Optimizing dose and image quality in fluoroscopy

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Disclosure

- I am co-owner of Fluoroscopic Safety, LLC, a company that markets educational programs on the safe use of fluoroscopy

Educational objectives

- Identify targets for dose and image quality optimization in fluoroscopy
- Describe strategies for exploiting these targets
- Realize that dose optimization must be consider in the broader context of procedural goals

Optimize, not reduce

- We should always be speaking in terms of *optimizing* clinical procedures that are *justified*
- The use of “dose reduction” implies efforts to reduce dose without consideration of image quality
- Especially in fluoroscopy, attempting to reduce dose with a blind eye towards image quality can actually *increase* dose in the end

Targets for optimization

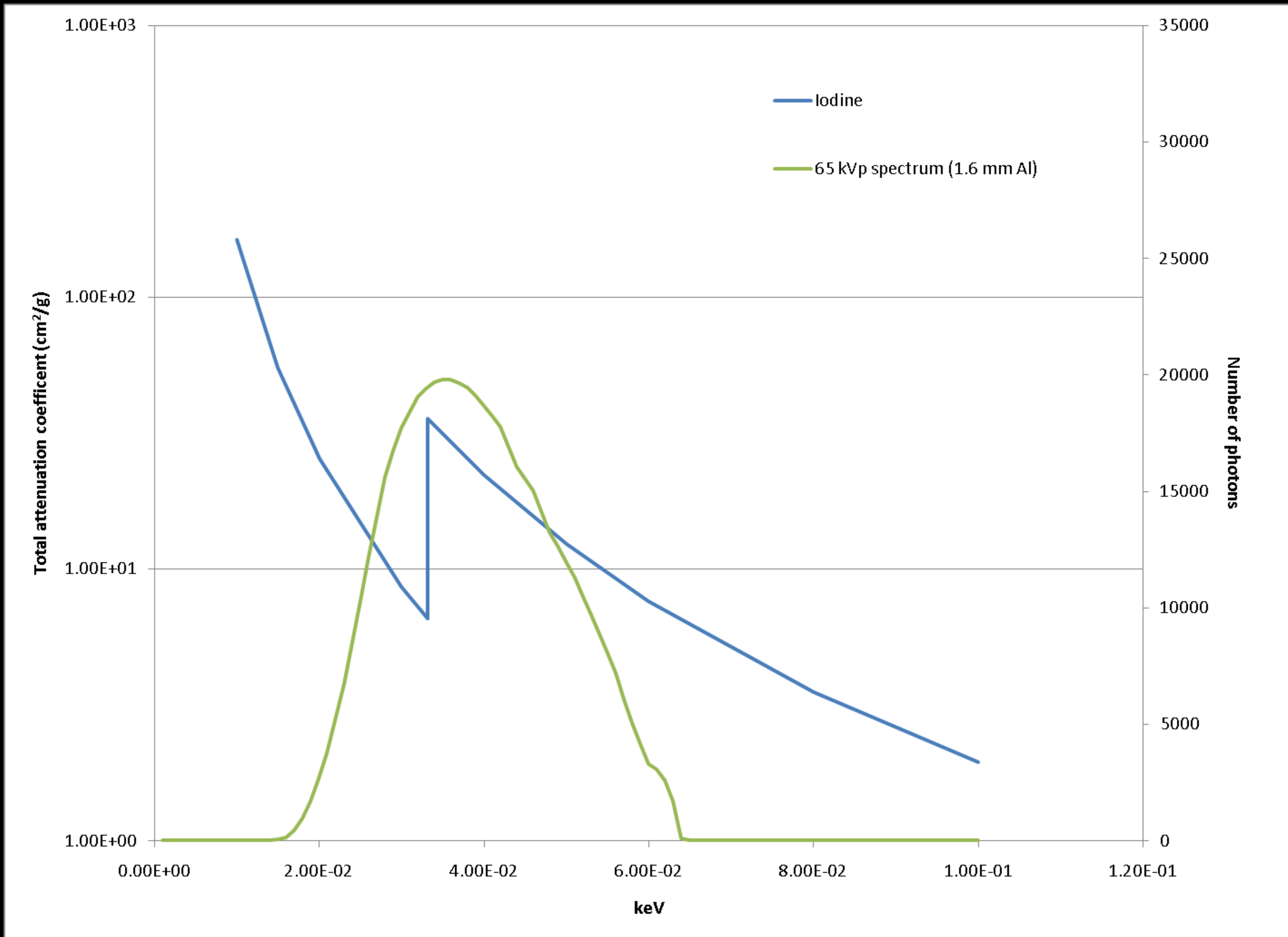
- Equipment configuration/calibration
- Practice/use of fluoroscopy
- Technology

