EVALUATION OF RADIATION EXPOSURE LEVELS IN CINE CARDIAC CATHETERIZATION LABORATORIES

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EVALUATION OF RADIATION EXPOSURE LEVELS IN CINE CARDIAC CATHETERIZATION LABORATORIES

A Report of the Cine Task Force
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I. INTRODUCTION

Cinefluorographic examinations are widely employed for cardiovascular examinations in which it is necessary to document dynamic physiological functions such as heart function and blood flow. Although it is a useful diagnostic tool, a cine examination has the potential of producing relatively high radiation exposure levels to both the patient and the medical personnel conducting the examination.

The basic reason for the relatively high exposure values is that the examination consists of a large number of high quality cine images which are obtained with relatively high radiation exposures. An additional factor which contributes to the exposure to the medical personnel is that in many cine examinations, it is difficult to shield the scattered radiation effectively in some of the x-ray beam projections.

The radiological physicist is often called on to evaluate specific cine systems with respect to patient and personnel exposures. The purpose of this report is to describe a procedure for conducting such an evaluation. By using a standardized procedure it then becomes possible to intercompare various systems and to compare specific systems to accepted norms and standards" [1,&2].

Excessive levels of radiation in the cardiac catheterization procedure, both to the patient and to the laboratory environment are often traced to improper adjustment and/or use of the following major factors: (1) the cine imaging chain, (2) the automatic cine film processor, (3) selection of cine fluorographic techniques, (4) excessive beam "ON" time, either fluoroscopy or cine filming, and (5) improper room layout.

The first factor, the cine imaging chain, can be evaluated through the measurement of the image intensifier input exposure sensitivity (IIIES). Establishment of a standard measurement protocol for IIIES is one of the main efforts in this report. Quality assurance monitoring of the cine automatic film processor reduces many problems associated with cine film processing. Selection of the cine fluorographic techniques should be reviewed from time to time to assure optimized utilization of the equipment capability: for example, use of lower filming rate, or selection of a higher speed cine film, etc. may result in lower x-ray technique factors for cine filming and reduce scattered radiation from the patient. However, clinical conditions may limit the range of selections of cine fluorographic techniques in favor of the image quality required.

This report begins with a general description of

cine systems. This is followed with a discussion of the factors which have an effect on both patient and personnel exposures. The report continues with a description of the instrumentation and procedures for conducting an evaluation of the IIIES, the patient exposure, and the personnel exposure. The interpretation of the evaluation results is then discussed following each physical parameter of interest.

II. SYSTEM DESCRIPTION[3]

The components comprising a basic cine system are depicted in Figure 1. Most of the components such as the x-ray tube, image intensifier tube and power supply are similar to the components of a conventional fluoroscopic system. A possible exception is a higher heat storage capacity x-ray tube. Two components which are not found in conventional fluoroscopic systems are the cine camera and the automatic exposure control (AEC) circuitry for cine fluorography.

A bi-plane cine imaging configuration utilizing a suspended C-arm or a ceiling suspended lateral plane cine imaging system, for example, may be found in the cardiac catheterization laboratories in addition to the basic single plane system. Although the lateral plane increases the mechanical and electronical complexity of the equipment, it is basically a duplication of the single plane cine system in terms of the operation.

II-A. Cine Camera

In the cine system the image is recorded on 35 mm film by means of a motor driven camera. In a typical system, the x-ray beam is pulsed so that the production of x-radiation is synchronized with the cine camera shutter movements. The camera speed is selected by the operator, and the framing rate is in the range of 15-90 frames per second depending on the type Of examinations and patients, i.e., adult or pediatric. The amount of light required is determined by the sensitivity (speed) of the cine film and the cine camera lens f-stop (the aperture size). -The focal length of the camera lens determines the degree of framing or matching between the image presented at the output phosphor of the image intensifier and the film area[1,2].

II-B. The Automatic Exposure Control (AEC) System

The AEC circuitry of typical cine systems is designed to maintain a constant light level at the image

intensifier output phosphor during cine filming. The basic operational purpose of the cine AEC circuitry is, therefore, similar to that of the photofluorographic spot film camera and radiographic AEC devices. The complexity and sophistication of the cine AEC systems is somewhat greater and deserves careful study.

Because of the generator designs and the method of achieving the constant light level at the output phosphor of an image intensifier, the measurement procedure may have to be tailored to each specific type of equipment. This report attempts to encompass all possible cine AEC logics by describing the cine system parameters that must he taken into account. Its purpose is to generate a standard protocol that can be applied to most cine imaging systems.
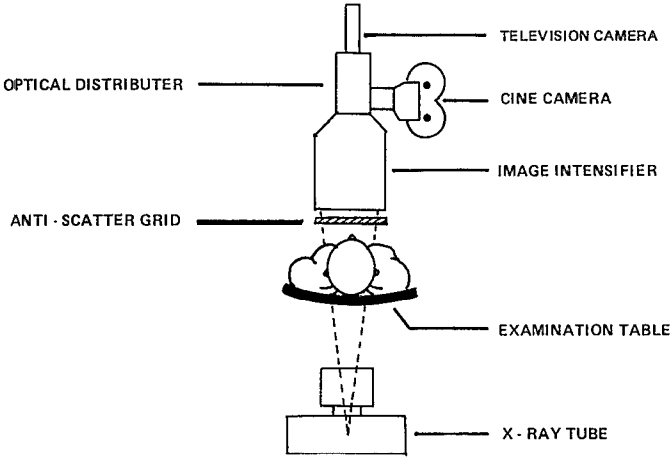

Figure 1. Schematic Illustration of A Cine
Fluorographic Imaging System.

