Beth Israel Deaconess Medical center

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Technical Advances of Fluoroscopy with Special Interests in Automatic Dose Rate Control (ADRC) Logic of Cardiovascular Angiography Systems

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PART I.

Review of Basic Automatic Brightness Controlled Fluoroscopy Systems.

And

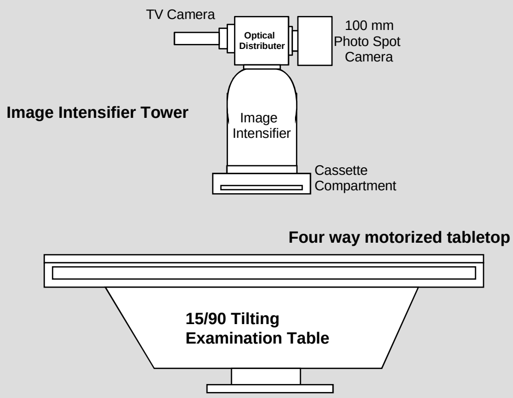
Some historical overview.

Review of Fluoroscopy Equipment

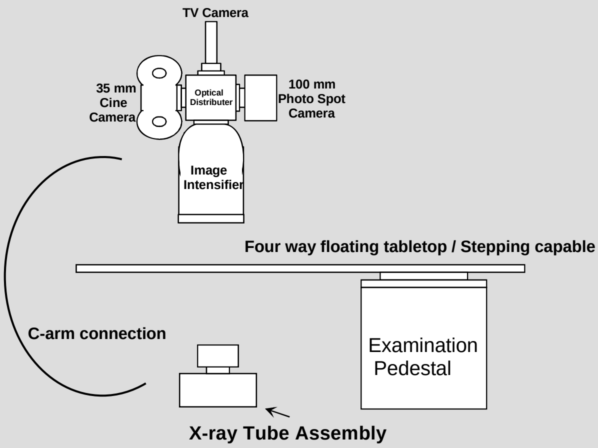
1) Conventional Fluoroscopy Unit
2) Special Procedures Fluoroscopy Unit
   a) Extension of conventional fluoroscopy.
   b) Pedestal Type examination table fluoroscopy and over-head hanger synchronized lateral plane.
3) Fluoroscopy Systems with Positioners for
   a) Cardiac Catheterization.
   b) Neuro Angiography.
   c) Visceral Angiography.
   d) Electrophysiology Laboratory.

The "Legacy" Fluoroscopy

1) Compartment for full size cassettes,
2) Either Conventional or Pedestal type examination table,
3) Image Intensifier,
   a) Input Phosphor, and Output Phosphor.
   b) Image intensifier is an Electron Optical Device.
   c) Optical Distributor mounted on I.I. to accommodate Cameras, i.e.;
      - Photospot (photofluorographic) Camera,
      - Cine (cinematographic) Camera, and
      - Closed Circuit Television Camera

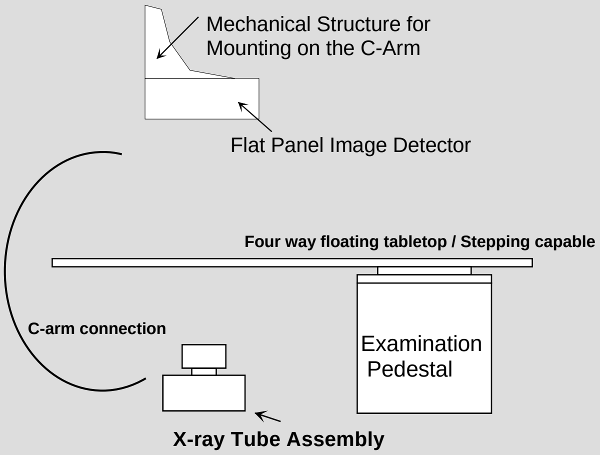


Typical Upper and Lower GI Fluoroscopy Equipment .



Up to this point may be considered "Legacy Fluoroscopy" Equipment.

- Irrespective of the geometrical configuration, the fluoroscopy is equipped with "Automatic Brightness Control" (ABC) circuit.
- The TV chain is equipped with "Automatic Gain Control" (AGC).
- The primary imaging parameter may be "tube potential", "tube current", or "pulse width" for pulsed fluoroscopy.



Internal Structure of Image Intensifier

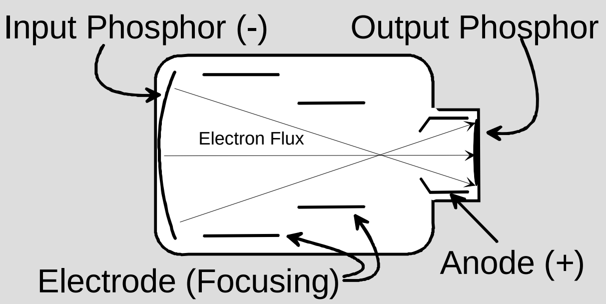
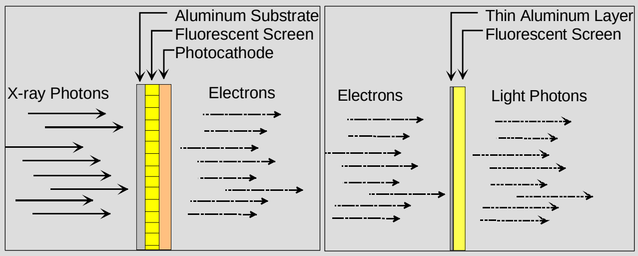


Image Intensifier Tube

Input Phosphor Output Phosphor



(a) Fluorescent screens are made of Cesium Iodide (CsI) which has a higher absorption of X-rays than the older silver-activated zinc-cadmium sulfide.

(b) Photocathode is a photoemissive metal; a combination of antimony and cesium.

