen contact, pieces of brass wire mesh of #40 and #60 mesh are mounted on steps 5, 6, and 7. No great significance is attached to the wire mesh other than for gross problems of film/screen contact or movement of some mechanical structure during exposure.

The Following Procedures are Used to Expose the Phantom:

1. Place the phantom on any level surface that will put the flat side of the wedge in contact with the cassette or the cassette holder. The support may be a box or stool. Do not try to hang the phantom since handling is somewhat difficult. Contact must be maintained with the cassette or cassette holder.
2. Center the useful radiation beam at the cross between steps 5 and 6.
3. Use technique factors which would be used for a patient measuring 23 cm. and make an exposure.
4. Process the film as any other chest radiograph.
5. Record the factors used on the radiograph.

The Phantom Radiograph (see Chapter II) is Evaluated as Follows:

1. The density of each step is measured and a graph of density versus step is plotted. The desired density range for patient radiographs is from 0.5 to 1.5. Higher densities may be acceptable if the range of densities remains around 1.0. This range of densities on the phantom corresponds roughly to steps 3 through 9 of the phantom. If all steps cannot be visualized in this range then contrast is poor (Figure 7).
2. The image of the pin must be within the image of the ring for tube centering to be acceptable (Figure 8). Centering is not acceptable if the image of the pin falls on, or outside, the image of the ring (Figure 9).

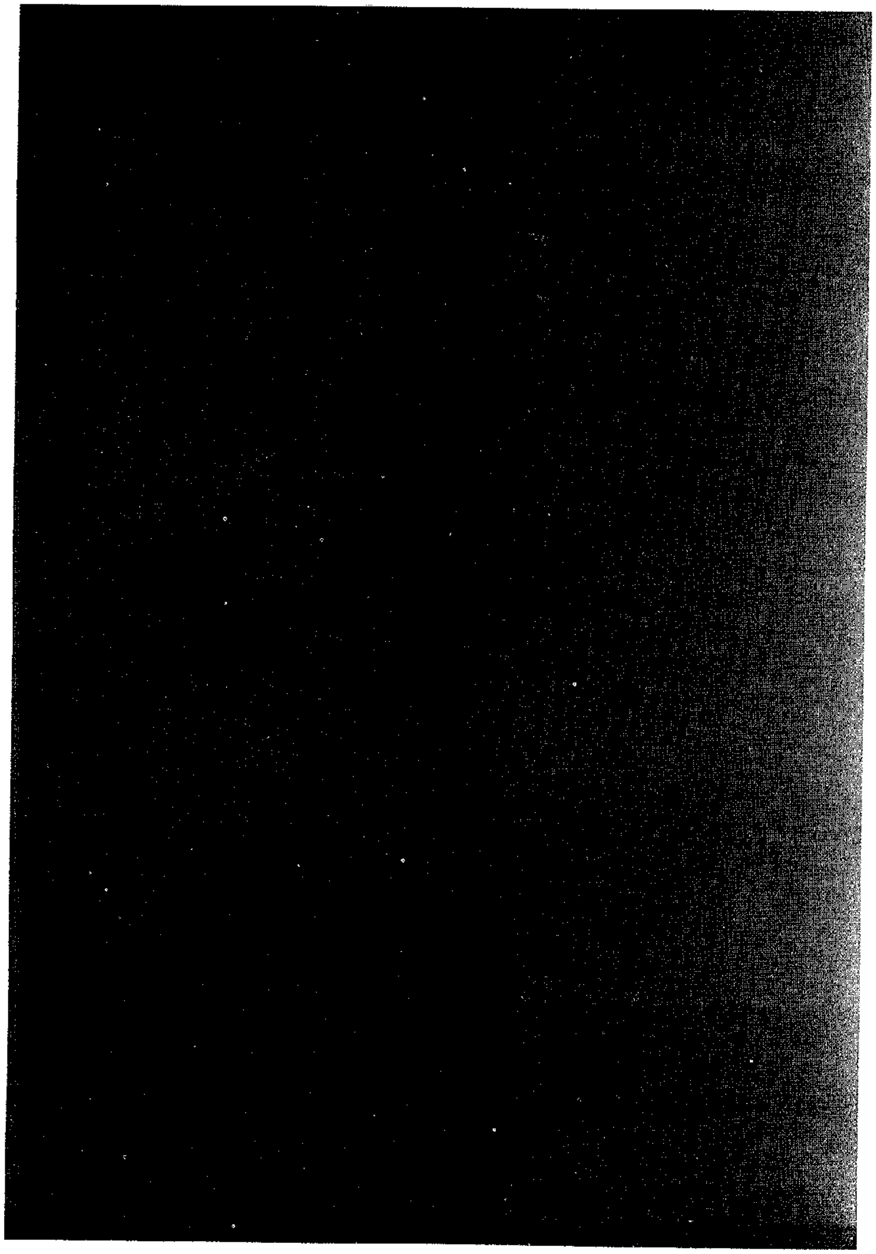

Figure 7. Radiograph chest test object where all steps cannot be visualized.

3. The lead bars should be visible with the distance between the inner edges of the bars being 10 cm. A greater distance between the edges indicates the actual SFD was less than 72 inches.
4. The wire mesh image should be reviewed for evidence of lack of film/screen contact or poor resolution.
5. The general appearance of the radiograph and evidence of collimation is evaluated.