II-C. Cine System Parameters

The complexity of the cine AEC system is primarily due to the number of variables and/or parameters involved in the cine filming. A change in any of the parameters listed in Table I will alter the light output of the image intensifier, and therefore results in a difference in the cine film exposure.

A typical cine system equipped with an AEC device utilizes one or two of the cine technique parameters to attain the constant light output from the image intensifier. The commonly employed parameters are: (a) the x-ray tube potential, (b) the x-ray tube current, or (c) the cine pulse width. Other parameters include: (d) cine filming rate, (e) focal spot size, and (f) cine run time may be considered secondary parameters and are often preset or pre-determined.

TABLE I. CINE PARAMETERS

Item	Physical Parameters	Typical Range in Clinical Case
(a)	X-ray Tube Potential	60 - 120 kVp
(b)	X-ray Tube Current	100 - 800 mA
(c)	Cine Pulse Width	1 - 5 msec
(d)	Cine Filming Rate	15 - 90 frames/sec
(e)	Focal Spot Size	0.3 mm - 1.2 mm
	(Power Rating)	(10 kW - 100 kW)
(f)	Cine Run Time *	8, 10, 12, 15 seconds
(g)	Image Intensifier	6"-14" (12 cm - 35 cm)
	Mode	(single or multi modes)
(h)	Cine Film Size **	35 mm (16 mm)

*For some special applications (such as for speech therapy and research) a cine run time of 120 seconds may be used, but is not applicable for cardiac catheterization.
**Practically speaking, all cardiac catheterization studies are now recorded with 35 mm cine cameras.

II-D. Description of Cine AEC System

The circuitry utilized in the AEC system varies with the manufacturer and the particular models of generators. A schematic block diagram of a typical cine AEC system

utilizing the x-ray tube potential as the principal variable is depicted in Figure 2. It should be noted that in many cases only one of the parameters in BLOCK A is employed as the principal variable of the AEC system.
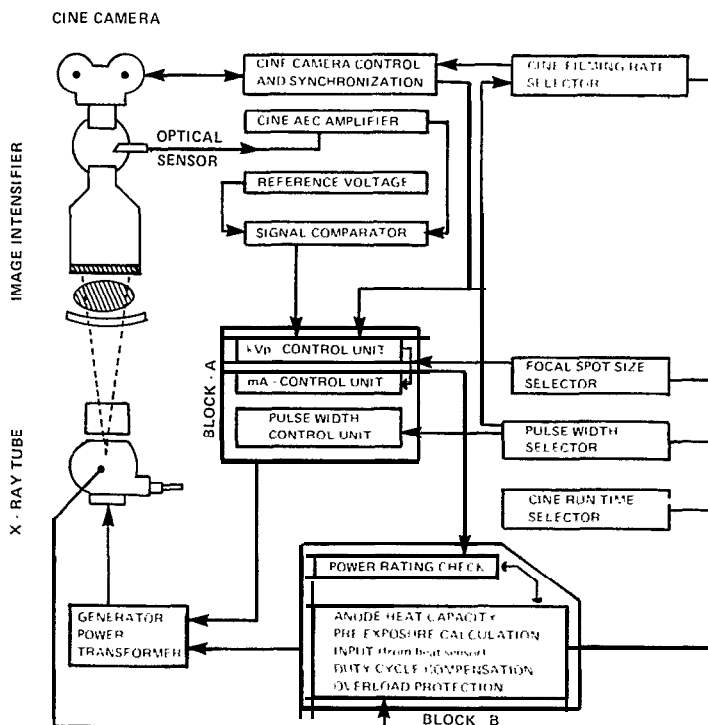

Figure 2. Schematic Block Diagram of Cine Automatic Exposure Control System.

Adapted from P.P. Lin, "Acceptance Testing of Cine Imaging Systems for Cardiac Catheterization Laboratories," in AAPM Proceedings Series No. 1, Acceptance Testing of Radiological Imaging Equipment, Ref. # 3.

Figure 2 is divided in three columns: the hardware on the left, the electronic and the electro-mechanical controls in the center, and the user selectors on the right. BLOCK A contains the microprocessors and/or the programing boards which interface the selected factors in the right column with the respective electro-mechanical circuits in the center column.

Let us follow the sequence of setting up the cine filming technique factors for an adult patient undergoing a cardiac catheterization examination:

(1) CINE FILMING SELECTOR: set to 30 frames/sec. The CINE CAMERA CONTROL AND SYNCHRONIZATION stand ready for cine filming and the actual cine filming rate along with the synchronization pulses are sent to BLOCK A for timing adjustments of x-ray pulses. The cine filming rate will significantly affect the total heat units to be stored at the anode, and hence the selected cine filming rate information is fed to BLOCK B for pre-exposure calculations.

(2) The FOCAL SPOT SIZE may also be selected with the same pushbutton as the cine filming rate selector. The power rating of the focal spot size determines the instantaneous heat loading allowable to the anode, therefore, this information is fed to the kVp-CONTROL UNIT, and the mA-CONTROL UNIT in BLOCK A as well as the POWER RATING CHECK in BLOCK B. Let us assume that the large focal spot size is selected and is rated at 1.2 mm nominal and 100 kW. The interface between BLOCK A and BLOCK B will become apparent when the cine exposure is made.

(3) The PULSE WIDTH SELECTOR determines the cine pulse width to be employed for each cine frame exposure. The allowable range of pulse width is limited by the time required for proper film transport in the cine camera and the cine filming rate. With the cine filming rate selected at 30 frames/sec, the cine pulse width can be as long as 5 msec/pulse. The cine pulse width thus selected is then presented to the PULSE WIDTH CONTROL UNIT in BLOCK A and to BLOCK B, as the pulse width will also affect the total heat units to be accumulated in the anode.

