AAPM REPORT NO. 24

RADIOTHERAPY PORTAL IMAGING QUALITY

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(with figures)

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Radiotherapy Portal Imaging Quality

I. INTRODUCTION

The major goal of radiation therapy is the delivery of a prescribed radiation dose as accurately as possible to a tumor region while minimizing the dose distribution to the neighboring normal tissues. There are several geometric factors which tend to compromise this goal such as patient movement, improper placement of shielding blocks, shifting of skin marks relative to internal anatomy and incorrect beam alignment. At present, the only method commonly available for measuring and documenting the extent of geometric treatment accuracy is the radiotherapy portal film. These films are used by most radiotherapy institutions to evaluate the degree to which the actual delivered radiation therapy matches the planned treatment.

Definitions

In the past the terms portal film, beam film and verification film have been used in an inconsistent manner. The definitions given below will serve to clarify future discussions.

Portal Radiograph: A radiograph produced by exposing the image receptor to the radiation beam which emanates from the portal of a therapy Three types of portal radiographs are defined below.

1. Localization Radiograph A portal radiograph produced by an exposure which is short compared to the daily treatment time required for' that treatment field. (Such images are frequently called localization films, beam films, or port films).

They can be used in an interactive manner to adjust the patient set up and field boundaries prior to the delivery of the major portion of the daily treatment.

2. Verification Radiograph: A portal radiograph produced when the image receptor is exposed to the entire treatment delivered with that field. This requires the use of a relatively insensitive detector, e.g. a slow film.

3. Double Exposure Radiograph: Localization radiograph, produced by a sequence of two exposures, first to a shaped treatment field, then to a larger rectangular field. The resulting image serves to locate the treatment field borders with respect to the patient's

anatomy.

Simulator Radiograph: A radiograph produced by exposing the image receptor (film) to the beam of a simulator unit. The simulator unit is usually a diagnostic quality x-ray unit which is capable of mimicking the geometry and movements of the radiation therapy unit.

The Need For Portal Radiographs

There is some evidence that accuracy in beam alignment is related to the use of portal film verification. Several studies have been published (l-3) which show a link between decreased localization errors and frequency of verification films. Marks et al pursued a six year study of localization errors for patients treated with extended mantle fields. A significant decrease in percent localization error was demonstrated as the number of verification films per patient increased. More specifically, they showed that increasing the frequency of verification films from an average of nine per treatment course to twenty-four decreased the frequency of a localization and field design error from 36% to 15%. The information provided by the verification films enabled the physician to modify patient positioning and the field blocking. The authors recommend that for complex fields with a known high error rate. daily verification films be taken until a reproducible, accurate setup is established.

Regions of high setup error rate were described by Byhardt et al (2). In a retrospective study, they measured the frequency of localization errors by comparing localization and verification films to simulation films. The average error rate was 15% with a wide variation, depending on the site being treated. Not surprisingly the highest error rate was prostate and bladder cancer (37% and 27% respectively) where patient anatomy is less conducive to precision set up; the lowest rate was for primary and secondary brain tumors (6% and 2% respectively). For the sites with high error rates they recommend detailed description of the setup tattoos and also frequent film checks.

Another more recent study describes the use of portal films to analyze variations from the planned treatment of the anatomical volumes treated for 71 patients (4). An average standard deviation of approximately 3 mm is reported independent of site. The authors show, however, far greater differences between portal and simulator fields relative to patient anatomy, with the mean worst case discrepancy (averaged over all sites) of 7.7 mm.

It is difficult to draw specific recommendations from these studies. However, two general principles are clear: portal films are essential to accurate radiation therapy and frequent filming may be required for difficult treatments.

Pattern of Use

A questionnaire was sent by the AAPM Task Group on Portal Film Quality (TG28) and a response was received from 158 institutions (5). An analysis of the responses showed that 90% of the institutions take portal films on the first day of treatment for more than 75% of their patients. In contrast, only 40% of these institutions repeat the check for these patients on a weekly basis. Considering the data of Harks and Byhardt, one must question whether such confidence in treatment reproducibility is justified.

Another survey question relates to the use of verification films (V-film). The responses reveal that while 30% of the institutions use this technique occasionally, less than 10% use it on a regular basis. This may reflect the reputation for poor image quality that verification images have acquired. We shall see later that this reputation is not necessarily justified when proper technique is used.

II. THE PROBLEM

The poor quality associated with high energy portal film imaging is, in general, caused by a mixture of several factors:

1) Poor contrast due to the predominance of Compton scattering which takes place at megavoltage energies. For such images, there is no strong dependence on atomic number (Z) and therefore very little of the differential absorption seen in diagnostic radiology.

2) Image degradation due to scattered photons, which cannot easily be removed, and secondary electrons.

3) Blurring of structures caused either by large source or focal spot size or patient movement due to long exposure times. This unsharpness is enhanced as patient to film distance is increased.

4) Beam edge "fuzziness" that makes it difficult to determine the field edge in relation to anatomy. This is a combination of collimator and phantom penumbra. The apparent penumbra is derived from the collimator geometry as well as scattering in the phantom, although the latter is usually the predominant factor for portal films. Also, in the case of an acceler-

ator, the penumbra is generally greater in the radial (bending) plane. Galvin et al (6) have observed a large difference in the collimator penumbra of 6 MV accelerators from two different suppliers.