In addition, the technique factors used, such as kVp, time, mA, grid and grid ratio,

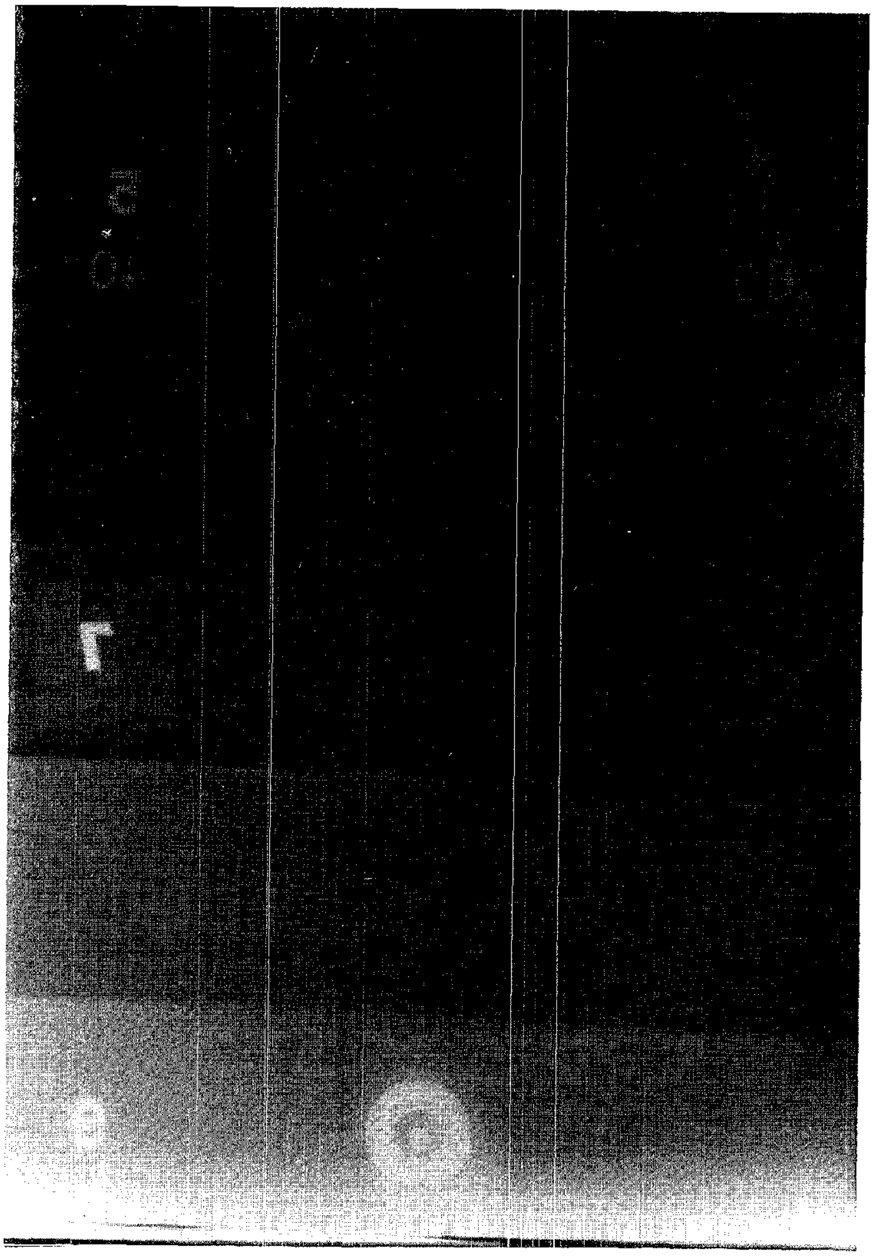

Figure 8. Radiograph chest test object where centering is good.

film/screen combination, focal spot size, and processor type, are recorded and reviewed. Final evaluation and certification of a medical facility is based on the judgment of the sponsoring agency after comparison with many other facilities.

Although the phantom is used to initially evaluate a facility, other test objects may be used by a facility in an ongoing quality assurance program designed to monitor the performance of the x-ray units. For example, the focal spot size is an important geometric contribution to image unsharpness. A star disc pattern may be used periodically to measure the size of the x-ray unit's focal spot to insure no change in its rated size. Resolution grids and aluminum stepwedges also have use in evaluating x-