(4) A modest selection of CINE RUN TIME choices are normally set by the installation engineer for the particular facility to meet the user's application requirements. (Usually this factor is not available for selection by users at the control panel.) The

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cine run time is most often set at 10 seconds. At the end of the cine run time of 10 to 12 sec., a warning buzzer is activated and the operator is then given another few seconds before the generator is automatically turned off to protect the x-ray tube.

BLOCK A is the heart of the cine AEC system. Prior to initiation of a cine run, let's assume that (a) the kVp-CONTROL UNIT drives the tube potential circuit for cine filming to the lowest potential setting of 60 kVp, and (b) the mA-CONTROL UNIT drives the tube current circuit for the cine filming to the highest current setting of 600 mA. The PULSE WIDTH CONTROL stands ready to provide 5 msec pulses as selected. The optical sensor may be a small prism or a mirror guiding the light to a photomultiplier (some cine systems utilize the TV camera in place of the optical sensor). The prism is usually designed that it looks at the central 40 % to 60 % of the output phosphor. The signal from the optical sensor is amplified at the CINE AEC AMPLIFIER and fed to the SIGNAL COMPARATOR. The SIGNAL COMPARATOR receives the signal from the REFERENCE VOLTAGE source and compares the signal voltage from the CINE AEC AMPLIFIER, and subsequently sends out a signal to activate BLOCK A in accordance with the brightness presented to the optical sensor.

Let's assume that the brightness is too low for proper cine film exposure and requires a higher x-ray tube potential of 68 kVp. The kVp-CONTROL UNIT activates the generator to increase the tube potential, and the AEC system may reach a stable state if the tube current rating allows 600 mA for cine filming. As the x-ray tube potential is increased, the POWER RATING CHECK circuit maintains monitoring of the techniques and will activate the mA-CONTROL UNIT to decrease the tube current to 400 mA. Meanwhile the optical sensor sends another signal out to increase the tube potential again because the brightness at the output phosphor may have been acceptable at 68 kVp, 600 mA settings but is not sufficient at 68 kVp, 400 mA settings due to decreased tube current. The same process repeats itself and may reach the final steady state at 72 kVp tube potential with 350 mA tube current.

The description given above is that of an automatic iso-watt cine AEC system. Replacing the mA-CONTROL UNIT with a manual tube current selector, the cine AEC system described here becomes that of an "automatic kVp" cine AEC system with constant tube current during cine filming.

Replacement of the kVp-CONTROL UNIT with a manual tube potential selector yields an "automatic mA" cine AEC system. Both tube potential and tube current may be

manually selected and the exposure time (the pulse width) may be automatically varied. This type of cine AEC system is very simple in its design concept, and is called "automatic pulse width" cine AEC system. If the electronics are fast enough, this type of control resembles a radiographic phototiming system, i.e., if one considers the image intensifier and the optical sensor together as the phototube, and each cine frame as the single radiographic exposure. For each of these types of cine AEC systems, a minor change is required in Figure 2 in accordance with its operational logic. For certain sophisticated AEC systems, additional features are provided, such as (a) automatic optimum tube potential search logic, (b) reduced x-ray tube loading during automatic search of the tube potential, etc.

III. RADIATION EXPOSURE

In a typical cardiac catheterization laboratory, the physical factors which are of primary interest include, the cine film image quality and the radiation exposure to the patient and the personnel conducting the examination. The radiation exposure values are affected by a number of parameters such as the geometry employed, the radiation exposure required to expose the cine film, etc.

There is one equipment setting that affects radiation levels as well as the image quality experienced with the cine imaging systems. This parameter is the image intensifier input exposure sensitivity (IIIES). The IIIES, in turn, is determined by a number of factors:

(1) Cine Film Sensitivity (film speed): can be processing dependent.

(2) The f-stop setting of the Cine Camera Lens.

(3) The Image Intensifier Conversion Factor, and Quantum Detection Efficiency (QDE); aging tendency is a slow (years) process.

(4) Light Transmission of the Optical Distributor and Lens System is affected by dirt collection.

In principle, the IIIES can be adjusted during the initial calibration of the imaging chain to any value within the equipment capabilities. However, the value of IIIES which is selected should represents a reasonable compromise between the quantum noise and the patient exposure.

During the initial calibration of the cine imaging

chain, the IIIES is obtained typically at 80 kVp tube
potential and adjusted to 10-20 µR/frame for 9" mode and
20-30 µR/frame for 6" mode operation of the image
intensifier. It is also assumed that the developed cine
film will be projected at a standard display rate of 24
frames/sec [1&3] for normal viewing.

The IIIES level adjustment is attained through the
cine AEC sensitivity control circuitry. Therefore, when
evaluating cine systems with respect to either patient or
personnel exposure, it is highly desirable to determine
the IIIES at which the system is operating. A procedure
for making this determination is described in Section IV
of this report.

A concept parallel to that of IIIES is the
fluoroscopic input exposure rate sensitivity (FIERs). The
FIERS is a s s o c i a t e d the fluoroscopic operation of
the same cine imaging system, and the sensitivity is
adjustable via the f-stop of the television camera lens,
the television camera target voltage, and the automatic
brightness control (ABC) for fluoroscopy. Typically, the
FIERS is set to 40-50 uR/sec (2.4-3.0 mR/min) for 9" mode
and 80-100 uR/sec (4.8-6.0 mR/min) for 6" mode operation
of the image intensifier [4].

III-A. Patient Exposure

The total amount of radiation received by the
patient undergoing a cardiac catheterization examination
is accumulated from the fluoroscopic exposure during the
catheterization and the subsequent cine filming.