"Gains" of Image Intensifier

$$\text{Brightness Gain} = \frac{\text{Intensifier Luminance}}{\text{Patterson B-2 Luminance}}$$

$$\text{Conversion Factor} = \frac{\text{Luminance (cd/m}^2\text{)}}{\text{Radiation Input (mR/sec)}}$$

$$\text{Minification Gain} = \left(\frac{\text{Input Phosphor}}{\text{Output Phosphor}}\right)^2$$

Flux Gain: Electrons are accelerated (~30kV)
Typical flux gain values; 50~60

Total Brightness Gain of Image Intensified Flurocopy System

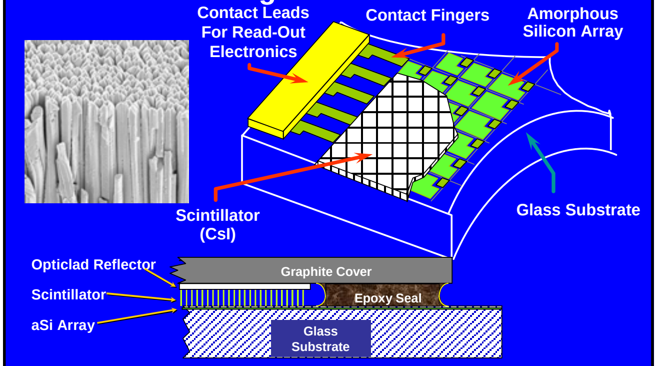
For a 9" mode image intensifier with 1" output phosphor, the minification gain is (9/1)X(9/1)=81.

The Flux gain is approximately ~50.

Therefore, the total brightness gain is = 81 X 50 = 4050.

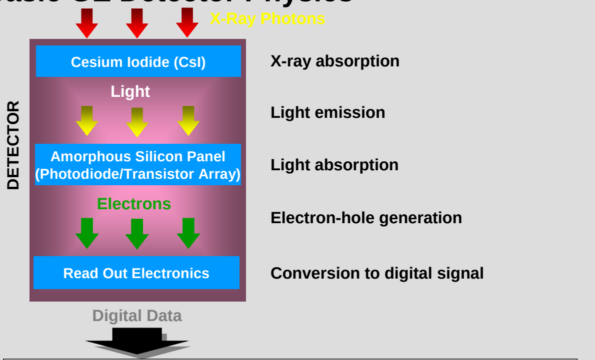
- The flat panel image detector technology as a whole (at a minimum) will have to; (1) have a similar electronic gain in order to maintain the input sensitivity enjoyed by the image intensifier television chain, (2) hence, a comparable input sensitivity to maintain the same patient exposure.

GE Detector Design



Courtesy of General Electric Heath Care Systems, Inc.

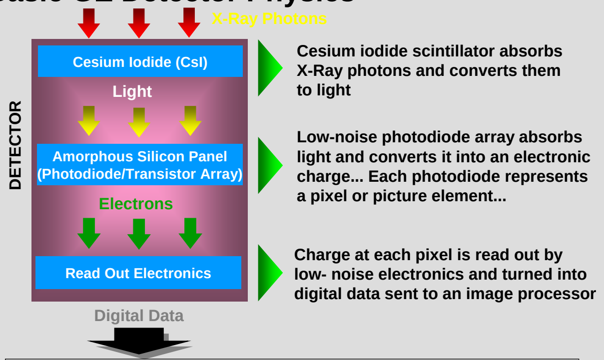
Basic GE Detector Physics



IQ, fast readout, low noise, no significant image retention

Courtesy of General Electric Health Care Systems, Inc.

Basic GE Detector Physics



IQ, fast readout, low noise, no significant image retention

Courtesy of General Electric Health Care Systems, Inc.

Automatic Brightness Control

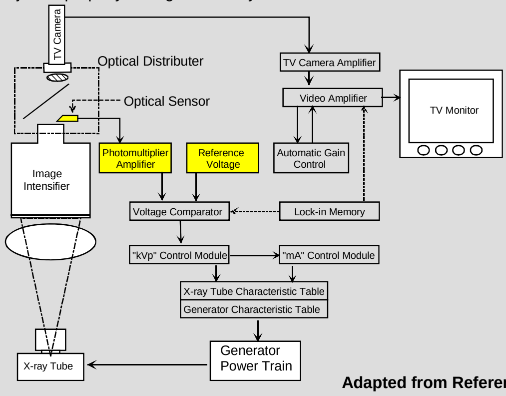
- There are there primary imaging parameters that may be employed to drive the ABC circuit, namely;

1) The tube potential “kVp”,
2) The tube current “mA”, or
3) The exposure time, more accurately; “pulse width” for a pulsed fluoroscopy system.

- System (3), “Exposure Time system” is similar to the radiographic automatic exposure control (AEC), it “phototimes” each fluorscopic pulse.
- Usually, the tube potential and tube current are manually selected.
- This method of brightness control has long been retired, and will not be discussed further.

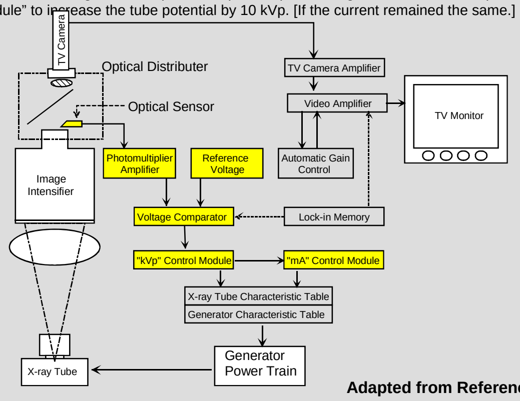
kVp-primary ABC Circuit

Let us go through the operation logic of a “kVp-primary” fluoroscopic ABC, as the one shown here in this slide. (a) Suppose, the x-ray tube potential and current are adjusted properly for a given steady situation.



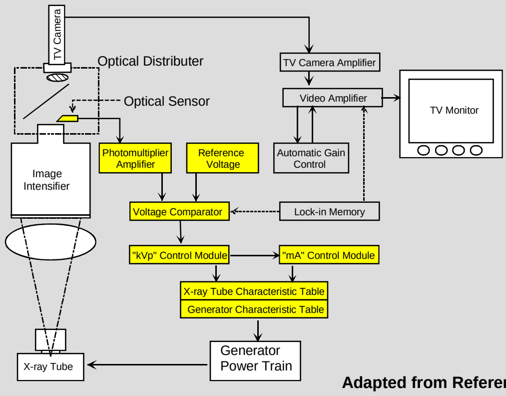
Adapted from Reference #1

(b) Assume that a patient has swallowed a large amount of barium meal. Therefore, a sudden increase in x-ray absorption had occurred. (c) The voltage comparator detects that a decrease in voltage from the photomultiplier amplifier. A signal is sent to the “kVp-control Module” to increase the tube potential by 10 kVp. [If the current remained the same.]