5) Poor quality portal imaging can also be caused by bad technique. For example, a surprising number of low quality portal films are caused simply by improper exposure. As a second example, if the front screen of the cassette is too thin, electrons exiting from the patient have sufficient range to reach the film.

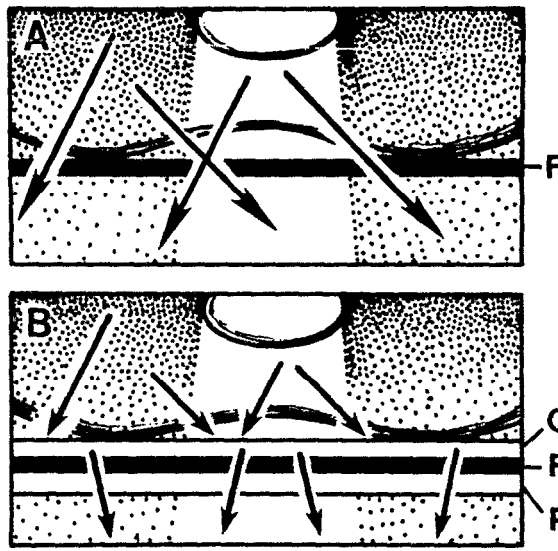
III. PRESENT UNDERSTANDING

Cassette Front Screen

The port film image is not formed directly from the incident primary photon beam, but rather from Compton recoil electrons produced in the vicinity of the radiographic film. If no screen is used then electrons emanating from the exit surface of the patient (Fig. 1A) and/or treatment couch are responsible for producing the radiographic image. The spatial variations in electron fluence are clearly proportional to the photon fluence transmitted through the patient, and thus contain image and contrast information. These electrons, however, are obliquely scattered and non-uniformally attenuated, and thus produce an image with undesirable levels of blur and contrast.

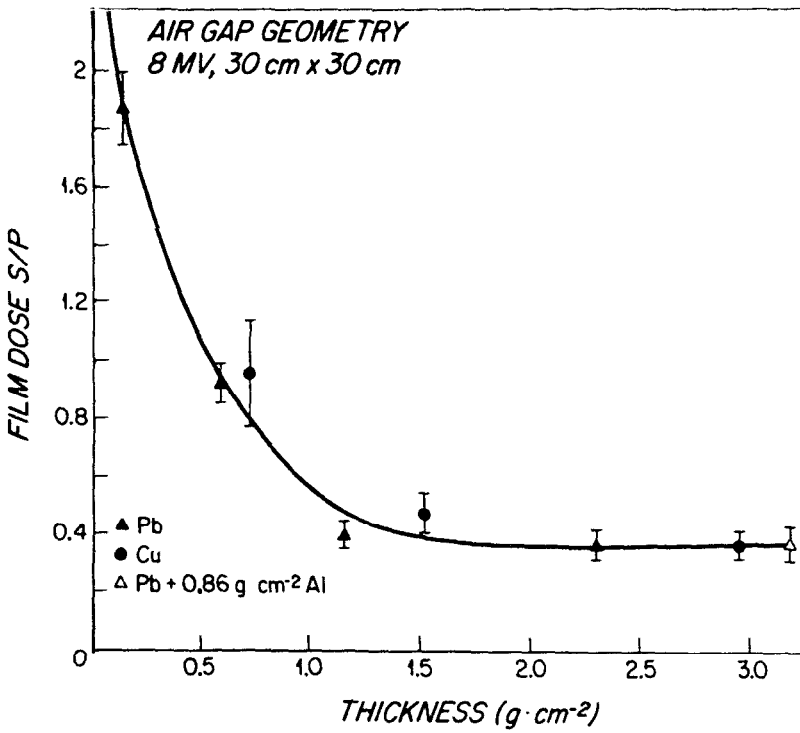
This image degradation can be greatly reduced by placing a metal screen in close contact with the film, with the screen being thick enough to absorb the shower of scattered electrons from the patient. The radiographic image information is then contained in the spatial variation of the x-ray fluence incident on the metal screen. This in turn causes the emission of Compton electrons from the screen itself which, being in good physical contact with the film, results in a better quality image (Fig. 1B).

A striking difference can be seen between portal radiographs using the same x-ray film but taken with no screen, insufficiently thick metal screens, and adequately thick metal screens. The increased screen thickness causes some loss of resolution since electrons originating within the screen now reach the film from more distant points and scatter laterally in the process. But if the thickness is reduced to improve resolution, electrons emanating from the patient will reach the film and reduce contrast. It follows that for a given screen thickness in gm-cm^{-2}, resolution is expected to be best for screens of relatively high density (e.g., lead, copper etc).



1A) Note that the images formed on the film (F) by electrons scattering at random angles from different points within the patient. Note in both figures the dots are a crude representation of the photon beam and the solid lines of the scattered electrons.

1B) In this configuration the cassette screen (C) absorbs the electrons which are scattered from within the patient. The image formed on film (F) is the result of electrons which emanate from the screen (C) itself, thereby forming a sharper image. In this particular case the rear screen (P) is plastic and does not significantly contribute to the image formation.



2) Plot of the scatter to primary ratio as a function of screen thickness for standard air gap geometry. The details of the experimental method are described in Reference 7.