The radiation exposure arising from the fluoroscopic
procedure is proportional to the field size selected, and
the total fluoroscopic "ON" time and the average
radiation output at the entrance site. A simplified
method to estimate the patient exposure, due to the
fluoroscopy, can be calculated from the entrance skin
exposure rate (typically, l-5 R/min) for an average size
patient multiplied by the total fluoroscopic "ON" time
(typically 10 minutes to 30 minutes). This simplified
approach assumes that the radiation beam is always
incident on the same site, and thus overestimates the
actual dose to any one site, i.e., patient exposure per
fluoroscopic/cine view (PA, LAO, RAO, LL, etc.)

The patient exposure due to the cine filming
exposures is largely dependent on the total number of
cine frames taken. The patient exposure due to the cine
filming is minimized by selecting the lowest filming rate
which adequately images the dynamic aspects of the
examination. If the cine patient exposure/frame is known

(typically 10-25 mR/frame) [5] for each cine view, the
cine patient exposure is simply proportional to the cine

patient exposure/frame (for that cine view) times the
total number of cine frames taken for the corresponding
cine view. Typically 300 frames to 1200 frames may be
taken for one complete examination consisting of few
different cine views.

The patient exposure of a given cine system may he
altered and affected by (1) the filtration provided in
the primary beam path, and (2) the anti-scatter grid
attached to the input surface of the image intensifier
housing. Therefore, in the evaluation and estimation of
patient exposure, the radiation beam quality in
Half-value Thickness (HVT) and the anti-scatter grid
employed for the cine imaging chain should be considered.

III-B.   Personnel Exposure

The radiation exposure to personnel conducting a
cine examination is produced by the radiation scattered
from the patient's body and by the leakage radiation from
the x-ray tube. For a given situation the scatter to a
specific point is approximately proportional to the
radiation entering patient and/or the image
intensifier tube. The actual relationship of the scatter
exposure and the IIIES is determined by a number of
factors including:

   (1) Orientation of the x-ray beam, patient and
       personnel.

   (2) Distance between the patient and the location
       of the personnel.

   (3) Radiation field size/collimation.

   (4) Patient size.

   (5) X-ray technique factors.

Since there are a large number of parameters which
affect personnel exposure, a complete exposure evaluation
requires the measurement of exposure values at specific
personnel locations during actual or simulated patient
examination conditions. The relative personnel exposure
produced by various cine systems can be indirectly
compared by measuring the IIIES, if so desired.

The stray radiation (scattered plus leakage) in the
cardiac catheterization laboratory has been measured by
various investigators[6&7] and expressed by
iso-exposure curves. Due to the high power loading of
cine fluorographic techniques, the iso-exposure curves
are often measured for the fluoroscopic case first.

Subsequently, these iso-exposure curves can be utilized with appropriate multiplication factors to account for the differences in the imaging techniques between the cine fluorography and the fluoroscopy. Depicted in Figures 3 and 4 are typical iso-exposure curves for the fluoroscopic operation of the cine imaging chain.

III-C. Summary

From the discussion of radiation exposures in a cardiac catheterization laboratories above, the following physical parameters can be listed as the physical factors that should be included in a complete evaluation of a cine imaging system:

(1) Image Intensifier Input Exposure Sensitivity (uR/frame).

(2) Fluoroscopic Input Exposure Rate Sensitivity (uR/sec.).

(3) The Beam Quality of Cine Operation in HVT's.

(4) Patient Exposure from Fluoroscopic Operation (R/min).

(5) Patient Exposure from Cine Filming (mR/frame).

(6) Personnel Exposure from Fluoroscopic Operation (mR/hr).

(7) Personnel Exposure from Cine Filming (mR/hr).
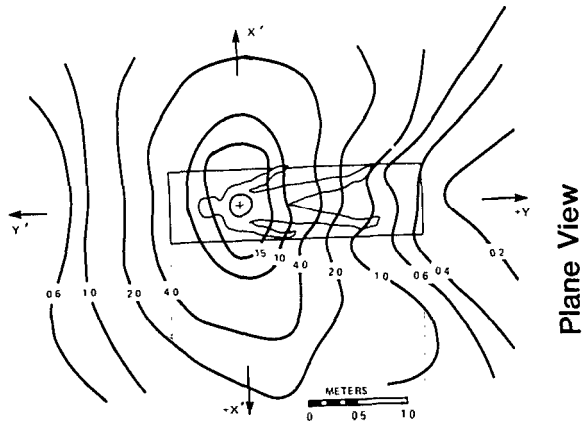
Plane View
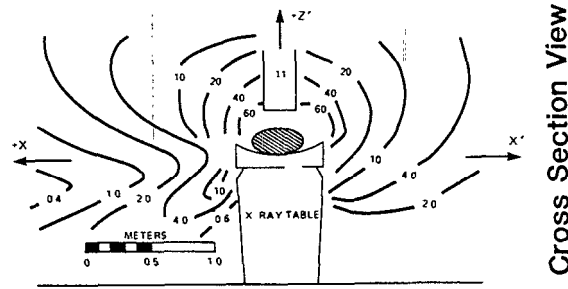
Cross Section View

STRAY RADIATION LEVELS

Iso-exposure Curves in units of mR/hr.

Figure 3.   Iso-exposure Curves Around A Cine Imaging
System Equipped with A Cradle-top Examination Table.