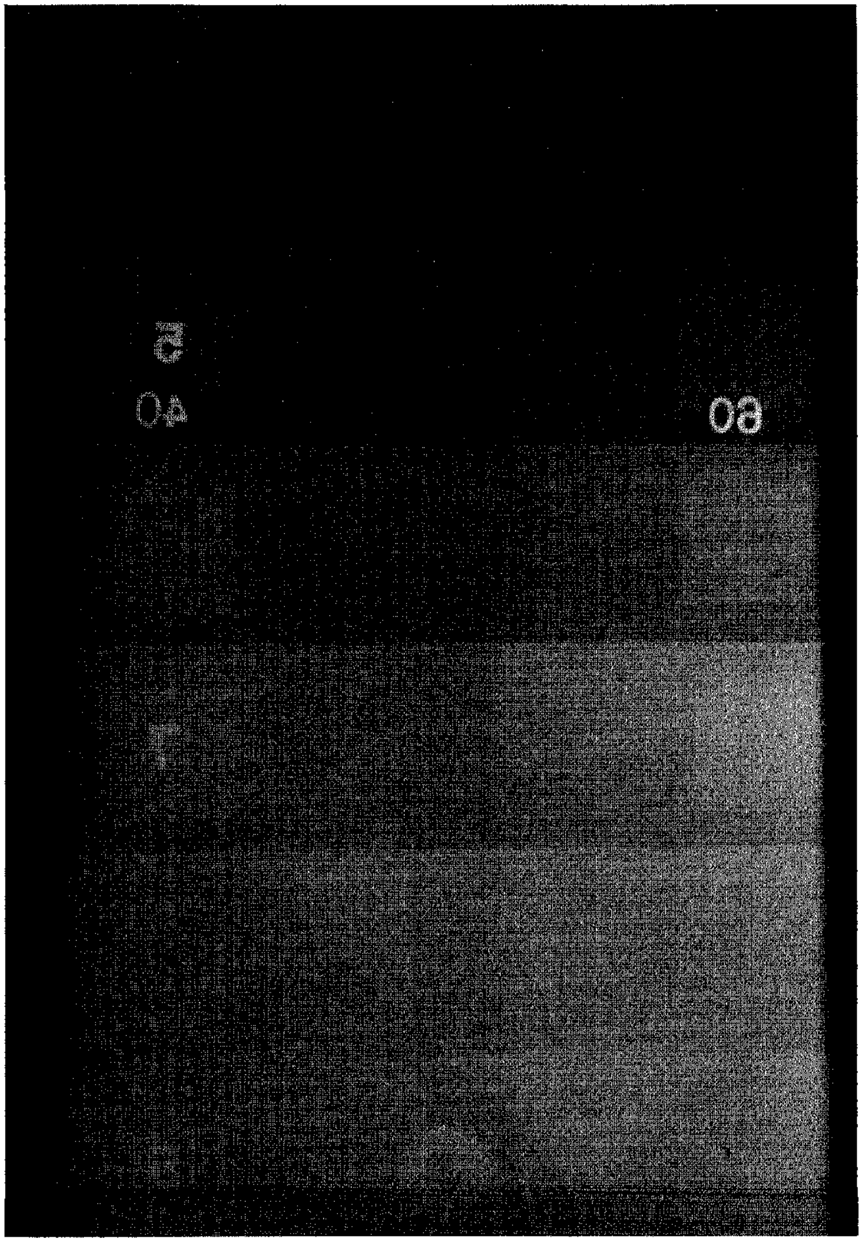

Figure 9. Radiograph chest test object where centering is poor.

ray unit performance. However, only the phantom specifically designed for use at high kilovoltage is highly suitable to evaluate the imaging system used for the study of the pneumoconioses.

Grid Alignment Test

Scattered radiation emerging from the patient does not contribute diagnostic information, rather it serves to degrade the radiographic image. The most frequently used

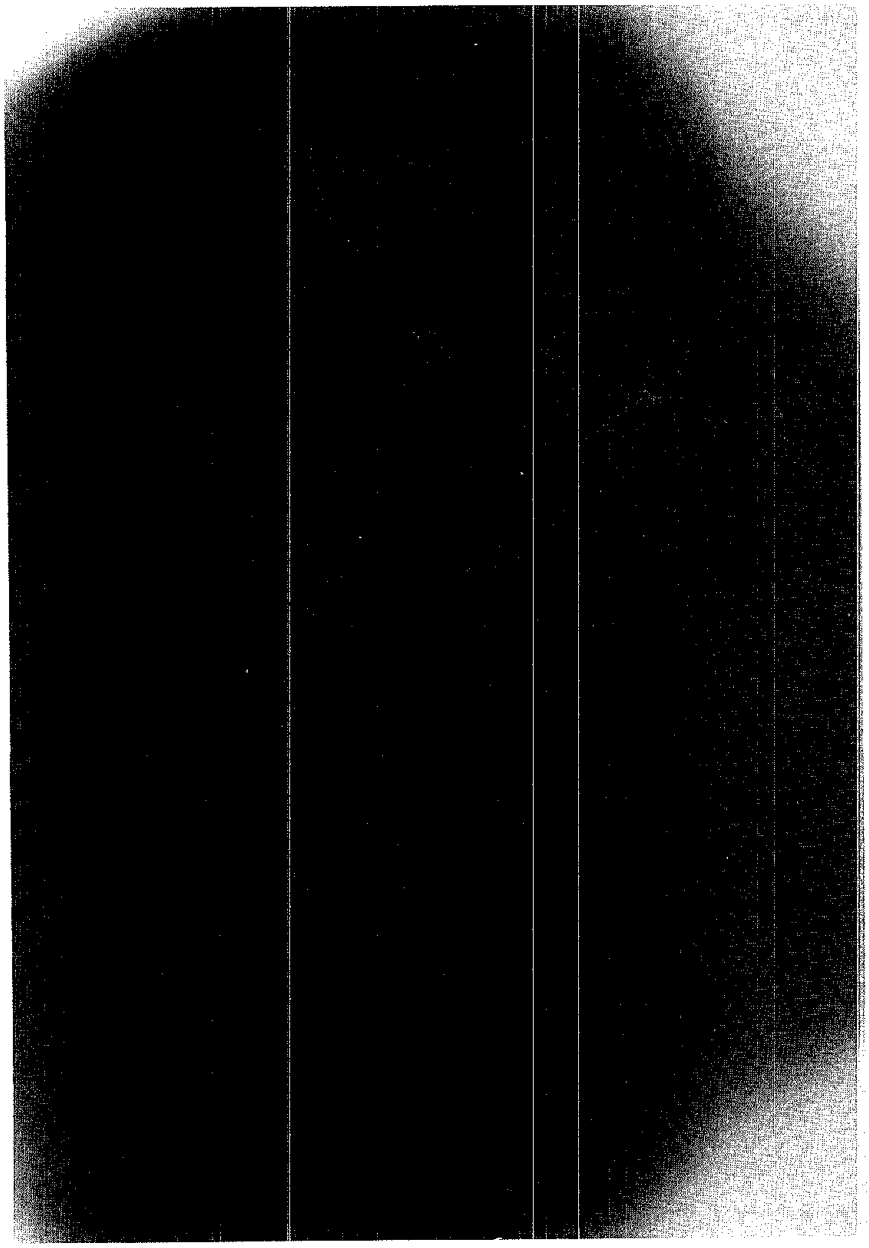

Figure 10A. 8:1, 103 l.p.i. grid upside down.

method to remove scattered radiation is placing a radiographic grid between the patient and the x-ray cassette. The grid, x-ray tube, and x-ray cassette must be accurately aligned so that grid cutoff will not occur. Cutoff results in absorption of primary radiation and decreased film density (Figures 10A and 10B). Grids with higher grid ratios require more precise alignment.

Procedures to check grid alignment are discussed in several publications (2,7). Grid alignment should be evaluated routinely every 6 months and immediately if any repair of the x-ray unit, grid, or x-ray cassette occurs which could change the alignment.