In two papers by Droege and Bjarngard (7, 8) the authors point out that the metal screen cannot increase the film gamma but can increase the overall contrast by reducing the scatter to primary ratio, S/P. In this case S refers to the film dose due to both scattered photons and electrons which originate in either the screen or the patient (Fig. 2). The primary dose P is due to unattenuated photons. If the screen is too thin the S/P ratio will be high and an image of poor contrast will result. Droege's measurements at 4 MV and 8 MV showed that for each energy the S/P drops with increasing screen thickness, and that there is no significant difference between copper and lead screens once the screen thickness approaches the "build up" thickness. Beyond this thickness there is little decrease in S/P. For 8 MV it can be seen from Figure 2 that a screen thickness of approximately 1 gm-cm^{-2} is quite reasonable for these high energies. This corresponds to a 0.9 millimeter thick lead or a 1.1 mm thick copper front screen. It should be noted that for Co-60 beams there Is an enhanced response of thin lead screens to the low energy scattered photons due to photo-electric absorption in the screen. This leads to an S/P which is 25% higher for a front screen thickness of 1 mm as compared to 2 mm of lead (7). Thus, at Cobalt-60, 1 mm is sufficient for copper, but 2 mm lead Is required for optimum contrast.

Results from the survey (5) mentioned earlier showed that of the 158 Institutions responding more than 20% of the cassettes lacked any front metal screen. In addition, of the 70% who used lead front screens, more than 10% were of thickness less than or equal to 0.1 millimeter, hardly adequate for megavoltage radiography.

Metal Rear Screen

Ordinarily, there is little photon radiation scattered back to the film from structures beyond. For this reason a rear screen generally has little effect on image contrast. If electrons are scattered back toward the cassette, a rear screen with a thickness comparable to the maximum electron range may be used to stop such electrons. However, it is preferable instead to minimize the source of the backscattered electrons since the addition of such a rear screen can significantly increase the weight of the cassette system.

A rear screen can affect speed and resolution. Speed is increased as much as 1.8 times when a high Z (e.g., lead) rear screen is used (9). That is, the film exposure is decreased by almost a factor of two due to the backscatter of electrons from a high Z

rear screen. A low Z rear screen will provide little speed or resolution change since few electrons are backscattered from such materials. But such a screen will reduce the artifacts caused by electrons backscattered from structures beyond the screen.

The electron backscatteringq between high Z front and rear screens produces a "cross-over" similar to that which occurs in diagnostic radiology when luminescent screens are used. Thus, a loss in resolution is expected when rear screens are used. Such a loss has been documented through a dramatic change in the MTF for single emulsion films when a rear screen is added (8). The degradation is expected to be less severe for double emulsion films. An observer study by Reinstein et al (10) did not find significant degradation in image detectability (or "film quality score") due to the presence of a rear metal screen provided that good front screen/film contact was maintained. It appears that the resolution decrease caused by the presence of a rear screen is overshadowed by the image degradation due to the use of double emulsion film and the unsharpness caused by the finite source (target) size in the "air gap" geometry. If a rear screen is not used, the rear of the cassette comes into contact with the film and in effect becomes the rear "screen". As such, it should be of a low Z material (e.g., aluminum or plastic) to minimize the backscattering of electrons.

Luninescent Screens

Luminescent screens are not expected to be useful in portal imaging. In spite of their potential to increase film contrast for a given film (ll), a reduction in subject contrast is expected due to their sensitivity to secondary electrons scattered from the patient. To exclude such electrons, the luminescent screen must be fronted by a metal screen. However, this combination is expected to have resolution inferior to a metal screen (8).

Cassette Design

The principal of good screen film contact is as important in therapy as in diagnostic radiology. The cassette provides the obvious functions of protecting the film from light and the screens from mechanical damage. However, it also serves the important function-of providing intimate contact between the screen and the film. Many cassettes fail this latter requirement. For example. thin plastic or cardboard cassettes provide inadequate film-screen contact. Even rigid aluminum cassettes with rear panel pres-

sure bars may warp and exhibit non-uniform film-screen contact if damaged or poorly constructed. Certain commercially available cassettes are constructed with bowed pressure plates which are designed to maintain a uniform film/screen contact; this feature makes them particularly suitable for portal radiography. A wire mesh imaged in contact with the cassette/screen can be used to evaluate the effectiveness of film screen contact over the entire surface of the image receptor.

If the rear of the cassette or its support structure contain moderately high atomic number (Z) materials, significant electron scattering back toward the film can result. This reduces contrast and/or creates image artifacts. Therefore, high Z materials should be avoided in the construction of the cassette backing or its support structures. Otherwise, a rear screen may be required.

Image Quality and Beam Energy

Observation suggests a degradation of portal film quality as beam energy is increased from the low megavoltage range (4 MV and 6 MV) to the higher energy range (10 MV and up). This appears to be attributable to changes in both contrast and resolution, although the relative importance of these factors is unclear.

Subject contrast undoubtedly decreases as beam energy is increased from the diagnostic kV range to the therapeutic MV range. This is due to the reduced probability of photo-electric interactions. Within the megavoltage range, however, Compton interactions dominate. This statement may not be true for very high energy beams (i.e., >20 MeV), where pair production is also of importance, and this is discussed below. If the effect of multiple scattered photons is ignored, contrast is expected to decrease as the photon energy increases, due to the decreasing probability of Compton interactions. However, the magnitude and direction of the scattered photon fluence also change with energy, with scatter being more forward peaked as energy increases. This has been theoretically analyzed by Amols et al (12) using differential Compton cross sections. The theory is consistent with results [i.e., image contrast (as measured by a parameter termed "visual contrast") decreases significantly as beam energy increases from 4 MV to 15 MV]. These results were derived in a relatively low -scatter geometry [i.e., with a thin phantom (8 to 9 cm) and a 10 x 10 cm field size].