Iso-exposure curves (mR/hr) with fluoroscopic
technique factors of: 96 kVp, and 1.5 mA, Field Size
(entrance): 10 cm x 10 cm, and Tabletop Exposure
Rate: 1.95 R/min. (By permission of the American
Heart Association, & F.C. Rueter, Ref. #6.)
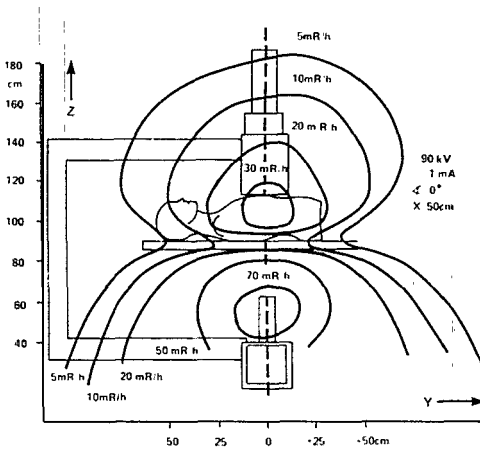
STRAY RADIATION LEVELS

Figure 4.   Iso-exposure Curves Around A Cine Imaging
System Equipped with A U-arm Type Geometrical design.

Iso-exposure curves are obtained with fluoroscopic
technique factors of: 90 kVp, and 1.0 mA, Field Size
(entrance): 8.5 cm x 11 cm, Tabletop Exposure Rate is
not Specified. (Courtesy of J.A. den Boer, and H. Mohr
and MEDICAMUNDI.   Adapted from Ref. # 7.)

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IV. IMAGE INTENSIFIER INPUT EXPOSURE SENSITIVITY MEASUREMENT

The IIIES of cine systems can be compared in a meaningful manner only if the measured values are obtained in accordance with a standard protocol. This section describes such a protocol and the necessary equipment to carry it out.

IV-A. Instrumentation

The measurement of the IIIES requires an appropriate ionization chamber and an absorber or phantom.

IV-A-l. Ionization Chamber

The ionization chamber should be small enough to be contained within the field of view of the image intensifier, and should also be relatively thin so that it can be located and positioned in the proximity of the input surface of the image intensifier. Flat, disk-shaped chambers are generally preferred. Due to their inherent inaccuracies, the pocket-type dosimetric chambers are not recommended. The ionization chamber and its associated electronic reader must be capable of accurately measuring exposure rates as low as l.0 mR/min or an accumulated exposure of as low as 1.0 mR per cine run. The energy response of the ionization chamber system should be calibrated for x-ray qualities at least in the range of 1.5 mm Al to 7.0 mm Al HVT's.

IV-A-2. Absorber

IIIES measurements must be made with an appropriate absorber within the x-ray beam. The following absorbers have been used for this purpose: (1) 15-20 cm of water, (2) 3.8 cm (1.5") of aluminum, and (3) 2.4 mm (3/32") of copper. It has been known that the accuracy of measured values is affected by the type of absorbing material, due to the differences in the resultant x-ray spectrum. It is recommended that measurements be made using a copper absorber to create a scatter free geometry. The thickness should be selected so that the cine system is operated at the 80 +/-5 kVp when controlled by the cine AEC circuitry. This can generally be achieved with a thickness of 2.2 mm to 3.0 mm of copper. For the cine AEC systems in which the x-ray tube potential is manually selected, the x-ray tube potential should be set at 80 kVp. The measurement is best accomplished with a kit consisting of8 pieces of 23 cm x 23 cm x 0.5 mm and 8 pieces of 23 cm x 23 cm x 0.2 mm of copper.

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The purity of the copper sheets employed as the absorber for simulation of the cine fluorographic examination should be better than 99.9% pure copper, such as type 110 copper sheets.

IV-R. Measurement Procedure

In order to insure reproducible results, the procedure described below and the geometry depicted in Figure 5 should be adhered to.

IV-R-l. Anti-Scatter Grid

In Figure 5, notice that the anti-scatter grid is removed from the image intensifier and the ionization chamber is positioned AS CLOSE AS POSSIBLE but not on the image intensifier input phosphor surface.

*********************CAUTION*************************

For image intensifier systems in which the anti-scatter grid is not readily removable, extreme care must be exercised. The image intensifier tube is an implosion hazard, and an expensive device to replace.

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In the event that it is not practical to remove the anti-scatter grid, the ionization chamber can be placed in front of the anti-scatter grid but the measured values must be corrected for attenuation due to the anti-scatter grid. The correction factor varies with the type of anti-scatter grid employed, and is normally available from the grid manufacturer. It should be pointed out that the anti-scatter grid is fragile and should be handled with care.

IV-D-P. Focal Spot Image Intensifier Tube Distance

If the distance between the focal spot and the image intensifier (FID) is variable it should be adjusted to 76 cm (30 inches) or as close to 76 cm as possible for systems in which the x-ray tube is installed under the cradletop. For the cine systems equipped with a C-arm or a U-arm, the FIT! varies depending on the particular design of the cine system and the adjustable range of the FIT! is also greater. The FID should be set to 100 cm (40") for these systems.

If the FIDs suggested above cannot be appropriately obtained, the FID employed should then be recorded.
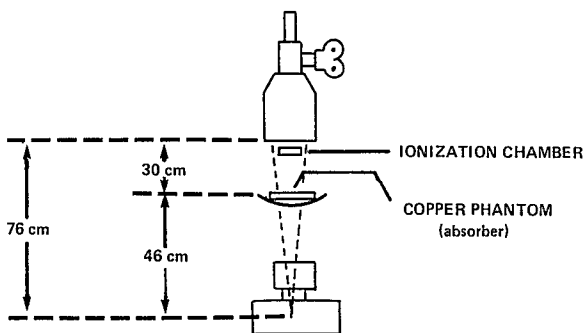
Ionization Chamber: Flatdisk-shaped
Copper Phantom Thickness: 2.4 mm
Field Size @ Image Intensifier:
        10 cm x 10 cm for 15 cm Mode
        18 cm x 18 cm for 23 cm Mode
X-ray Tube Potential: 80 +/- 5 kVp
Anti-scatter Grid: Removed

Figure 5.   Schematic Illustration of Measurement
Arrangement for Image Intensifier Input Exposure
Sensitivity.