The following steps should be used in testing grid alignment:

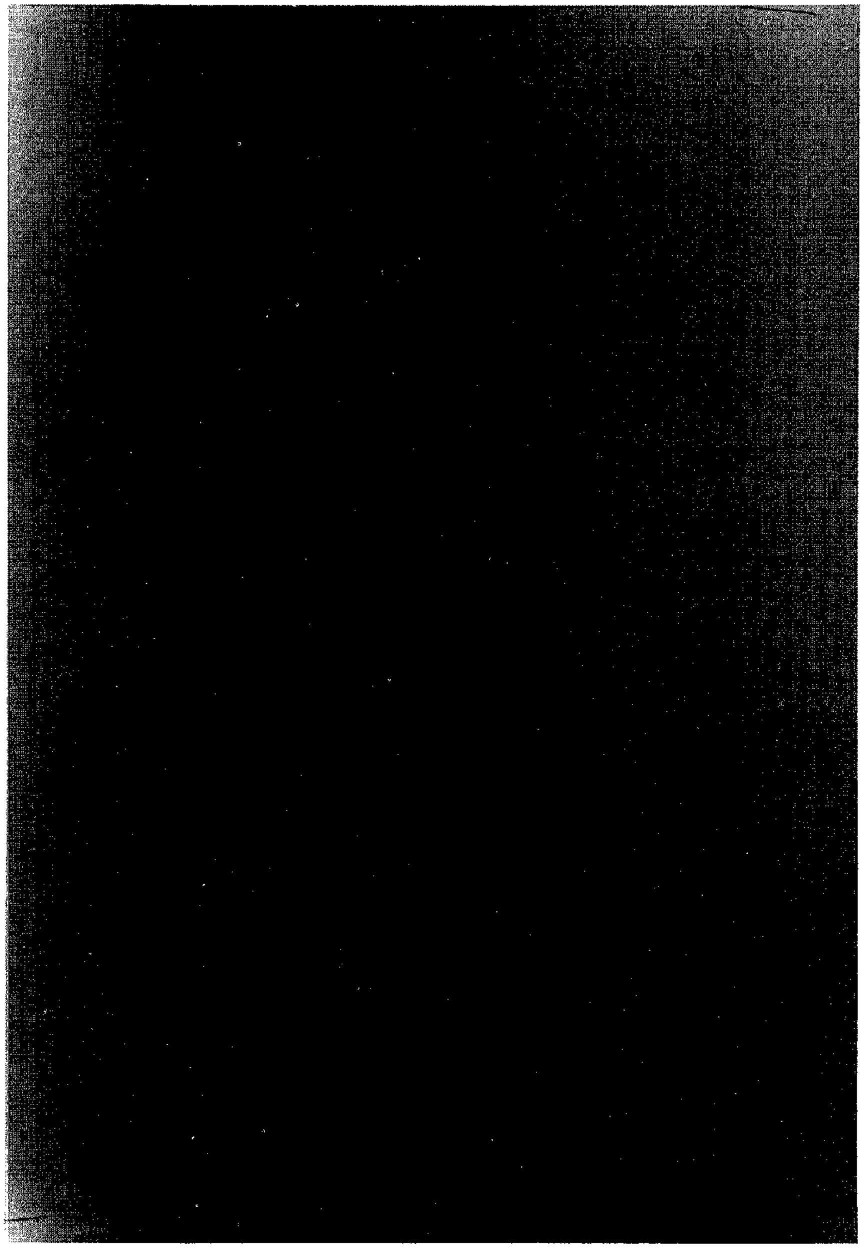

Figure 10B. 8:1, 103 l.p.i. grid distance decentered.

1. Position the cassette and grid as for any patient chest radiograph.
2. Using a 72-inch source to film distance, center the x-ray tube with the grid and cassette.
3. Collimate the useful radiation beam to cover a space of ½ inch at the center of the image receptor. Make an exposure at 60 kVp and 20 mAs. (Adjustment in techniques may be necessary depending on film/screen speed.)
4. Laterally decenter the x-ray tube 1½ inches to the left and make another exposure at the same technique factors. Again laterally decenter the tube an additional 1½ inches and make another exposure. Realign the tube with the original center position and then laterally decenter the tube to the right 1½

GRID ALIGNMENT

Date: ____________ Room No.: ____________

Equipment Identification: ______________________________

Grid Tested: ______________

Grid Ratio: ____________ Line Number: ____________ Focal Distance: ______

SID Used for Test: ______________

kVp: ____________ mA: ____________ Exposure Time: ____________

Reference Location	Measured Optical Density						
	←						
		2	1	0	1	2	

Remarks/Comments:

____
Signature

Figure 11. Sample grid alignment log.