EQUIPMENT CONFIGURATION AND CALIBRATION

Easy targets for optimization

- Minimum filtration
- Positioning without radiation configured to be enabled by default
- Configure desired organ program to be loaded by default
- Use of variable frame rate
- Mask averaging
- Choose the right equipment
- Use pulsed fluoroscopy and configure it to use the Aufrichtig scale

Scott Adams, www.dilbert.com



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1.00E+00
Total attenuation coefficent (cm2/g)
35000
30000
25000
20000
15000
10000
5000
0
Number of photons
0.00E+00
2.00E-02
4.00E-02
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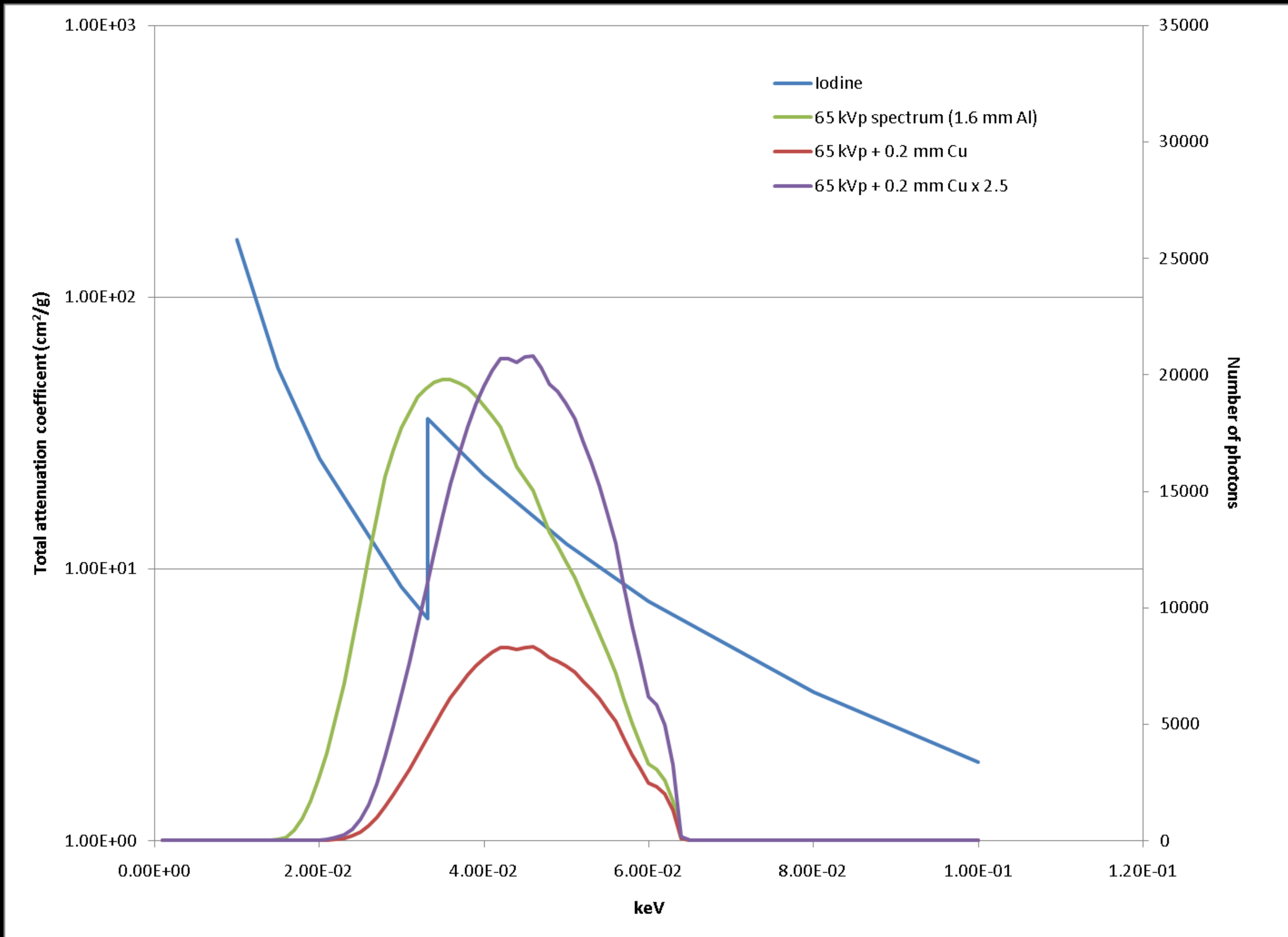
keV
Iodine
65 kVp spectrum (1.6 mm Al)