In high scatter geometry, however, contrast is not so severely affected at the higher megavoltage energies. Droege's (7) measurements with a thick

phantom (20 cm) and a 30 x 30 cm field size indicated only a slight contrast reduction from 4 MV to 8 MV. This is also consistent with the theory of Amols, since increased field size increases the scattered photon fluence at the center of the image (thus reducing contrast). The contrast reduction is slight for high megavoltage beams (10 and 15 MV) since scatter tends to be forward directed. At 4 MV, scatter generated near the periphery of large fields is less forward directed and more likely to degrade contrast at the center of the image. Accordingly, the significant contrast advantage observed at low megavoltage energies under low scatter geometry tends to be lost if large field sizes are used. Increased patient thickness has a similar effect. Both Amols and Droege measured significant increases in contrast as the film-screen detector is separated from the phantom by an air gap.

Image resolution also decreases with increasing photon energy. Droege (8) measured the modulation transfer function (MTF) of film-screen combinations and demonstrated significant reductions in detector resolution from 4 MV to 8 MV. This is explained by the increased range of the Compton electrons generated in the screen.

At very high energies, however, (i.e., 20 MeV), photon interactions via pair production become a competing process to Compton scatter. At 10 MeV for example, 23% of all photon interactions in water occur via pair production. At 20 MeV, the percentage rises to 44%. In addition, unlike the Compton effect, pair production is Z-dependent. Thus the possibility exists that portal film contrast might actually improve at very high energies. This phenomenon, however, has not been explored experimentally. Further, it should be noted that even very high MV photon beams contain relatively small fractions of high MeV photons.

Film Type

To date no comprehensive study of different films in combination with a standard metal screen cassette and megavoltage beam has been done. Certainly a desirable localization film should have a high film gamma. Some rather scanty evidence has been published (10, 13) which suggests differences in quality in the megavoltage x-ray range for several available films. A more complete study of this question is to be encouraged.

Noise in portal images has not been seriously studied by previous investigators. This is unfortunate since noise is known to affect the perception of low contrast objects and film-grain noise is known

to be visually evident in radiographic images. Members of this task group have found fine grain film (e.g., Kodak Verification Film) to perform surprisingly-well in visual detection tests 'when compared to films having similar film gamma. The low film-grain noise is thought to be partially responsible. Low noise film may be especially advantageous if post processing of the original radiography is performed. Investigations concerning the role of image noise are to be encouraged.

Other factors to be considered when choosing the most suitable film for portal radiography are: speed, storage, handling convenience, cost. These may necessitate compromise with optimum image quality and each other.

Is there measurable degradation in quality when using the convenient (but more costly) "Ready Pack" film in its light tight wrapper enclosed in a cassette? The study by Reinstein et al (10) tested a "high quality" (copper screen) cassette using XTL film with and without its paper packaging on a 10 MV linac beam. Three situations' were compared:

(1) XTL alone,
(2) XTL in Ready Pack with paper insert removed and,
(3) XTL in Ready Pack

Although the results show all 3 situations to be at least 'acceptable", the data does confirm the expected degradation in quality due to the insertion of the wrapping materials between the film and the screen. For the above 3 situations, the 50% detection thicknesses (i.e., the thickness of a PVC test object which could be correctly identified 50% of the time) were found to be 11.4 mm. 12.9 ma, and 13.7 mm respectively. Thus, in using- Ready Pack wrappers, one suffers a decrease in PVC (and presumably bone) detectability of more than 2 mm, which may be clinically significant.

Proper Exposure

What is the best optical density range for viewing portal radiographs using conventional hospital view boxes? A recent observer study (10) using a portal film phantom (13) has shown that the low contrast detectability was "excellent" in the optical density range from 1.6 to 2.0, and "acceptable" down to 1.2 and as high as 2.3. The films in this study were viewed under good conditions with essentially no time limit imposed.

A technique chart which consists of tabulated values of exposure parameters, is useful in producing suitable optical densities in radiographic images. Technique charts for portal films are quite easy to

determine and use and a simple methodology is described in the literature (14).

Observer Study: Results

The observer study, previously referred to, evaluated a selection of 23 film/screen/cassette combinations using a 10 MV linear accelerator. The results suggested-that portal film cassette systems fell into three categories.

1) Excellent: These systems all had metal front screens of either lead or copper. The lead screen systems in this category all had thicknesses of at least 0.8 mm and those with copper front screens had thicknesses of at least 1.0 mm. (Copper screens of less than 1.0 mm thick were not considered in this study.)

The cassettes were conventional rigid diagnostic cassettes made of aluminum or rigid plastic, all assured a close contact between the film and the front screen. No significant difference was seen between the lead or copper screens of the same thickness, in this group. There was no paper separating the film from the front screen as in the "Ready Pack" format. (There were 13 systems which fell into this group.)

2) Acceptable: The system in this category also used rigid cassettes as above but either had thinner-front screen (0.5 millimeter stainless steel or 0.3 millimeter lead) or had less reliable film screen contact, e.g., using "Ready Pack" film or interleaf paper separating the screen from the film. (There were 5 systems in this category.)