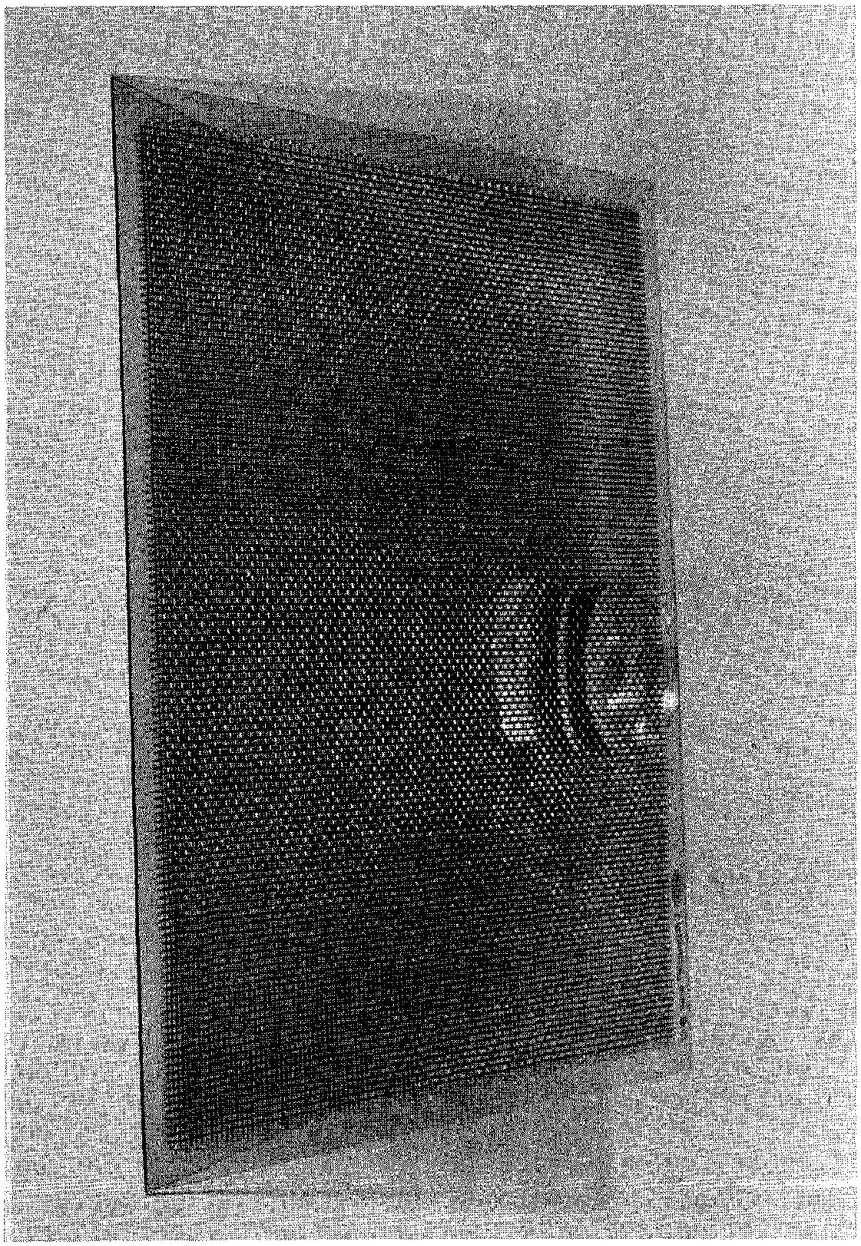

Figure 12. Wire mesh test tool.

inches and make an exposure. Move the tube an additional 1½ inches to the right and make another exposure.

5. Process the film as any other radiograph.
6. With the densitometer, read the density in each of the five locations where exposures were made. The central exposure should be the darkest. The exposures on either side of the central exposure should show a symmetrical decrease in density or "blackness" (i.e., "white" on either side). The exposure factors may have to be adjusted to obtain a central density of approximately 1.0 to 1.5 optical density units.
7. Record the results on the log as shown in Figure 11.

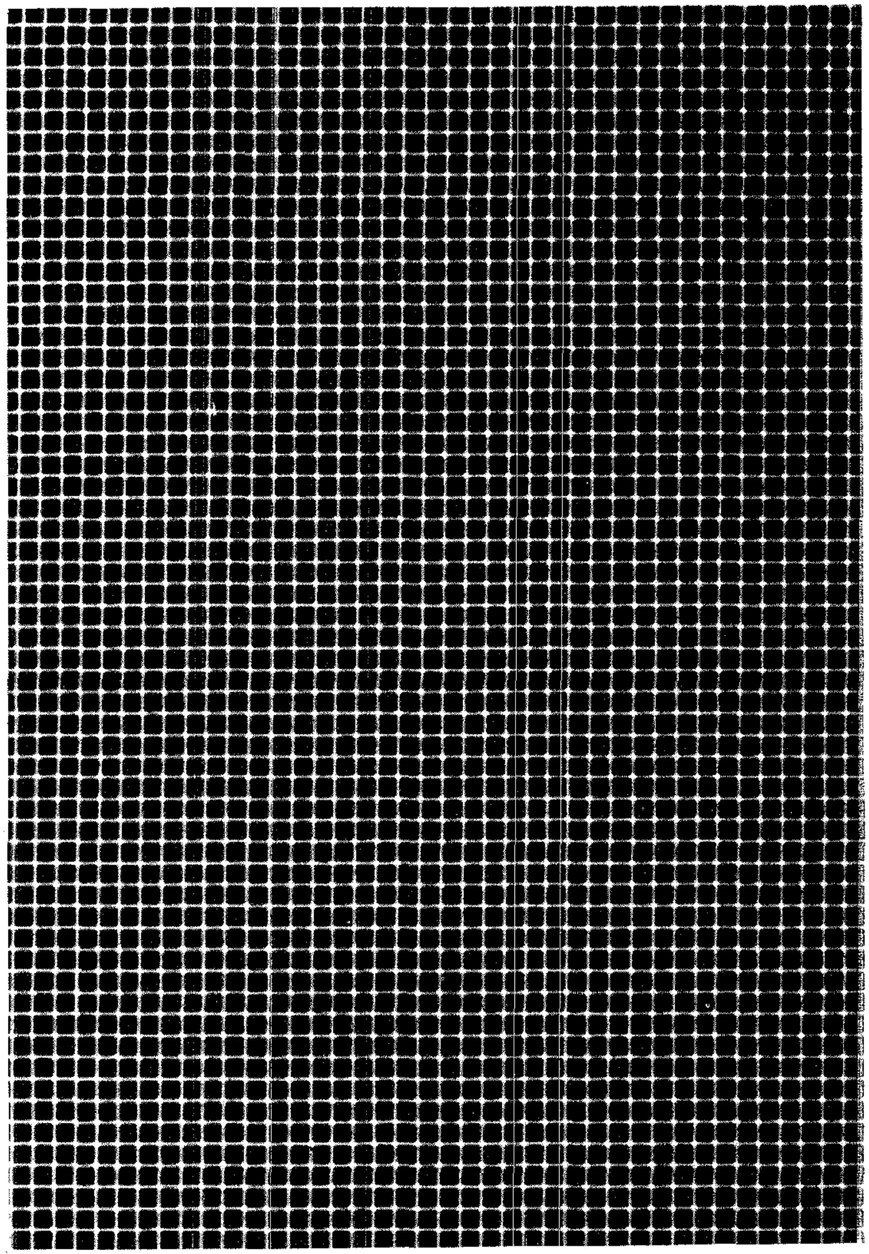

Figure 13A. Wire mesh radiograph, good screen contact.