The copper phantom should be located at the x-ray
tube collimator when accessible, or alternatively
at the tabletop as illustrated.

IV-B-3 Field Size

Adjust   the   radiation field size   (via   automatic
collimation system,   or manually) to the   size   of the
active   image   intensifier   input phosphor.   The actual
radiation   size should be measured and recorded along with
the   measurement data.   Typically the radiation field can
be set to 10 cm x 10 cm for the 15 cm (6") input phosphor
and 18 cm x 18 cm for the 23 cm (9") input phosphor.

IV-B-4. X-ray Tube Potential

Because   the sensitivity (conversion factor) of image
intensifier   tubes   is photon-energy dependent it is
desirable to make measurements at 80 +/- 5 kVp.

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If the tube potential can be selected manually, set
it to 80 kVp, place 2.4 mm of copper in the beam and
proceed with the measurement. If the x-ray tube
potential cannot be selected manually, proceed as
follows: place a 2.4 mm copper phantom in the beam and
observe the x-ray tube potential which is being selected
by the cine AEC. If the x-ray tube potential is not
within the 75-85 kVp range adjust the preset or
pre-determined x-ray technique factors such as the x-ray
tube current, and/or pulse width to bring the x-ray tube
potential into range. If the x-ray tube potential cannot
be brought into range change the attenuator thickness
until the x-ray tube potential falls within the
acceptable range. Thicknesses of the copper filters in
the range of 2.0 mm to 3.6 mm are acceptable.

IV-B-5. Measurement

It is generally desirable to operate the ionization
chamber in the rate mode. The x-ray exposure must be long
enough to permit the x-ray system and exposure meter to
reach a stable value and should be terminated as soon as
a stable reading is obtained in order to reduce x-ray
tube heat loading. Normal precautions should be exercised
on repeat runs to prevent overloading the x-ray tube and
housing.
A safety interlock mechanism is normally provided
with the cine camera so that the cine exposures cannot be
made with an empty film magazine. This interlock should
be bypassed to avoid wasting cine film.

IV-B-G. Correction Factors

A. distance correction factor should be applied if
the ionization chamber is not located precisely at the
image intensifier housing surface.

V. FLUOROSCOPIC INPUT EXPOSURE RATE SENSITIVITY
MEASUREMENT

The FIERS can be measured with the same arrangement
and instrumentation described for the IIIES measurement
and depicted in Figure 5. With the system operated in the
fluoroscopic mode, the measurement geometry, the copper
phantom, etc. may remain exactly the same as that of
IIIES measurement. The fluoroscopic mode of the cine
imaging system is activated by stepping on the
fluoroscopic pedal rather than the cine filming pedal.

VI. HALF-VALUE THICKNESS MEASUREMENT

Utilizing the IIIES measurements arrangement described in section IV, one can simply place appropriate thicknesses of aluminum filters to carry out the HVT measurement in accordance with the good geometry conditions[8]. The ionization chamber is, of course, now positioned in front of the copper phantom in the cine imaging system for the measurement of HVT. The ionization chamber and its associated electronic reader should be capable of accurately measuring exposure rates as high as 10 R/min or an accumulated exposure as high as 10 R per measurement. There should be a distance of approximately 10 cm between the ionization chamber and the copper phantom to reduce the back scatter from the phantom. A copper phantom of 2.4 mm is placed at the image intensifier as specified previously. However, it is not necessary to remove the anti-scatter grid.

When the fluoroscopic automatic brightness stabilization (ABS) circuitry of the cine imaging system cannot be overriden, a modified approach is necessary in order to maintain the x-ray tube potential as the aluminum filter is introduced into the primary beam. This can be accomplished by replacing 0.4-0.6 mm of the copper filters with approximately 5.0 mm of aluminum.

The aluminum filters should be the same size as that of copper. Proceed to initiate a fluoroscopic exposure, and compare the fluoroscopic technique factors with that of the IIIES measurement. Reduce or increase the aluminum filter thickness until the desired x-ray tube potential or 80 kVp is obtained. Once this is accomplished the HVT measurement can be carried cut employing the following procedure.

(1) Record the radiation exposure rate, the geometry and the combined aluminum/copper phantom (including the total thickness of each absorber).

(2) Take one 1.0 mm aluminum filter from the combined aluminum/copper phantom, and insert the aluminum filter between the x-ray tube and the ionization chamber. The aluminum filter can be conveniently attached to the collimator face with adhesive tape.

(3) Record the radiation exposure rate as I.0 mm aluminum attenuation data. The fluoroscopic technique factors should remain the same, since the total attenuation of the radiation to the image intensifier is not significantly altered by the re-location of the aluminum filter.

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(4) Repeat the above steps until sufficient data are obtained to determine the HVT.

VII. ESTIMATION OF PATIENT AND PERSONNEL EXPOSURES

The radiation exposures (or exposure rates) receivable by the patient and the personnel can be measured by actual monitoring utilizing film badges (not practical for patients) or thermoluminescent dosimeter (TLD) chips taped onto the patient, the physicians, and other personnel. Exposure measurements utilizing TLD chips, for instance, can then be conducted while the catheterization procedure is in progress[6,7]. However, in general, radiation exposure levels are sought afterwards and can only be estimated.