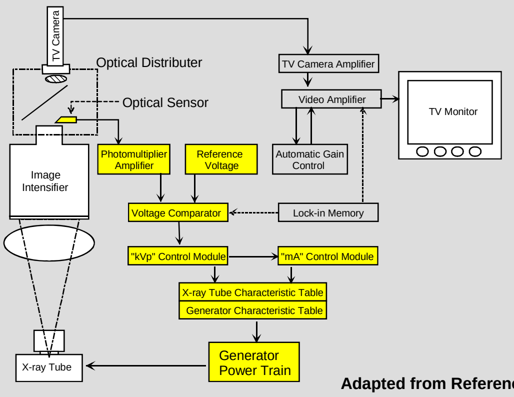
Adapted from Reference #1

(d) The “mA-control module” receives a signal from the “kVp-control Module”, and will increase the tube current in accordance to a preprogrammed value based on the **“fluoroscopy loading curve”.** (e) As the x-ray tube current rises, the required increase in tube potential is reduced to perhaps 5 kVp, rather than 10 kVp.



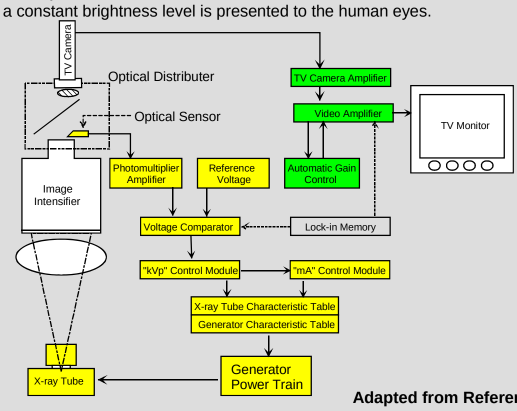
Adapted from Reference #1

(f) A newly established steady state is then presented to the output phosphor of the image intensifier with a constant brightness again. (g) This whole process may take somewhere around 1 to 2 seconds.



Adapted from Reference #1

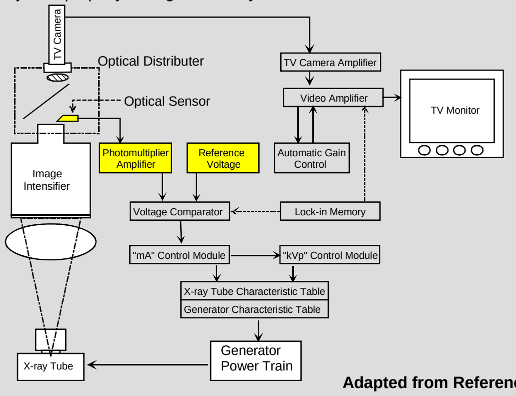
(h) During this transition time, the TV monitor image brightness is maintained to a constant by the Automatic Gain Control in the video chain. The reaction time of the AGC is approximately 40~60 mSec. This short reaction time of the AGC circuit essentially ensures a constant brightness level is presented to the human eyes.



Adapted from Reference #1

mA-primary ABC Circuit

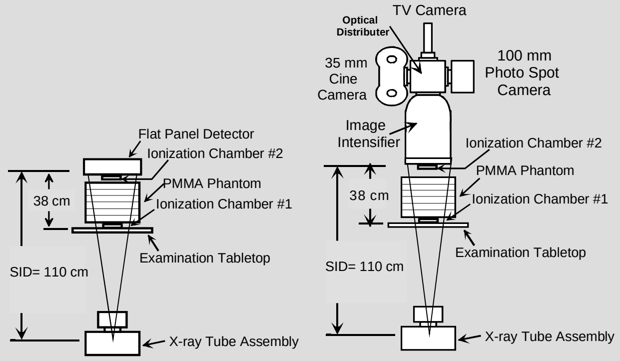
Let us go through the operation logic of a "mA-primary" fluoroscopic ABC, as the one shown here in this slide. (a) Suppose, the x-ray tube potential and current are adjusted properly for a given steady situation.

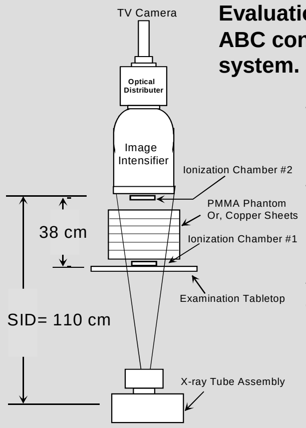


Adapted from Reference #1

- A few slides ago, it was mentioned that the "mA-control module" receives a signal from the "kVp-control Module", and will increase the tube current in accordance to a preprogrammed value based on the **"fluoroscopy loading curve"**.
- The fluoroscopy loading curve is at the heart of the ABC, and verification and/or evaluation of fluoroscopy ABC logic can be obtained through a simple experimental setup.

Irrespective of the image receptor system, i.e., whether the image receptor is an image intensifier or a flat panel image detector, the subject of discussion does not change. The primary theme of this presentation is on the Automatic Brightness Control, or the updated version, called Automatic Dose Rate Control (ADRC) Logic which is available and installed on either of these image receptors.



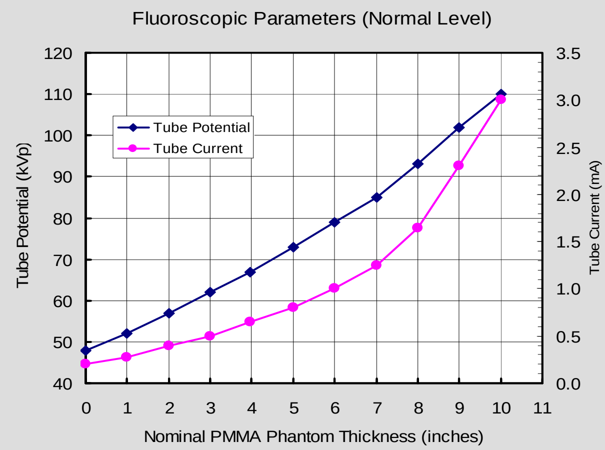


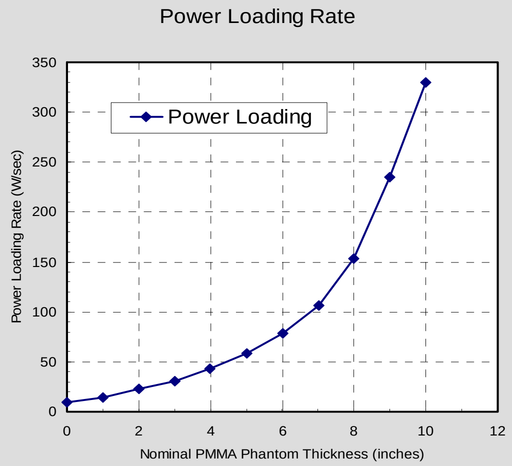
Evaluation of the characteristics of an ABC controlled "legacy" fluoroscopy system.