Film/Screen Contact

Image receptor unsharpness due to poor film/screen contact contributes to overall unsharpness of the radiographic image. For best image sharpness the x-ray film should be in intimate contact with the intensifying screen. A radiograph taken with poor film/screen contact exhibits noticeable lack of detail. Periodic testing of film/screen contact is necessary. Specific procedures for the tests are discussed in several publications (2,7).

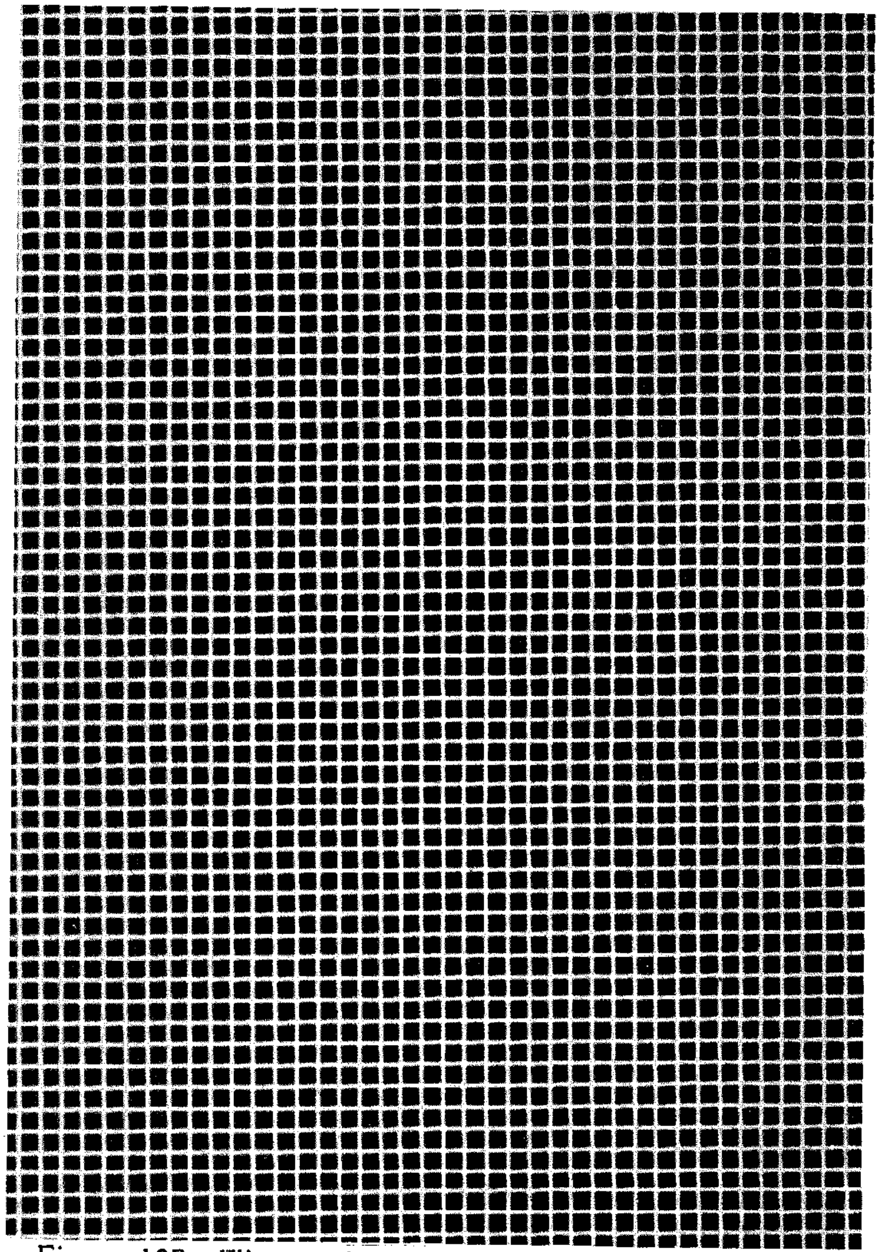

Figure 13B. Wire mesh radiograph, poor screen contact.

The test should be performed initially upon receipt of a cassette, if the cassette is repaired and/or damaged, and routinely at 6 month intervals.

The following steps should be followed:

1. Visually inspect the screen and cassette for worn or stained areas or yellowing due to age. Problems with poor contact may result from a warped cassette, warped screens, bulges in the screen due to a foreign body caught in the screen, or worn and broken latches. The screens should be cleaned periodically with cleansing material recommended by the manufacturer.

FILM SCREEN CONTACT

Date: ____________

X-Ray Equipment Used for Test: ______________________________

Focal Spot Size Used for Test: ____________mm

Technique Factors: ____________kVp ____________mA ____________Time

Film Type Used for Test: ______________________________

Cassette Type	Screen Type	Cassette Identification	Screen Mounting Date	Test Film Identification	Contact Test Results	Action Taken

Remarks/Comments:

____
Signature

Figure 14. Sample film/screen contact log.