When necessary, an approximate estimate of patient exposure can be obtained from the IIIES and the FIERS by assuming that the patient attenuates the primary beam by a kVp-dependent factor of approximately l/200 to l/1000. Corrections must then be applied to take into account the difference in distances, the number of cine frames, and the fluoroscopy time.

The personnel exposure can be estimated by the application of similar assumptions, viz: the scattered radiation exposure at 1 m from the patient is modified by the angular dependent factor and therefore is approximately l/200 to l/l000 of the patient exposure[9]. The accuracy of such an approach is only acceptable to obtain a rough estimate in the absence of accurate data.

A more practical and accurate estimate can be achieved by conducting radiation exposure measurements under a typical catheterization condition. A suggested method for accomplishing this task is described below.

VII-A. Instrumentation

The instrumentation required for the measurement of patient exposure is similar to that required for the IIIES measurement. Some differences exist, however, they are: (1) the ionization chamber and its associated electronic reader must now be capable of accurately measuring exposure rates as high as 600 R/min or an accumulated exposure as high as 150 R per cine run, (2) the anti-scatter grid is installed (not removed), and (3) the copper absorber is replaced by a water phantom or plastic phantom. For personnel exposure measurements, a survey meter type ionization chamber with 100 cm^2 or greater active area is required. Its energy response and calibration should be similar to the ionization

chamber employed for IIIES measurement. The sensitivity of the survey meter should be capable of measuring exposure rates ranging from 0.1 mR/hr to 10 R/hr.

VII-B. Preparation

In order to simulate the clinical examination conditions, a number of physical factors must be reproduced. They are:

   (1) Image Intensifier Mode, i.e. 15 cm (6") or 23 cm (9") mode.

   (2) X-ray tube potential for an average patient.

   (3) X-ray tube current, pulse width.

   (4) The focal spot size.

   (5) Cine filming rate employed.

   (6) Geometry of the examination.

   (7) Location of personnel in the room.

VII-C. Phantom

Unlike the absorber (or, phantom) employed in the IIIES protocol, the phantom utilized in the patient and personnel radiation exposure measurements must yield a radiation pattern similar to the actual clinical situation. Therefore, the phantom should be made of water, plastic (i.e., Plexiglas), or other tissue approximating material.

A phantom consisted of several pieces of plastic plates 35 cm x 35 cm x 2.54 cm (14" x 14" x 1") is suitable. A total of 20 cm (8") thickness closely simulates an average size patient.

VII-D. Measurement Procedure

The cine fluorographic imaging chain is set up similar to that of a typical catheterization examination. The scattering phantom (20 cm thick, or 8") is placed and positioned on the examination table in the middle of the primary beam. The ionization chamber for patient exposure measurement is positioned on the x-ray tube side of the phantom.

For personnel exposure measurement, one can position the survey meter type ionization chamber at the location where the operator stands, or other desired locations. At

each location where the radiation exposure measurement is desired, a minimum of five measurements should be conducted, namely, at five distances from the floor: (a) eye/thyroid level, (b) chest level, (c) abdominal / gonads level, (d) knee level, and (e) ankle level.

The contributions to the different radiation exposures from fluoroscopy and the cine fluorography are measured with the ionization chamber underneath the phantom and with the survey meter positioned at the different personnel locations. The same measurement arrangement is employed for the fluoroscopy and cine fluorography. The exposure time for both measurements must be sufficiently long to allow for the ionization chamber/electrometer system to stabilize (approximately 4 sec.).

VIII. MEASUREMENT EXAMPLES

In accordance with the description and protocols, a set of sample measurements is presented. The technical and physical factors are listed in Tables II, and III [Table II for cine fluorography and Table III for fluoroscopy], and the measurement results in Tables IV, V, and VI. The cine imaging equipment employed for these measurements had a U-arm type configuration similar to the equipment used in Figure 4, and was calibrated and optimized by the field service engineers a few days prior to the measurements. The image quality of clinical studies for fluoroscopy and cine fluorography was acceptable to the cardiologists. The results of this particular cine fluoroscopic imaging system for IIIES, FIERS, and HVT are listed in Table IV. The acceptable range of each parameter is also listed in Table IV for comparison[10,11]. It is noteworthy to point out that the input phosphor material of the image intensifier was CsI and had A high quantum detection efficiency (QDE).

TABLE II. LIST OF PARAMETERS EMPLOYED IN
THE EVALUATION OF CINE SYSTEMS

Item	Physical Parameters	Measured Values
(a)	X-ray Tube Potential	78 kVp*, 82 kVp**
(b)	X-ray Tube Current	240 mA*, 360 mA**
(c)	Cine Pulse Width	3.2 msec
(d)	Cine Filming Rate	60 frames/sec
(e)	Focal Spot Size (Power Rating)	1.2 mm 100 kW
(f)	Cine Run Time	12 seconds
(g)	Image Intensifier	9" (23 cm) 6" (15 cm)
(h)	Cine Film Size	35 mm
(i)	Radiation Field Size	18 cm x 18 cm* 10 cm x 10 cm**
(j)	Phantom Thickness For Scattered Radiation:	2.6 mm Copper, or 20 cm Plexiglas
(k)	SID+	100 cm
(l)	TID++	25 cm

* For 9" (23 cm) mode, ** For 6" (15 cm) mode
+ Source-to-Image Receptor Distance
++ Tabletop-to-Image Receptor Distance