The geometry of experimental arrangement Is not critical as long as "clinical" situation Is simulated.

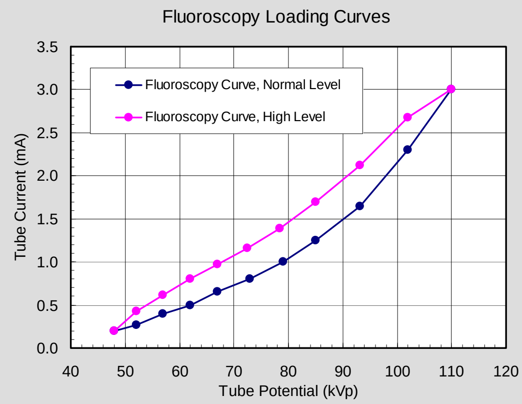
The phantom material may have been (1) aluminum, (2) copper, and (3) PMMA Plastic. Pressed wood had also been Employed without consistent results.

The accuracy of the fluoroscopic "kVp" & "mA" should be assessed with appropriate measurement devices so that the "power Loading" can be correctly calculated.

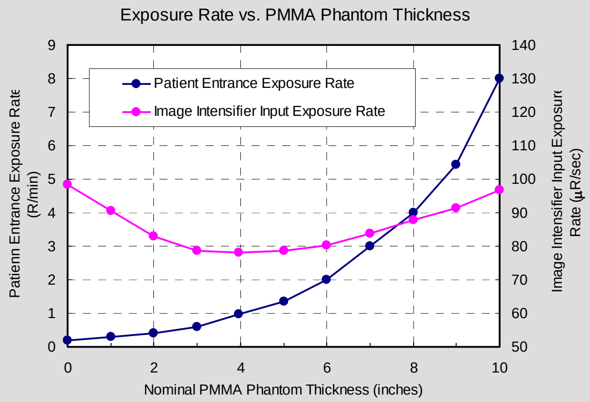




These two fluoroscopy loading curves can be compared to verify the system operation against the manufacturer supplied Technical Data Sheets.



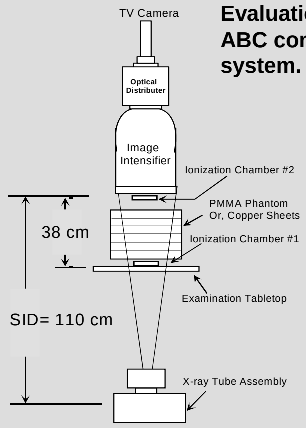
The image intensifier input exposure rate (air kerma rate) beyond the 10" phantom thickness will starts to fall down due to the ABC Logic that limits generator to 110 kVp/3.0 mA



PART II.
Evaluation of ABC Logic

- Let us conduct the same test on a typical "Upper/Lower GI" Study fluoroscopy system (Philips Eleva System).
- With Phantom Materials of; Copper and Aluminum.
- Compare the data to find out what thickness aluminum is equivalent to what thickness of copper.

- The Philips Eleva System evaluated in this study was equipped with the following features;
  1) Image Intensifier Format: Tri mode I.I.
     a) 17/25/31 cm active phosphor sizes. (3)
  2) Fluoroscopy Operation:
     a) Continuous Fluoroscopy Mode. (2)
     b) Pulsed Fluoroscopy Mode. (2)
     c) Low Dose Level & High Dose Level Modes. (2)
  3) Anti-scatter Grid may be removed.(2)
- The permutation of available modes under fluoroscopic operation configuration ~ 48
- Not all available modes of combination were evaluated.



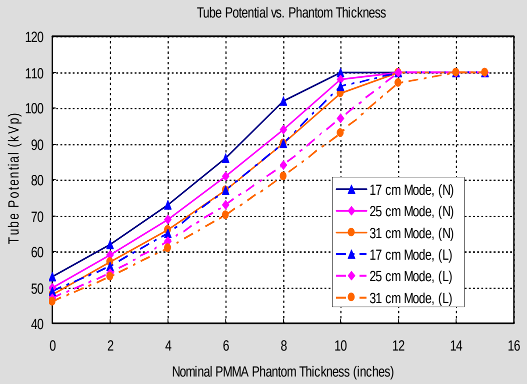
Evaluation of the characteristics of an ABC controlled "legacy" fluoroscopy system.

The geometry of experimental arrangement Is not critical as long as "clinical" situation Is simulated.

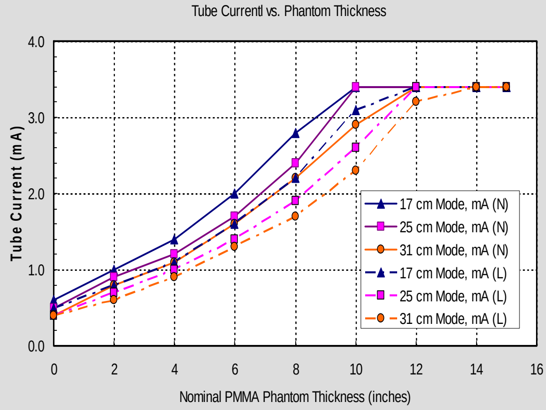
The phantom material may have been (1) aluminum, (2) copper, and (3) PMMA Plastic. Pressed wood had also been Employed without consistent results.

The accuracy of the fluoroscopic "kVp" & "mA" should be assessed with appropriate measurement devices so that the "power Loading" can be correctly calculated.