1.00E+03
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Total attenuation coefficent (cm²/g)
0.00E+00
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6.00E-02
8.00E-02
1.00E-01
1.20E-01
keV
35000
30000
25000
20000
15000
10000
5000
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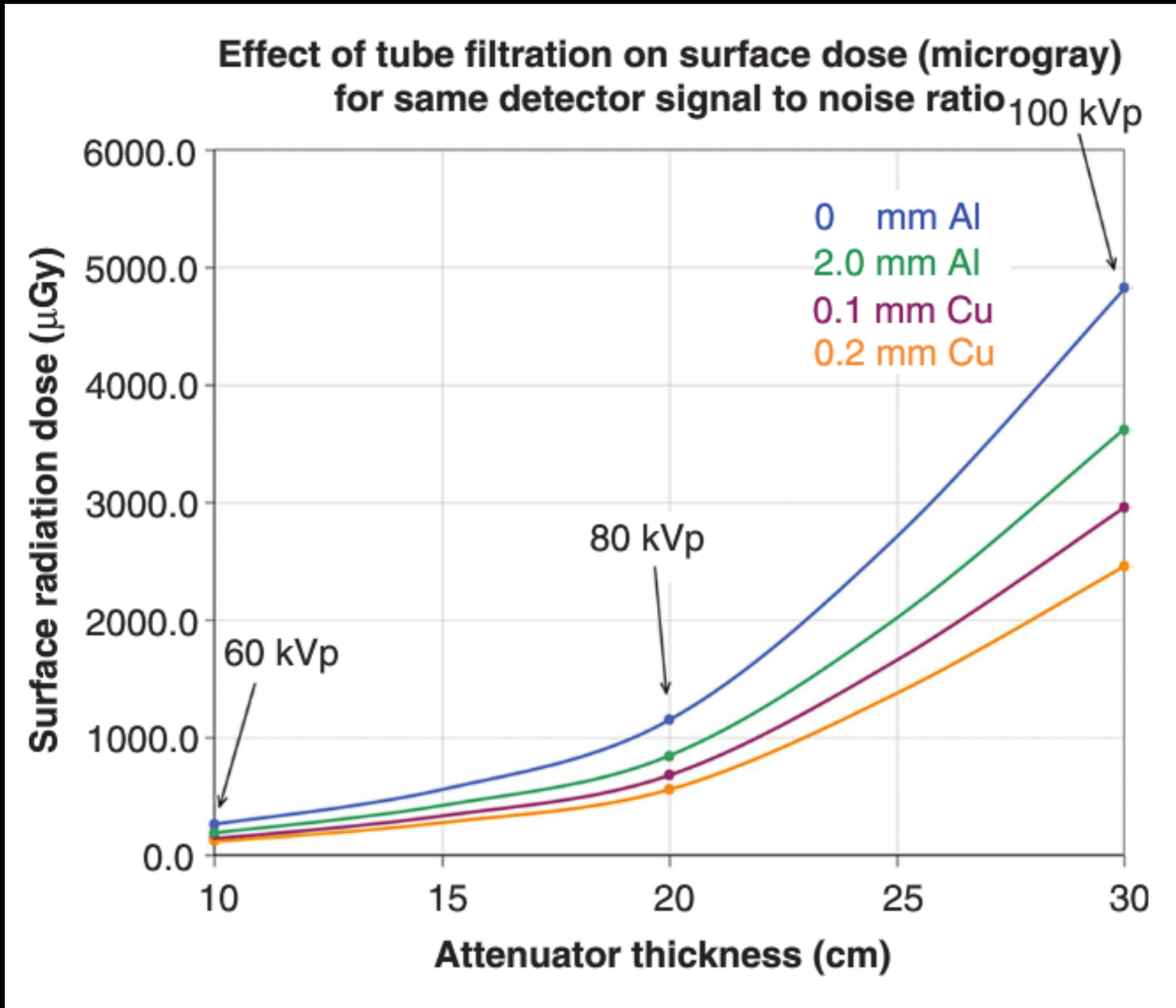
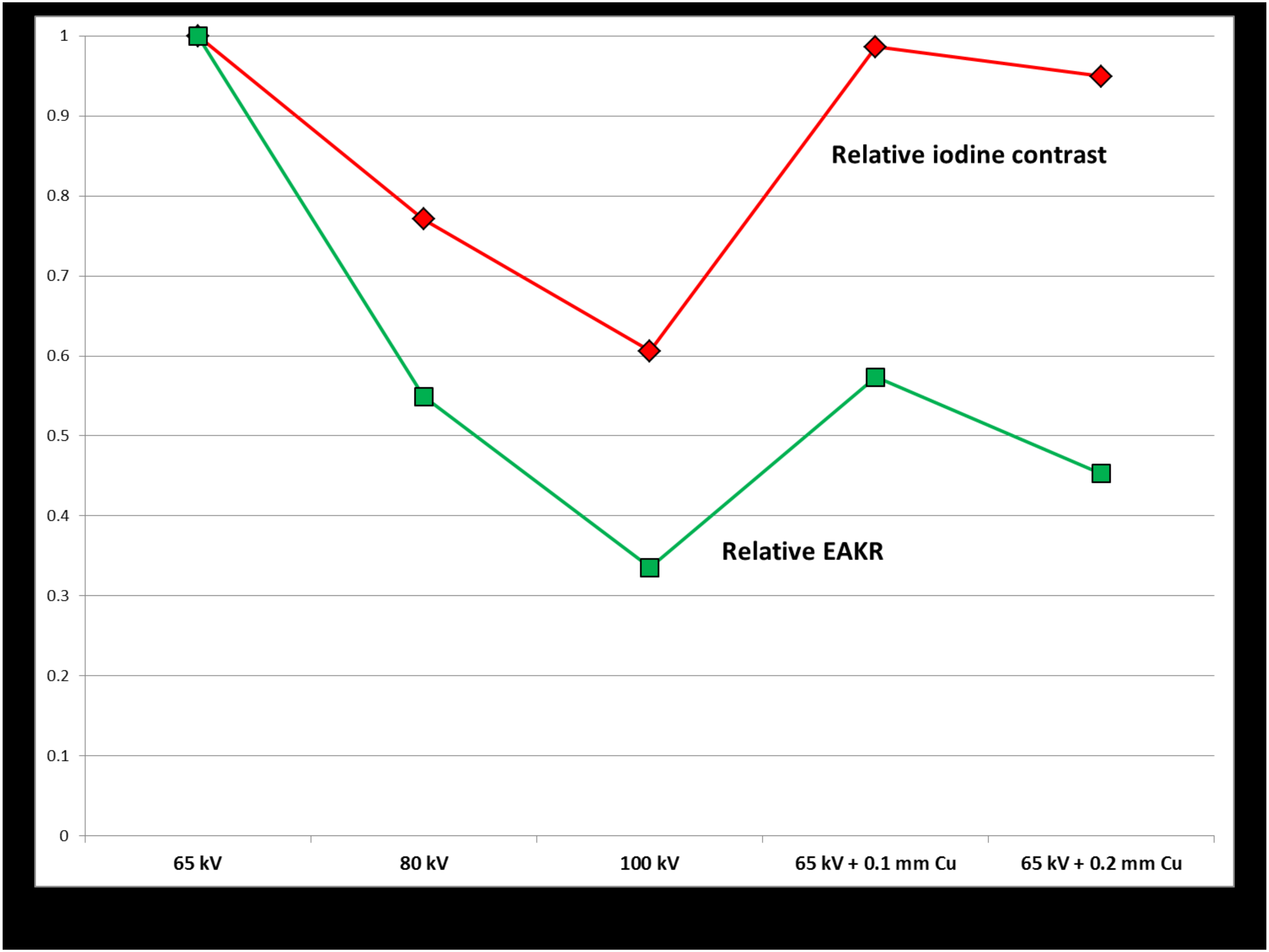
Number of photons
Iodine
65 kVp spectrum (1.6 mm Al)
65 kVp + 0.2 mm Cu
65 kVp + 0.2 mm Cu x 2.5