2. Place the cassette to be tested on the x-ray table. Position the long axis of the cassette perpendicular to the anode-cathode axis of the x-ray tube.
3. Adjust the x-ray tube and beam collimators such that at least a 40-inch source to film distance is obtained and the useful radiation beam is centered on, and just covers, the cassette.
4. Place the film/screen contact test grid on top of the cassette (Figure 12).
5. Using x-ray techniques of 60 kVp, 3 to 5 mAs, and a small focal spot for a medium speed film/screen combination, make an exposure. Adjustment in technique may be required for other film/screen combinations to obtain the desired 1.0 to 3.0 density in the central portion of the test radiograph.
6. The exposed film is processed and the radiograph placed on a radiographic illuminator for viewing at a distance of 6 to 9 feet. Areas with poor contact will be demonstrated by a nonuniform density or reduced sharpness of the image (Figures 13A and 13B).
7. Note the identification of any cassette showing poor contact. Areas of poor contact around the edges of the cassette may be considered acceptable

if the unsharpness does not extend more than 1 inch into the center; however, unsharpness in the center of the image is completely unacceptable.

8. Determine if the cassettes showing poor contact can be repaired. If repair is attempted, the test should be redone. Cassettes which cannot be repaired should be removed from service.
9. Appropriate log entries should be made to record test results. Figure 14 provides a sample log format.

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Chapter XII

Radiation Protection

Gordon C. Johnson, M.D.

The primary and proper concern of the readers of this syllabus will be the optimization of radiographic technique for the purpose of detecting and diagnosing disease in the chest. This is the primary objective of the diagnostic procedure and must remain the dominant consideration. Radiation protection which is also important for good patient care also has a direct bearing on the selection of patients for examination and the choice of technique factors. Protection considerations are not unique to chest radiography, but their application in this context is worthy of review and comment. Physical considerations of equipment protection are addressed in NCRP Reports No. 33 and 39 (1) and will not be reviewed here.

Radiation Protection Philosophy

Good radiation protection practice reflects a general philosophy that is based upon sound underlying physical and biologic concepts. One of these is the assumption that radiation effects follow a linear nonthreshold dose-response relationship. Although few scientists agree to a precise linear relationship at diagnostic levels, there is wide agreement that the use of the linear relationship concept is reasonable for purposes of public health policy, and for clinical decision making in medicine. There is also scientific skepticism about the nonthreshold concept. It too is generally accepted as being a useful tool for planning purposes, particularly when dealing with populations as opposed to individual patients. According to the nonthreshold concept there is no radiation dose so small that it does not involve some degree of risk or probability of a detrimental radiation effect. Based on these two concepts, the real magnitude of risk is considered to be directly proportional to the dose delivered. Adverse effects at low dose levels would not be recognizable unless very large numbers of individuals were exposed.

Balancing the risk is based upon the premise that the use of radiation in medical diagnosis confers benefits on both the individual and society. If it is judged that the benefit to the individual and/or to society outweighs the risk, whether real or postulated, then the use of radiation is judged to be justified. Thus, a weighing or balancing must be undertaken in each situation where a decision is to be made regarding the use of radiation for diagnostic purposes.

The goal of the public health concern in medical radiation is to achieve the maximum advantage or benefit from the use of ionizing radiation while minimizing exposure. One of the most effective approaches toward that goal is the elimination of unnecessary exposure to radiation. This can be accomplished in two ways. The first involves the use of optimal equipment with quality controls and techniques designed to acquire the most useful diagnostic information with a minimum of radiation exposure (or absorption). The other is to avoid the use of unnecessary radiographs; i.e., those in which the potential benefit is not believed to outweigh the potential risk of radiation.

Based on a 1970 survey by the Bureau of Radiological Health and by extrapolation, it is estimated that 240 million diagnostic x-ray examinations involved almost half of the U.S. population in 1978. It is apparent that even a small amount of excess or unnecessary radiation, when multiplied by the huge numbers of examinations and people involved, can have a substantial adverse impact on public health. Although from the individual patient's point of view there is little likelihood of an adverse effect from a single examination, the population effect is cumulative and is the total result of all the individual encounters. It is therefore appropriate to apply optimal medical judgment to each individual patient encounter.

Radiation Protection Practice

Good radiographic technique includes the application of radiation reduction principles, most of which also enhance film quality and diagnostic effectiveness. Although the reader is probably familiar with these principles, they should be reemphasized. The x-ray beam should be "collimated" or restricted at least to the size of the image receptor (the x-ray film). When dealing with chest radiography in this country, this is most commonly a 14 x 17 inch chest film. It is optimal to reduce the beam size to the anatomic area of concern even if it is less than the film size, but as a minimum the beam size should be reduced to the receptor size. Scattered radiation, which reduces the diagnostic quality of the image, increases with increasing beam size. Therefore, reducing the beam size contributes to improved image quality. An ancillary benefit is the avoidance of unnecessary radiation outside the area of primary interest that might affect critical or sensitive organs such as the gonads, active bone marrow, the thyroid gland, or the lens of the eye. The breast, now recognized as a radiosensitive organ, cannot be excluded from conventional chest film radiography. However, the dose to the breast is considerably less from a posteroanterior chest view than from an anteroposterior view.

Although good collimation is accepted as standard practice today, it is not consistently used as indicated by surveys of actual clinical practice. The ratio of beam size to film size was reported from a 1972-1974 survey as 1.30 (2). Thus, a 30% greater area was exposed to radiation then could have contributed to useful diagnostic information.

All new general radiographic systems are required under Federal regulation to have positive beam limitation. This is intended to reduce the exposure area to at least the film receptor size under normal modes of operation. This does not preclude reducing the beam size to less than the receptor size as appropriate for particular examinations or anatomic configurations. On older units that may not be equipped with positive beam limitation, mechanical collimation should be used to accomplish the same results.

Various technical factors also influence radiation dose. They should be selected to optimize image quality of course, but within the range of acceptable image quality. Considerations for higher kilovoltage, appropriate filtration, the use of grids (when necessary and matched to kVp), faster films and screens (when they will not significantly degrade image quality), and quality assurance (including stability and reliability of processing) should all be given careful attention in developing technique charts and establishing standard procedures. Proceedings of a recent symposium, Optimization of Chest Radiography, offers a number of interesting and relevant discussions (3).