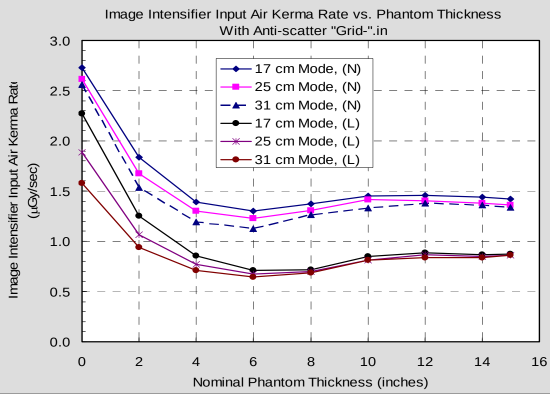
These graphs show that (1) the "Low Level" modes employ lower "kVp" than the "Normal Level" modes. And, the larger the active phosphor size employs lower "kVp" than smaller active phosphor sizes, (2) at the same time the larger active phosphor size with "Lower Level" fluoroscopy has a wider dynamic range in coverring the patient (phantom) thickness.



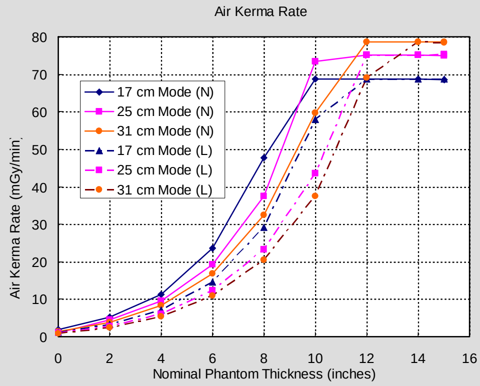
The x-ray current graphs show similar trends as that of the previous slide on "kVp".

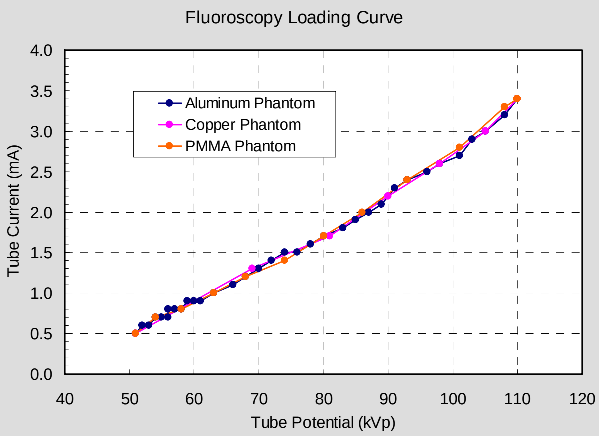


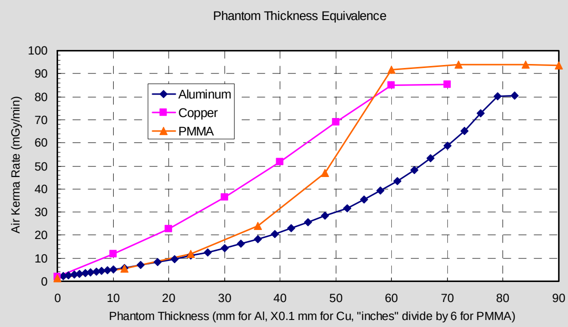
Low level IIIAKR is approximately 0.7~0.75 µGy/sec, and the Normal level IIIAKR is 1.1 µGy/sec for the 31 cm active phosphor size, and 1.25 microGy/sec, and 1.35 µGy/sec for the 25 cm and 17 cm active phosphor sizes, respectively.



The "Air Kerma Rate" graphs show and confirm the same trends described in previous slides. Essentially, this fluoroscopy system is able to penetrate 10" to 14" of PMMA equivalent patient thickness depending on the mode of operation. This is typical of fluoroscopy systems employed for upper/lower GI studies.



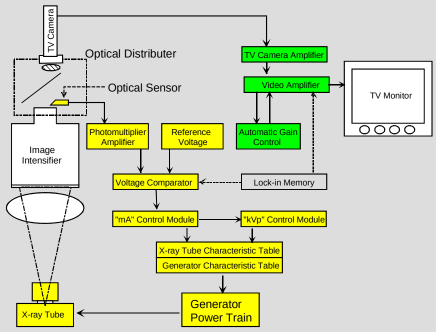




Thickness Equivalence (Philips Eleva System)

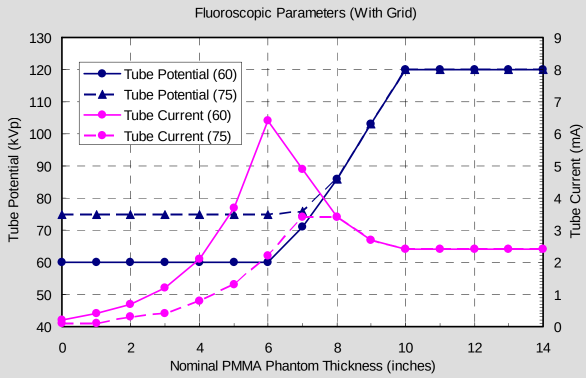
Air Kerma Rate (mGy/min)	Copper (mm)	Aluminum (mm)	Aluminum (inches)	PMMA (inches)
10	0.8	19	3/4	3.67 [3-3/4]
20	1.6	38	1-1/2	5-1/2
40	3.2	58	2-1/4	7.3 [7-1/2]
80	5.6	76	3	9.3 [9-1/2]

"mA-primary" ABC Logic

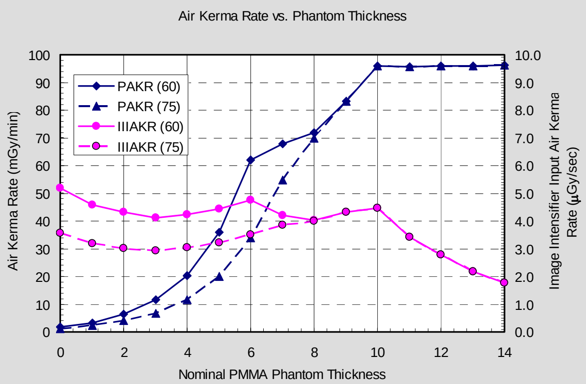


- A GE Advantx fluoroscopy system is equipped with the "mA-primary" ABC Logic.
- The tube potential may be pre-selected, and defaulted to 75 kVp for fluoroscopy operation. This is the minimum "kVp" unless the "kVp" is manually selected at a lower value.
- The tube potential is increased by a preset value (5, or 10 kVp) when the Patient Air Kerma Rate approaches the regulatory limitation.
- The system is calibrated to work at a given "kVp" while the "mA" is varied in accordance to the attenuation the optical sensor "sees".