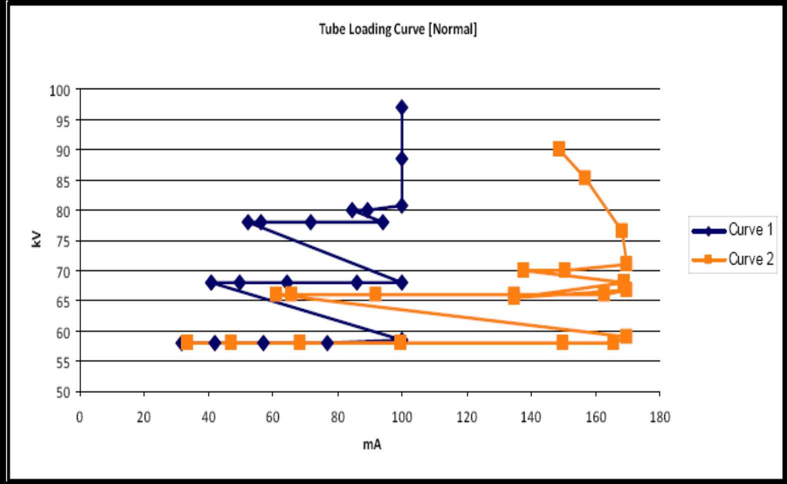


Bushberg et al. The Essential Physics of Medical Imaging, 3rd ed.


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Relative iodine contrast
Relative EAKR
65 kV
80 kV
100 kV
65 kV + 0.1 mm Cu
65 kV + 0.2 mm Cu

Contrast and beam quality

- Iodine contrast is strongly affected by beam quality
- The addition of filtration allows the use of low kV while maintaining dose at an acceptable level
  - Traditional, Program-Switched
- Sacrifices may need to be made to maintain kV at desired level
  - E.g., focal spot



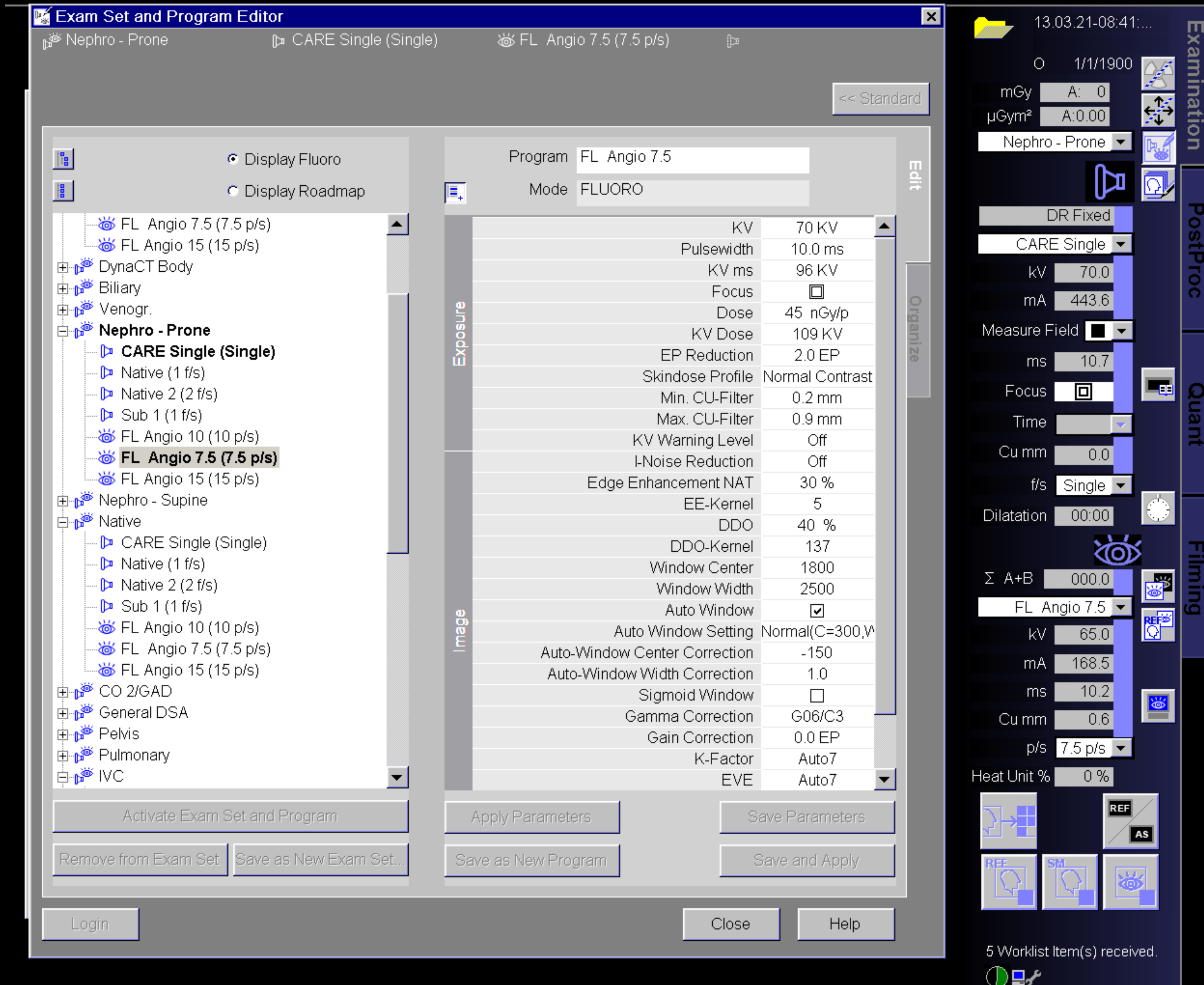
Ishida E et al. Image quality improvement and patient dose reduction by optimization of x-ray spectrum. Jpn Radiol Technol **55**:582-587 (1999).