A fringe benefit of reduced dose to the patient is the reduction of occupational exposure to technologists and to other personnel who are involved in diagnostic procedures. Simplistically, one can assume a reduction at least proportional to the reduced patient dose. Considering physical and geometric factors, the reduction may be substantially greater.

Gonad shielding should, of course, be used when appropriate. Recommendations are based on considerations of practicability and effectiveness. Whenever the gonads are expected to occupy a position within or closely adjacent to the primary x-ray beam, gonad shielding should be considered. If its use is likely to obscure an area of interest or importance to the interpreter of the radiograph, then modification or deletion of the shielding is appropriate. This decision making process is, or should be, a routine or automatic part of positioning practice for every radiographer.

Protection of the uterus is of particular importance in the pregnant or potentially pregnant patient. With conventional chest radiography, using good collimation, the amount of scatter reaching the uterus in early pregnancy is extremely small and routine shielding has not been recommended. Toward the later stages of pregnancy, with expansion of the uterus into the upper abdomen, the possibility of significant exposure is increased and, therefore, the desirability of abdominal shielding should be considered.

Personnel Monitoring

Personnel monitors for professional and technical personnel have, on occasion, been misinterpreted as a form of radiation protection. Indirectly they are useful as a way of recording and signalling excessive exposure or improper practices, thereby stimulating improved protection or safety procedures. Monitoring devices do not protect anyone, but they are a critical part of good radiographic practice. Appropriate personnel dosimeters such as film badges, thermoluminescent dosimeters, or ionization chamber monitors should be worn regularly by all personnel exposed or potentially exposed to ionizing radiation and readings reported frequently enough to provide for corrective action if excessive exposure is suggested.

Recommendations for location of monitoring devices vary with the character and pattern of exposure and work load. Questions should be resolved by consultation with the health physicist, radiation safety officer, or radiation safety consultant at each facility. It is important to distinguish the doses reported from personnel monitors worn at the maximum point of exposure, such as outside a protective apron and closest to the scattering medium, from those that are worn, for instance, to identify gonadal exposure at a point inside any protective material and closest to the location of the gonads. A procedure manual should indicate the recommended practice for the particular facility and category of personnel, and deviation from that practice should be recorded in a log. It is important to recognize that the monitor readings do not necessarily represent occupational exposure. Appropriate corrections and extrapolations based on the individual situation and on reasonable assumptions are necessary to arrive at estimates of exposure to the total body or its parts. Professional and technical personnel should understand the significance of dosimeter reports and use them appropriately. Unfortunately, this kind of information is commonly misunderstood and, therefore, misused in both the lay and scientific literature.

Exposures in Chest Radiography

Historically there has been little concern on the part of the diagnostic radiologist or radiographer for chest film exposure levels. Techniques were selected to achieve satisfactory radiographic images. In recent years, exposure surveys conducted by the Bureau of Radiological Health (Nationwide Exposure X-Ray Trends) have revealed that there is a large range of exposures even for single view posteroanterior chest examinations of patients of similar size. Exposure levels are not found to correlate directly with variation in image quality or informational content. Entrance exposures ranging from 2 to 283 mR have been reported with a mean value of approximately 23 mR for a reference standard size patient of 23 cm. anteroposterior diameter (4). Acceptable radiographs can be obtained using exposures at the measured means. Some experts believe that optimal chest radiography requires techniques that deliver higher exposure levels. Even allowing for that possibility, careful adherence to good practice can result in substantial reduction in total exposure without loss of image quality.

Indications for Chest Radiography

Although not within the control of the radiographer, the "need for" or appropriateness of chest radiographs should be assessed in the same way as are other radiographic procedures, with the same considerations of risk versus benefit in the broadest sense. When questions are raised, such as the availability of a recent similar examination, apprehension or fear on the part of the patient, or the possibility of pregnancy unknown or not considered by the requesting health care provider, such questions should be addressed by consultation with the supervising radiologist, referring physician, and/or the patient, as necessary and appropriate, to resolve questions and uncertainties. Such a procedure will generally avoid the occasional misgivings, recriminations, or even litigation that may otherwise ensue.

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INDEX

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50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO.

2.

3. Recipient's Accession No. PB89 216204/AS

4. Title and Subtitle: Technique for Chest Radiography for Pneumoconiosis

5. Report Date: 82/00/00

6.

7. Author(s): Sargent, E. N., Editor

8. Performing Organization Rept. No.

9. Performing Organization Name and Address: American College of Radiology, Chicago, Illinois

10. Project/Task/Work Unit No.

11. Contract (C) or Grant(G) No.
(C) 210-81-2101
(G)

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This guide was intended to assist the user in obtaining good quality roentgenograms. It was the product of the efforts of many radiologists and highly qualified technologists working to produce films of optimum technical quality for the study of pneumoconioses while restricting the radiation dose to the patient to a minimum. Specific topics considered individually included: chest radiography for the detection and study of pneumoconioses; equipment requirements and the use of the test phantom; positioning of the patient; technique guides for consistently good radiographic quality; good radiographs obtained through the proper use of the darkroom (included manual and automatic processing, storage of films and use of safe lights); the physical basis for optimum chest radiography (included a discussion of the major problems in interpretation of radiographs and in radiographic technique); control of scattered radiation by means of collimation, grids or air gaps; the blurring and quality assurance of the screen; the choice of film/screen combinations; sensitometric monitoring for film quality; and radiation protection.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms: NIOSH-Publication, NIOSH-Contract, Contract-210-81-2101, Diagnostic-techniques, Respiratory-system-disorders, X-ray-diagnosis, Radiation-exposure, Radiological-equipment, Radiology

c. COSATI Field/Group

18. Availability Statement

19. Security Class (This Report)

21. No. of Pages: 148

22. Security Class (This Page)

22. Price: PC $21.95 / MF $6.95

ANSI-Z39.18) — See Instructions on Reverse — OPTIONAL FORM 272(4-77)