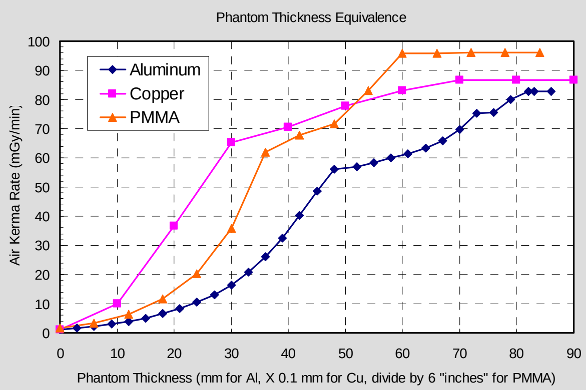
The same set of data obtained on the Philips System is also obtained. This slide shows the Tube Potential and Tube Current as functions of the PMMA Phantom Thickness. NOTE: the default "kVp" values for the 60 kVp, and the 75 kVp are represented here.



Note: This is a 10 year old system and the IIIAKR has been increased to account for the decreased image intensifier efficiency. At the 6" of phantom thickness, there is a singular point that corresponds to a jump in Tube Potential.

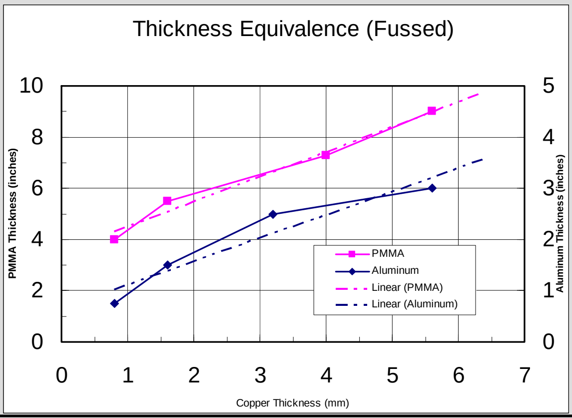


The phantom thickness equivalence graphs are charted on this slide. The points of discontinuity correspond to the phantom thickness that triggered the generator to increase the tube potential.



	Philip Eleva		GE Advantx		Philip Eleva	GE Advantx
Cu (mm)	Al (mm)	Al (inches)	Al (mm)	Al (inches)	PMMA (inches)	
0.8	19	0.75	22	0.87	3.65	2.5
1.6	38	1.5	36	1.42	5.5	4.3
3.2	58	2.25	68	2.7	7.3	7.3
5.6	76	3	82	3.2	9.3	9

This chart may be used to convert the phantom thickness from one material to another, amongst copper, aluminum, and PMMA plastic.



PART III.
The ADRC; new generation of ABC

- Application of filters using aluminum, copper and high atomic number elements for patient exposure reduction had been studied for use in radiographic examinations.
- On the other hand, the introduction of copper filters for spectral shaping during fluoroscopic imaging procedures had been available for the past decade,
- However, extensive application of spectral shaping filters started in its earnest as the interventional angiography procedures become widely practiced in the US in the early 1990s.
- Use of spectral shaping filters contributed to minimize the patient (skin entrance exposure) air kerma dramatically while the image quality is optimized and maintained.

Excerpt from Reference #2

New Generation of Cardiovascular Fluoroscopy Systems are equipped with;

1) High Frequency Inverter Type Generator
   a) Precise switching time (1 msec)
   b) Better Pulse Shape (less over/under shoot)
2) Spectral Shaping Filters
   a) 0.2 ~ 0.9 mm copper (beam hardening)
   b) On a rotating wheel in collimator assembly (interchangeable filters during fluoroscopy)
3) High Heat Capacity X-ray Tube
   a) High Anode Heat Capacity (2 MHU)
   b) High X-ray Tube Housing Heat Capacity (3 MHU)
   c) To counter attenuation by spectral shaping filter

Automatic Dose Rate Control (ADRC) Logic

(a) A sophisticated software programming to control the copper filter thickness in response to x-ray attenuation.

(b) The ADRC is designed to control various imaging parameters including; (1) focal spot size, (2) kVp, (3) mA, (4) pulse width, etc. during fluoroscopy.

(c) The heavy copper filter preferentially removed low energy photons and the mean x-ray beam energy is, thus, increased.

(d) For the same applied tube potential this would require a higher "tube current" to produce an acceptable image quality. --- Hence, a "high power" x-ray tube is required.

Automatic Dose Rate Control (ADRC) Logic

(a) The fluoroscopy system employed is a Siemens Bi-plane angiography system AXIOM Artis dBA.

(b) Operated under 22 cm flat panel image receptor mode. [It is a 48 cm flat panel.]

(c) Pulsed fluoroscopy rate @ 15 pulses/sec.

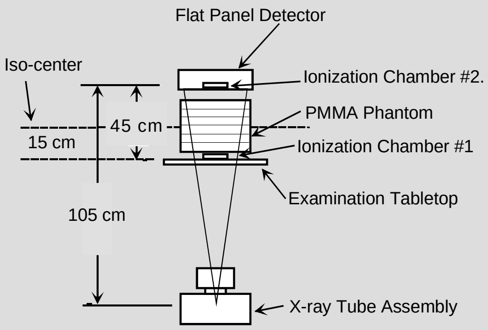
(d) Fluoroscopy curve name: 80kV10RAF2kW

(e) Equipped with spectral shaping filters of; 0.2, 03, 0.6, and 0.9 mm of copper.

(f) The small focal spot (0.6 mm) is the default.

(g) SID = 105 cm, Source-to-chamber #1 = 60 cm.