3) Poor: These systems were noticeably inferior and included cassettes with poor film screen contact, (warped soft cardboard or steel sandwiches) and front screens of .2 millimeter lead or less. (The remaining 5 were in this group.)

Admittedly, the cutoff points for these groupings were arbitrary, but meaningful conclusions can still be drawn. The data are consistent with the previous discussions regarding desired screen thickness, cassette construction and film screen contact. It should also be pointed out that these results were obtained using a 10 MV linear accelerator exclusively, and may not be easily extended to very high energy. It is hoped that further exploration of optimum film screen cassette combinations will be carried out at higher energies.

Viewing Conditions

A. Image Brightness

The resolution of the eye is strongly dependent on image brightness, so it is desirable to assure an appropriate level of view box luminance. Measurements performed by members of this task group indicate average luminance levels of 1300 to 1900 cd. m^{-2}. It should be recalled that luminance is a measure of "brightness" at the surface of the radiator or view box, while the illuminance of an area, a sensor, or a viewers eye is the flux density incident on that area (measured in lux). Assuming a value of 1300 cd. m^{-2}, the maximum resolution of the eye is about 12 lp/mm (line pairs per millimeter) at a viewing distance of 25 cm (15). although reduced resolution results if the eye accommodates to a darker surrounding environment (16). Radiographs with an average density of 1.6 reduce the illuminance by a factor of approximately 40, at which the resolution of the eye is reduced to about 5 lp/mm. This resolution loss is of little consequence since minimally magnified portal images convey almost no object information beyond 5 lp/mm even in the absence of patient motion (17). However, if a film image is too dark (e.g., a film density over 2.5) and/or the view box too dim, resolution can drop below 4 lp/mm and significant object information might not be appreciated by the eye under these limited conditions. In addition, if the film optical density Is high enough to be on the shoulder of the H&D curve there will be a loss of contrast and therefore Image information.

B. Ambient Light

The contrast detection of the eye is approximately 2% of the illuminance to which the eye is adapted, provided the difference in illuminance is greater than about 0.3 cd. m^{-2} (18). Assuming the eye suitably accommodates to the relatively low illumiation level of the radiograph, this implies that radiographic density differences as small as 0.01 are detectable. When a radiograph is viewed in a situation of relatively bright ambient light, the ability of the viewer to detect small changes in contrast is degraded. This is because the contrast detection limit of the eye is now 2% of the combined illuminance from the radiographs and ambient light sources.

C. Practical Implementation

Proper film viewing requires uniform and a sufficiently bright level of view box luminance (about 1600 cd.m^{-2}). An additional high intensity "hot light" should be available to provide sufficient luminance for slightly overexposed small portions of

the image. Such a light should provide at least a 2X increase in luminance (preferably variable up to 4X) compared to the conventional view box. When a hot light is available, slight overexposure can be tolerated. By comparison, an underexposed film has reduced contrast (i.e., lower gamma) which cannot be Corrected by altered viewing conditions. The prefer ence for overexposed (compared to underexposed) films should be considered in the preparation of technique charts (i.e., the selection of a target density).

Viewing room light levels should be reduced so that the illuminance at the viewers' eye from the ambient sources is less than that from the radiograph itself. That is, room lights should be dimmed, and unused view boxes should be turned off or covered. Even the view box being used should be appropriately masked if unexposed or lightly exposed areas of the film transmit significant extraneous light to the eye of the observer.

Film Processor Quality Assurance

In diagnostic radiology, it has been documented that unsuitably darkened films are often due to improper film processing. In one study, 30% of all retakes, due to improper film density, were attributed to processor variation (19). In another study, both the number and type of film retakes were found to be highly correlated with processor "speed" variations (20). Similar retake problems may be expected to occur In radiation therapy departments if film processor quality is not assured. It is therefore recommended that all port film processors be evaluated daily. A test, requiring only a few minutes, should be performed in the morning so that corrective action (if necessary) can be completed before clinical films are developed. The reader is directed to other references for details concerning the establishment and maintenance of a film processor testing program (21, 22, 23). Here, a protocol is briefly outlined, primarily to indicate the ease with which such testing can be performed.

Procedure: A sensitometer is used to expose adjacent portions of a test film to "steps" of increasing illumination levels. Typically, the test film is selected to be the same type as that used clinically, but is taken from a supply reserved exclusively for processor testing. Once the processor has been given sufficient time for fluid temperatures to stabilize, and temperatures are within acceptable limits, the exposed test film is fed into the processor. After development a densitometer is used to measure the film density of selected steps. The measured values are compared to

the range of acceptable values to determine if the processor is functioning properly.

The steps to be measured are selected on the basis of the information desired. One step should be selected to indicate processor "speed". This step should have a density on the steep portion of the Film response curve and have a density of at least 1.0 when the processor is functioning properly. Measured values for this step should be within about ± 0.1 optical density units of the expected value for well controlled processors. Variations exceeding ± 0.2 should not be tolerated. It is often recommended that steps of greater and lower density are measured so that "fog" and "contrast" can be monitored. However, if the speed measurement is within acceptable limits fog and contrast will generally be acceptable. Thus, a single speed determination generally provides adequate processor monitoring. Nevertheless, baseline fog and contrast values should be established, since these parameters are often helpful in diagnosing a processor problem if the speed value is found to be unacceptable.