TABLE III. LIST OF PARAMETERS EMPLOYED IN
THE EVALUATION OF FLUOROSCOPIC OPERATION

Item	Physical Parameters	Measured Values
(a)	X-ray Tube Potential	85 - 98 kVp
(b)	X-ray Tube Current	2 - 3 mA
(c)	Image Intensifier	9" (23 cm) 6" (15 cm)
(d)	Radiation Field Size	18 cm x 18 cm* 10 cm x 10 cm**
(e)	Phantom Thickness For Scattered Radiation:	2.6 mm Copper, or 20 cm Plexiglas
(f)	SID+	100 cm
(g)	TID++	25 cm

* For 9" (23 cm) mode, ** For 6" (15 cm) mode
+ Source-to-Image Receptor Distance
++ Tabletop-to-Image Receptor Distance

Table IV. MEASUREMENT RESULTS

Physical Parameters		Measured Values	Acceptable Range
IIIEF (uR/frame)	9" mode	12	8 - 16[+], 10-20[++]
	6" mode	20	15 - 30[+], 20-40[++]
FIERS (uR/sec)	9" mode	35*	25 - 50*
		80**	50 - 100**
	6" mode	80*	60 - 100*
		155**	120 - 180**
HVT (mm Al.)	9" mode	3.10	2.5 - 4.0[+++]
	6" mode	3.33	2.5 - 4.0[+++]

* Low level exposure rate operation.
** High level exposure rate operation.
+ High QPE systems.
++ See References 10 and 11.
+++ Values shown are for 80 kVp (Empirical).

Table V. ESTIMATED PATIENT EXPOSURE

Image Intensifier Mode		6" (15cm)	9" (23 cm)
Fluoroscopy (R/min)	Low Level	3.2	2.4
	High Level	4.8	3.5
Cine (mR/frame)		12	20

Note : Actual patient exposure can be estimated using these values, the total fluoroscopic "ON" time, and the total number of cine frames.

Personnel exposure measurements conducted for various cine systems have shown a real possibility of delivering excessive amounts of radiation to the physicians and other personnel in the cardiac catheterization laboratories[12,13,&14]. Table VI shows an example of the benefit of using lead protective devices during catheterization procedures. The locations A, B, and C correspond to that of a physician, his/her assistant, and a nurse, respectively. Their relative geometrical relationship with respect to the cine imaging system and the examination table is depicted in Figure 6.

Table VI.   PERSONNEL EXPOSURE RATES

Height or Level		Location		
		A	B	C
		(mR/hr; while beam is "ON")		
Eye	Fluoroscopy*	12.2	5.0	M
	Fluoroscopy**	1.0	1.5	M
	Cine*	183.6	102.4	10.3
	Cine**	14.5	18.7	M
Chest	Fluoroscopy*	25.5	5.3	M
	Fluoroscopy**	1.0	2.0	M
	Cine*	352.9	115.2	8.3
	Cine**	15.4	20.1	M
Abdomen	Fluoroscopy*	22.2	7.3	M
	Fluoroscopy**	M	M	M
	Cine*	402.3	172.7	5.2
	Cine**	11.2	9.5	M
Knee	Fluoroscopy*	7.4	3.2	M
	Fluoroscopy**	1.0	M	M
	Cine*	162.6	74.3	18.5
	Cine**	10.9	8.6	M
Ankle	Fluoroscopy*	47.5	26.8	3.0
	Fluoroscopy**	M	M	M
	Cine*	684.0	425.1	30.5
	Cine**	10.5	10.1	M

 * No special lead protective devices were installed
   on the examination table.
** With lead protective devices (0.25 mm Pb Equ.)
   specially designed for this particular cine system.
"M" minimal or not measurable.
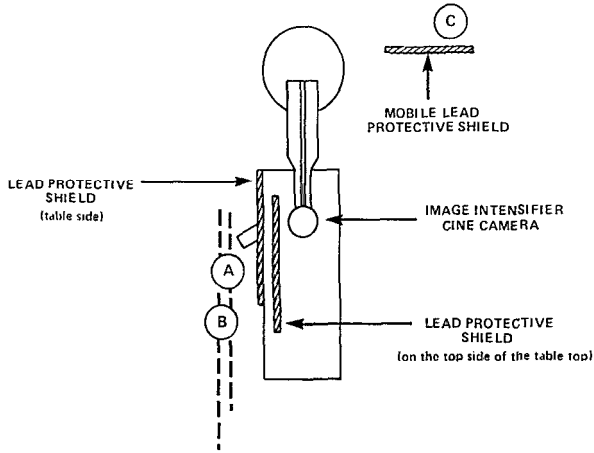
(A) Physician, 70 cm from Phantom.
(B) Assistant, 100 cm from Phantom.
(C) Others, 180-200 cm from Phantom.

Figure 6. Plane View of Cine Fluorographic
System Equipment Layout and Personnel Locations
Utilized for Radiation Exposure Estimates.

IX. CONCLUSION

     The   radiation   exposure   levels in   cardiac
catheterization   laboratories   are   addressed in this
report. Physical parameters important to the evaluation
of cine systems have been described and defined, and
procedures   are presented for their measurement. Of
these, the image intensifier input exposure sensitivity
(IIIES), and the fluoroscopic input exposure rate
sensitivity (FIERS) are the most important factors.
     Typical patient and the personnel exposure levels

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are presented for reference and comparison purposes. The relationships between IIIES, FIERS, patient exposure and personnel exposure are system dependent and physicists should measure these relationships as necessary. It is the intent of the task force that this report offer some guidance, and be utilized by practicing radiological physicists to assist in the evaluation of a cardiac catheterization laboratory when the need arises.

The procedure described can be modified to account for various equipment configurations and operations under different clinical arrangements such as (1) single plane angled view using a cradletop, (2) bi-plane cine systems, and (3) lateral cine fluorography utilizing either a single plane or a bi-plane system.

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