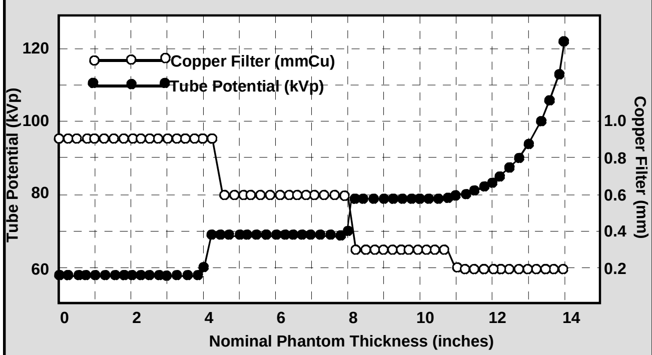
Evaluation of the Automatic Dose Rate Control (ADRC) Logic



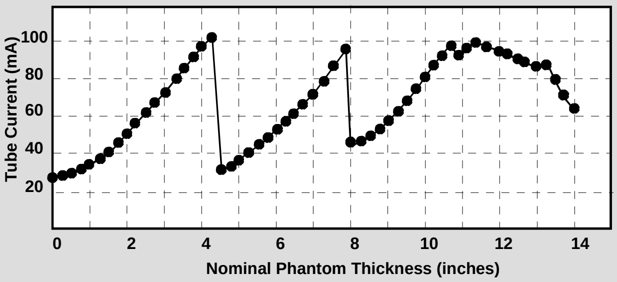
Geometrical Arrangement

Adapted from Reference #2

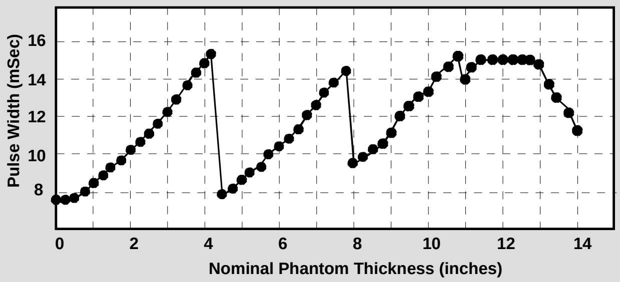
Tube Potential (kVp) and Filter Thickness (mmCu) vs. PMMA Thickness (inches)

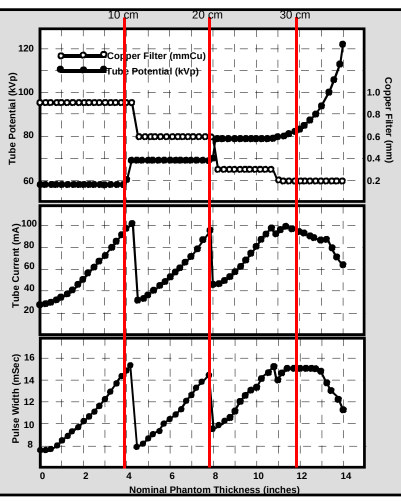


Tube Current (mA) vs. PMMA Thickness (inches)



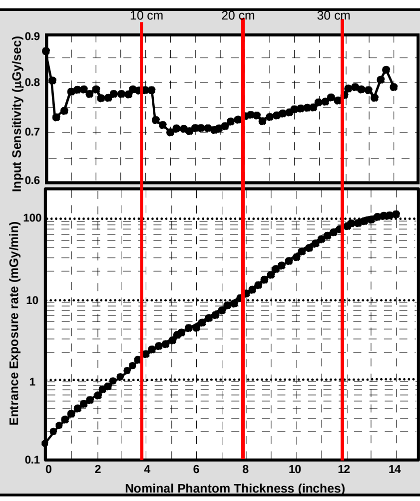
Pulse Width (mSec) vs. PMMA Thickness (inches)





Input Sensitivity in front of the Flat Panel Image Detector

Patient Skin Dose (Air Kerma)

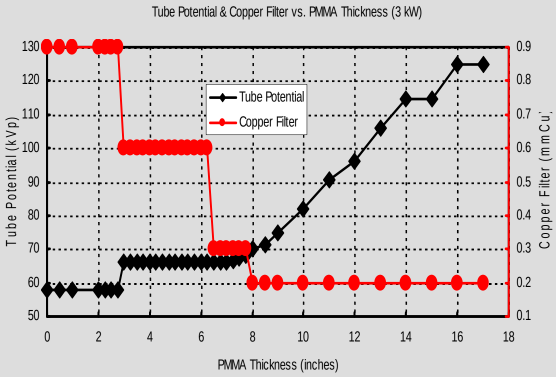


Why is it possible to have a “Better Image Quality” & “Lower Patient Dose” at the same time?

- Image quality is “better” because of consistently lower tube potential is employed---higher image contrast!
- Radiation dose to the patients, especially, small and average size patient, is significantly reduced due to the use of spectral shaping filters --- considerably amount of low energy portion of spectrum is removed before hitting the patient.

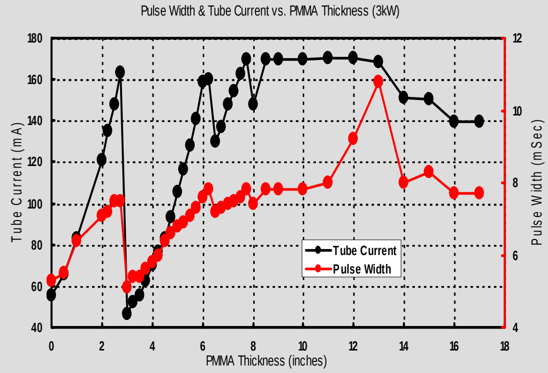
- There are many fluoroscopy curves designed by the manufacturers tailored to fit specific types of examination.
  - Some 256 fluoroscopy curves are available.
  - Cardiac vs. Neuro vs. Visceral angiography
  - For adults ? Or for pediatric patients?
- Needs to verify the preprogrammed fluoroscopy curves for the intended use of the system.
- Not only the acceptance testing of the hardware is necessary, but also evaluation of the software becomes increasingly important.