The most critical element in processor testing is reproducibility. Each day the test film should be drawn from the same supply (same box), and the same emulsion should be exposed (the two emulsions of a double emulsion film are not always identical). The film should be fed into the processor identically each day (e.g., low density step first). The densitometer accuracy should be checked for day-to-day reproducibility by means of a calibrated film strip. To increase precision, the test film can be exposed twice (at different locations) so that an average speed value can be determined. This requires little additional time or effort.

Other: In addition to the daily processor testing, clinical films should be examined for processor artifacts which may result from inadequate processor maintenance (24). An occasional test is also recommended to evaluate darkroom safelights and possible light leaks. The reader is directed to the appropriate references (25, 21) for details of safelight test methods.

IV. Recommendations and Practical Considerations

Recommended Indications for Frequent Portal Filming

It is recommended that frequent portal films be taken in the following situations:

1) An uncooperative patient.
2) Treatment of a critical site where accuracy on the order of 3-4 millimeters is needed.

3) A difficult set-up such as an obese patient or one with moveable, unstable skin marks.
4) Treatments where matching of field edges is important (e.g., breast, mantle para-aortic, Total CNS).
5) Pediatric treatment.

Considerations for Obtaining Good Quality Portal Radiographs

In general, one should be wary of using visual impressions to identify the cause of image quality differences. For example, resolution loss may be visually indistinguishable from contrast loss (17). Whenever possible, objective measures of noise, contrast and resolution, should be obtained for comparison. Unfortunately, It is difficult to combine such measures of image quality into a single parameter which is indicative of observer performance for a particular task. Therefore, visual tests are preferred when comparing the clinical utility of imaging systems. If the visual test is based on phantom images, phantom design should attempt to simulate the tasks required In clinical portal film evaluation, e.g., visualization of bony landmarks, field edges, etc.

The following are important for obtaining good quality high energy radiographs:

1) Excellent film screen contact -
   a) the use of high quality rigid commercial film cassettes, especially those which are specifically designed to provide good film screen contact.
   b) Flat (unwarped) screens.
2) Adequate screen thickness -
   a) approximately l-2 mm of lead or copper will be suitable over the energy range of 4 MV to 15 MV. (For Cobalt-60, a copper front screen approximately 1 mm thick is preferable.)
   b) Optional rear screen for "intensification" or backscatter artifact reduction.
3) Long term stability -
   a) the cassette/screen system chosen to avoid degradation through bowing, warping, screen damage (scratching), loose hinges, etc.

   Towards this end, copper screens are clearly superior to lead.

Practical Considerations

There are some practical considerations which sometimes preclude using optimal filming conditions. These include:

1) Cassette Weight -
Although the thick front screen may improve the image quality and the rear screen will reduce exposure time (and, therefore, the likelihood of blurring), they also tend to make these cassettes extremely heavy. A compromise may be required.

2) Cassette Placement and Mounting -
In general localization films provide better visualization of anatomic structures when the patient to film distance is kept small. There are, however. some trade-offs. At small patient-to-film distances unsharpness is minimized. On the other hand, for small distances there is more loss of contrast due to patient scattered radiation (7) than at larger distances.
Often it is considered desirable that simulator and portal/localization films be taken at the same, standard magnification. This criterion may result in a larger than optimal patient-to-film distance. On most machines cassettes can be supported under the treatment couch on special rails. For other gantry angles, several cassette holder designs exist. Some attach to the couch, but several free standing cassette holders are commercially available which are more or less convenient to use, depending on design (26). It should be noted that several of these do not assure that the film is perpendicular to the radiation beam axis. Care must be taken in the use of these.
One particular type of holder, now in use at several centers (27), allows the cassette holder to be mounted on the gantry counterweight so that it is always aligned with the beam central axis during any isocentric gantry rotation. Its advantages are ease of use and standardization of magnification. A disadvantage is that the isocenter to film distance must be 40-50 cm, which can produce excessive magnification for large fields (e.g., "Mantles") and increased unsharpness.

3) Localization vs. Verification -
The use of "V" film is not very popular, probably reflecting the poor quality images associated with radiographs taken using the "Ready Pack" alone without cassette or

blurred by patient motion. Recent experiments (10), however, show that acceptable quality portal verification films can be taken using the "V" film in a well designed portal film cassette with adequate metal front screen. This study does not, however, take into account the potential blurring due to the increased probability of patient motion during the long exposure time. On the other hand, the advantages of the "verification" film technique Is that it involves less technician time, uses a finer grain emulsion, (which thereby reduces noise), and can be used to document patient motion during the entire treatment fraction. Its major disadvantage is that the "double exposure" technique can not be used and, therefore, the treatment field is not viewed in the context of its anatomic surroundings. The quality of verification films can be improved if the "V" film is taken out of its "Ready Pack" envelope and used In a high quality portal film cassette.

4) Film Choice & Exposure Time -

As stated earlier, a desirable localization film should have a high gamma, fine resolution, and a speed slow enough to permit optimization of optical density (particularly necessary in double exposure techniques) but fast enough to reduce patient dose and motion blurring.

The time needed for optimal exposure of a portal film can vary by a factor of 10 according to the selection of different radiographic film sensitivities as well as whether or not a rear metal screen is used. Short exposure times reduce potential motion error, as well as unnecessary exposure to uninvolved regions using the "double exposure" technique. Long exposure times, however, allow greater adjustment precision in selecting the optimal technique to produce a good density film. Exposure times can be reduced significantly, through the use of rear screens. While it has been shown that the use of rear screen reduces resolution there will not necessarily be a noticeable reduction in image quality due to several other effects.

5) Daylight vs Darkroom Cassette Loading:
Ready Pack -

This issue involves questions of convenience, quality, and philosophy. It is certainly more convenient for technologists to be able

to load and reload therapy cassettes without carrying the cassette to the darkroom. In this practice Ready Pack film can be used either with specially designed cassettes or in a currently available smaller format which enables it to fit a standard therapy cassette. As discussed earlier, there is a modest decrease in quality with Ready Pack and an increase in cost.

Another convenience suggested for the use of Ready Pack film is the ability to delay processing of all films until the end of the treatment day, when they can be processed in batch for review. Herein lies the philosophical question: What is the ideal use of the portal localization film? It is clearly more in keeping with a strict interpretation of quality assurance review for the portal/localization film to be processed and evaluated immediately, with the patient still on the treatment table. In this case, the feedback from the radiotherapist is used to adjust the field prior to treatment delivery. It is understood, however, that the compromise of daylight loading and deferred evaluation may be a necessary expedient.

A final word about the use of portal films for evaluating the accuracy of radiation therapy treatment. Often the difficulty in determining whether the actual delivered treatment is identical to the planned or simulated treatment is not due to the quality of the megavoltage image but rather to the lack of a common reference frame on which to base the evaluation. Besides poor image quality other geometric conditions which render this task more difficult are differences in magnification and non-orthogonal film positioning. A device which was designed to minimize these latter two problems and to enhance the therapists' ability to evaluate the degree of difference between the simulator and portal films is called a "graticule" (28) which projects a precise scale on the image to be used as a common reference frame.

V. IMAGE PROCESSING

Photographic Method

Several methods for enhancing the quality of portal films have been reported. The simple and inexpensive photographic technique described by Reinstein and Orton (29) can be performed using equipment generally available in the radiotherapy

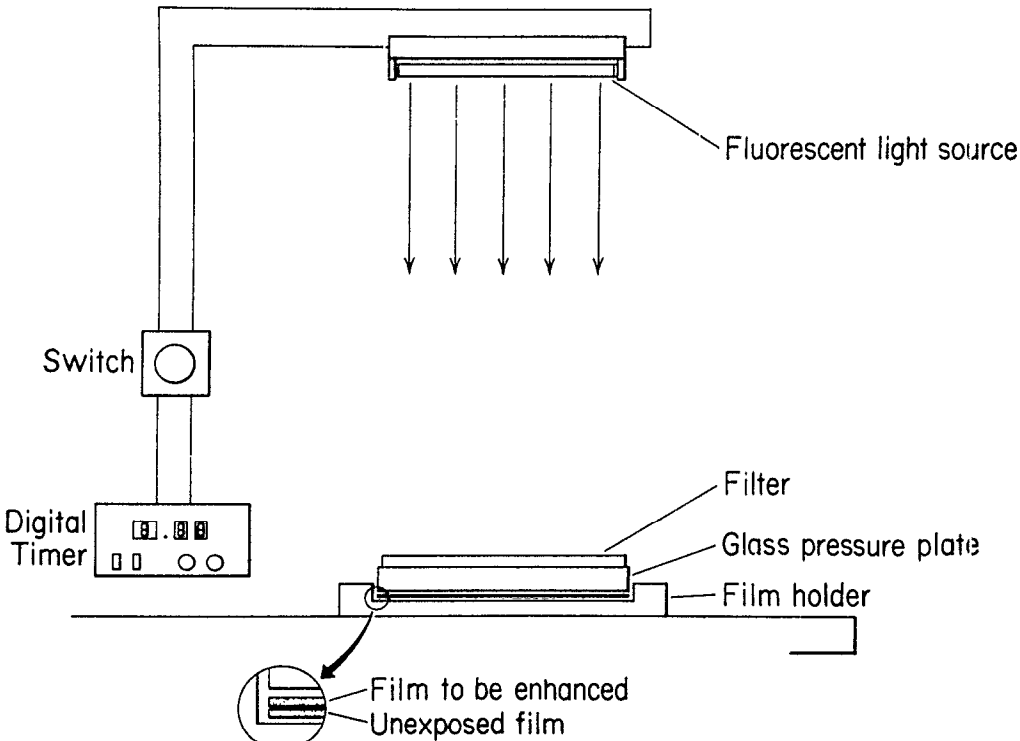
department. A contact copy of the original portal film is produced within the department's darkroom using a ceiling mounted low intensity light bulb connected to a timed switch (Fig. 3). A variety of different films are suitable for use as the copy medium, although the wide latitude XL film has been found Lo be very practical, since this film largely prevents the loss of the field edge caused by the optical density dropoff in the penumbra. The precise localization of field edge is critical for the proper interpretation of the portal film. The contact copy is processed using an X-Omat processor, and the resulting film is a reversed ("black bone") image whose effective gamma (contrast) is the product of the gammas of the original and the copy film.

Sometimes the single enhancement is adequate but often it is necessary to repeat the contact COPY process a second time. This yields a final high-gamma image with the original ("white bone") polarity. Using this technique- extremely high contrast images have been achieved which reveal good bony detail, adequate for portal evaluation. With certain films effective gammas of 30 and greater have been achieved but better results with less noise are obtained in the gamma range of 15-20. Several drawbacks of this technique are the slight loss in resolution, the magnification of film processor noise, the sharp decrease in latitude, and increased processing time.