Fluoroscopy Curve 70kV10RAF3kW



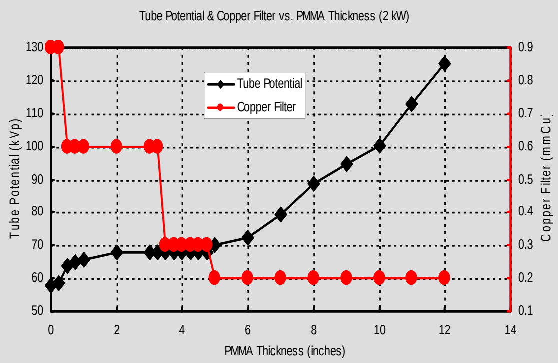
Data Source: AAPM TG 125

Fluoroscopy Curve 70kV10RAF3kW



Data Source: AAPM TG 125

Fluoroscopy Curve 70kV10RAF2kW



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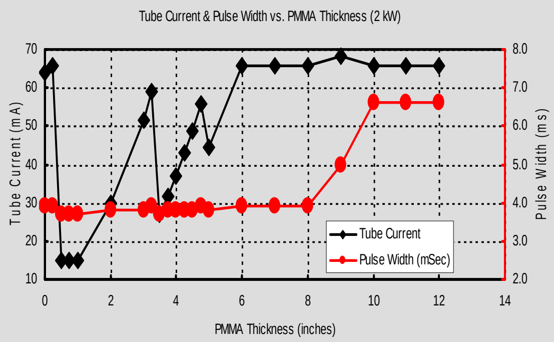
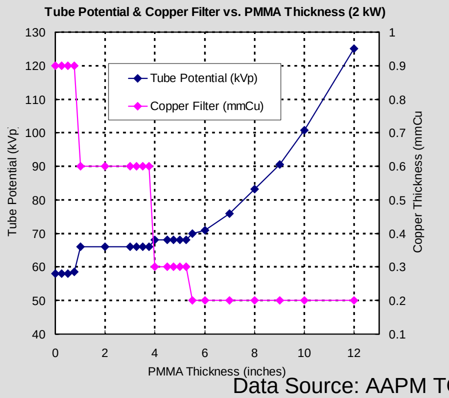
Fluoroscopy Curve 70kV10RAF2kW



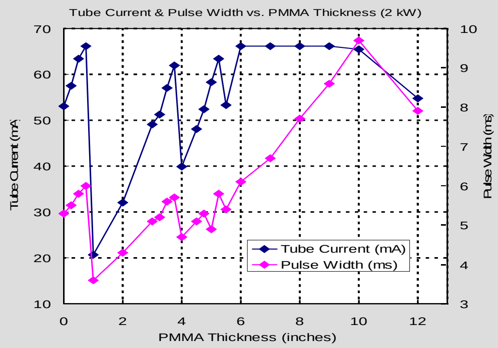
Data Source: AAPM TG 125

Fluoroscopy Curve 70kV10RAF2kW (Pediatric)



Data Source: AAPM TG 125

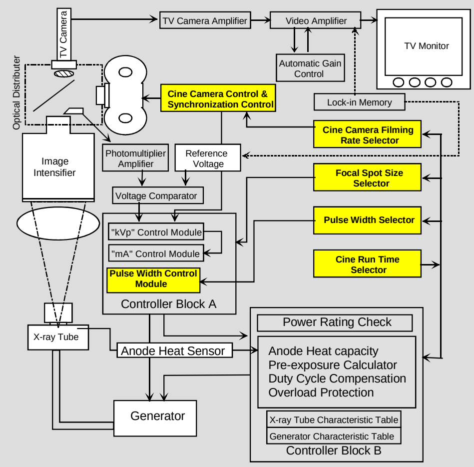
Fluoroscopy Curve 70kV10RAF2kW (Pediatric)



Data Source: AAPM TG 125

What's beyond the ADRC Logic?

- The fluoroscopy is employed to find the passage and manipulate the catheter and/or the guide wire to the point of interests.
- The mission of the ADRC for fluoroscopy may be accomplished but is just the starting point for the acquisition of diagnostic information.
- In other words, the "acquisition mode" of the examination, as opposed to the "fluoroscopic mode" lies ahead.



Comparison of Input Sensitivities

23/25 cm Image Intensifier Input Phosphor (Active) Size	Current Practice	Used To Be
Low Level Fluoroscopy	25 μR/sec	50 μR/sec
Normal Level Fluoroscopy	50 μR/sec	75-100 μR/sec
High Level Fluoroscopy	75 μR/sec	N/A
100 mm Photospot Camera	50-100 μR/frame	100-200 μR/frame
Digital Photofluorography	25-100 μR/frame	100 μR/frame
Digital Subtraction Angiography	100-500 μR/frame	500-1000 μR/fram
35 mm Cine Camera	10-20 μR/frame	15-30 μR/frame
Digital Cine Photofluorography	7-12 μR/frame	N/A

<u>Due primarily to the better image intensifier, television chain.</u>

Data Date: 2001

Comparison of Patient Exposure/Air Kerma Rate

23/25 cm Image Intensifier, Patient Exposure Rate	Current Practice	Used To Be
Low Level Fluoroscopy	> 1 R/min	3 R/min
Normal Level Fluoroscopy	3 R/min	6 R/min
High Level Fluoroscopy	5 R/min	N/A
100 mm Photospot Camera	100 mR/frame	200 mR/frame
Digital Photofluorography	75~100 mR/frame	200 mR/frame
Digital Subtraction Angiography	100~300 mR/frame	500 mR/frame
35 mm Cine Camera	30~80 R/min	70~160 R/min
Digital Cine Photofluorography	20~60 R/min	N/A

<u>Due primarily to the better image intensifier & television chain.</u>

Data Date: 2001

Photo: Courtesy of Siemens Medical Systems

References & Other Reading Material

1. PP Lin, “Acceptance testing of automatic exposure control systems and automatic brightness stabilized fluoroscopic equipment”, in *Quality Assurance in Diagnostic Radiology, AAPM Monograph No. 4*, New York: Am. Inst. Phys., pp 10-27 (1980)
2. PP Lin, “The operation logic of automatic dose control of fluoroscopy systems in conjunction with spectral shaping filters”, Med. Phys. Vol 34 no 8, pp 3169-3172 (2007)
3. PP Lin, “Cine and Photospot Cameras”, in *Encyclopedia of Medical Devices and Instrumentation*, John G. Webster Editor, John Wiley & Son, Publisher, 1st Edition, Vol. 2, pp 681-693 (1988)
4. AAPM TG 125 Home Page.

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