A recent study (30) has shown that under good viewing conditions with "unlimited" viewing time the probability of small object, low contrast detection was not statistically different between the photographically enhanced and the unenhanced images. However, when viewing conditions worsen and viewing time was limited, the average quality scores were significantly better for the enhanced films. Thus, the decision to incorporate photographic contrast enhancement into the portal film quality assurance program should depend on the viewing circumstances of each particular radiotherapy department.

Digital Techniques

Alternative methods using digital imaging technology have been reported (31, 32, 33, 34) to achieve -similar results. In addition, several producers of commercial "tele-radiography" systems have been applying video enhancement techniques to the improvement of radiotherapy portals (35). Most of these systems digitize the film via a high quality low light video camera or laser scanning techniques, and process the data with a specialized graphic processor or digital imaging computer. The typical. commercial tele-radiography system produces a 512 x



3) Diagram illustrating the photographic contrast enhancement technique, for details see Reference 28.

512 electronic matrix with 256 gray levels, with "real time" digitizing capabilities, electronic zoom, and disk storage facilities. While the use of such commercial systems for the radiotherapy department is merely a spinoff of the much larger diagnostic imaging market, several of these manufacturers are making a serious effort to develop this new application.

A variation on this concept being pursued commercially is the use of a reusable imaging medium (RIM) to replace conventional radiographic film for the production of portal imaging and diagnostic radiographs (36). Ordinary cassettes are used during the exposure of the RIM (a photo stimulable luminescent material) and the image information is captured. Afterwards, the RIM is read by a laser scanner to produce the digital image. The RIM can be erased and reused many times. Such films can be loaded in daylight and scanned in less than a minute to produce a 2048 x 2048 point sample matrix with 4096 shades of grey. Research is currently underway to develop the ideal RIM material for high energy therapy imaging.

Photographic vs. Digital Enhancement

The major advantage of the contact copy gamma-multiplication technique is that it can be done with available equipment at small expense and produces high quality enhancements. Although the initial investment for a digital enhancement system is high, it has the following benefits:

1) Enhancement algorithms can be chosen to suit individual situations. Software for edge enhancement, histogram equalization, gamma correction, and low frequency filtering are available. For large fields with severe variation in patient thickness, these algorithms can be used to optimize the display of available information.

2) Image storage and fast retrieval is easily incorporated into the system.

3) Software can be developed for superimposing anatomical landmarks as well as field outlines of films taken on different simulation and treatment days. These can be used to aid in the comparison of planned versus executed treatment as well as repeatability.

VI. ALTERNATIVES TO CONVENTIONAL PORT FILMS

One method to improve the quality of portal films is the creation of a special low energy "port film mode" on the linear accelerator. Several manufacturers have provided this option in order to

counteract the degradation in quality seen at the higher energies. It is, of course, unnecessary in the newer dual energy machines with beam energies as low as 6 MV.

Another alternative is the gantry mounted diagnostic x-ray tube, an idea which dates back to 1958 on some cobalt units (37). In a recent publication, Biggs et al (38) describe a system which has the capacity for checking fields with fabricated blocks. The x-ray tube is mounted on the gantry at a fixed offset angle from the therapy beam target. The "portal film" is taken of the patient in the setup position by a precise offset of the gantry. Early versions of this unit could only be used to check alignment of the rectangular field edges while this new unit makes possible beam alignment of shaped fields using diagnostic quality films. A major drawback is that this attachment prevents collimator rotation so that all fields need special blocking and a specially designed rotating wedge tray was required. It implies a rather time consuming setup and, in general, is not recommended as a "workhorse" unit in a busy clinic. A commercial version of the gantry mounted diagnostic tube is currently available (39).

An innovative application of the gantry mounted x-ray tube technique was developed by Shiu et al (40). This new approach is to superimpose the standard megavoltage portal image on the diagnostic x-ray image using a single film. With careful alignment procedures this technique can provide the radiotherapist with "diagnostic quality" portal images.

The use of an on-line radiotherapy fluoroscopy system was described several years ago by Bailey (41). In this setup, an E2 fluoro screen was cemented to a l/16" thick steel front screen. The image was intensified using a low light TV camera. A 90° bend necessary for the side mounting of this system was achieved through the use of a planar mirror. The images were plagued by electronic interference resulting from the linac. With this system. the entire treatment could be easily videotaped and used for patient motion studies and other teaching purposes.

Another effort at real time on line imaging was reported by Partowmah and Lam (42) who use a scanning linear array of silicon diodes on the exit side of the therapy beam. The array is mounted 150 cm from the target with a detector separation of 2 mm yielding an estimated 1.5 mm per pixel resolution. The linear detector array is mechanically scanned and an image reconstructed using digital processing and signal averaging techniques.

Digital megavoltage imaging is being developed at several other centers using digital image processing techniques (43, 44). With these systems the image produced on a fluorescent screen is captured by a video camera and digitized in a 512 x 512 matrix. Using sophisticated image processing techniques the authors have demonstrated the ability to produce clinically useful on line portal images in a matter of seconds.

Efforts are being made to use computer technology to help expedite and improve the evaluation of patient treatment accuracy. Ideally a computer assisted verification system can be used for an automated "go/no go" treatment decision. A first step towards this end would be the superposition of the shaped treatment field (as drawn on the simulator/localization film) on a digitized portal image. Even more exciting is the notion of accomplishing this task in "real time" in an on-line imaging mode. Some very promising preliminary results in this direction have already been discussed.

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