Balancing filtration

- Impact in FLU vs. ACQ
- Must consider impact on related organ program parameters
  - Pulse width
  - Focal spot size
- Configuration options
  - "Traditional" method
    - Static filter
  - "Program-switched" method
    - Filtration linked to organ program (e.g., Philips)
    - Seissl method (e.g., Siemens)

FLUORO	(2) Cardiac Cath		
	FL Card Low (21,4)	FL Card Avg (21,5)	FL Card Lg (21,6)
EXPOSURE	FLUORO	FLUORO	FLUORO
kV	81	70	70
Pulse Width	8	8	8
kV ms	90	90	90
kV dose	109	109	off
EP Reduction	2	2	
Cu mm Min	*0.6*	*0.2*	*0.1*
Cu mm Max	*0.9*	*0.6*	*0.3*
Dose	*36*	*45*	*55*
High Contrast (20R)	*Normal*	*Normal*	*High*
kV Warning	*109*	*109*	*off*
Focus	*s*	*s*	*s*

Lin PP and Rauch P. AAPM Report 125 – Functionality and operation of fluoroscopic automatic brightness control/automatic dose rate control logic in modern cardiovascular and interventional angiography systems, 2012.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FL Angio 7.5 (7.5 p/s)
<< Standard
Display Fluoro
Display Roadmap
FL Angio 7.5 (7.5 p/s)
FL Angio 15 (15 p/s)
DynaCT Body
Biliary
Venogr.
Nephro - Prone
CARE Single (Single)
Native (1 f/s)
Native 2 (2 f/s)
Sub 1 (1 f/s)
FL Angio 10 (10 p/s)
FL Angio 7.5 (7.5 p/s)
FL Angio 15 (15 p/s)
Nephro - Supine
Native
CARE Single (Single)
Native (1 f/s)
Native 2 (2 f/s)
Sub 1 (1 f/s)
FL Angio 10 (10 p/s)
FL Angio 7.5 (7.5 p/s)
FL Angio 15 (15 p/s)
CO 2/GAD
General DSA
Pelvis
Pulmonary
IVC
Program FL Angio 7.5
Mode FLUORO
Exposure
Image
Edit
Organize
KV 70 KV
Pulsewidth 10.0 ms
KV ms 96 KV
Focus
Dose 45 nGy/p
KV Dose 109 KV
EP Reduction 2.0 EP
Skindose Profile Normal Contrast
Min. CU-Filter 0.2 mm
Max. CU-Filter 0.9 mm
KV Warning Level Off
I-Noise Reduction Off
Edge Enhancement NAT 30 %
EE-Kernel 5
DDO 40 %
DDO-Kernel 137
Window Center 1800
Window Width 2500
Auto Window
Auto Window Setting Normal(C=300,W
Auto-Window Center Correction -150
Auto-Window Width Correction 1.0
Sigmoid Window
Gamma Correction G06/C3
Gain Correction 0.0 EP
K-Factor Auto7
EVE Auto7
Activate Exam Set and Program
Remove from Exam Set
Save as New Exam Set...
Apply Parameters
Save Parameters
Save as New Program
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Login
Close
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13.03.21-08:41:...
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Nephro - Prone
DR Fixed
CARE Single
kV 70.0
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f/s Single
Dilatation 00:00
Σ A+B 000.0
FL Angio 7.5
kV 65.0
mA 168.5
ms 10.2
Cu mm 0.6
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AS
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Examination
PostProc
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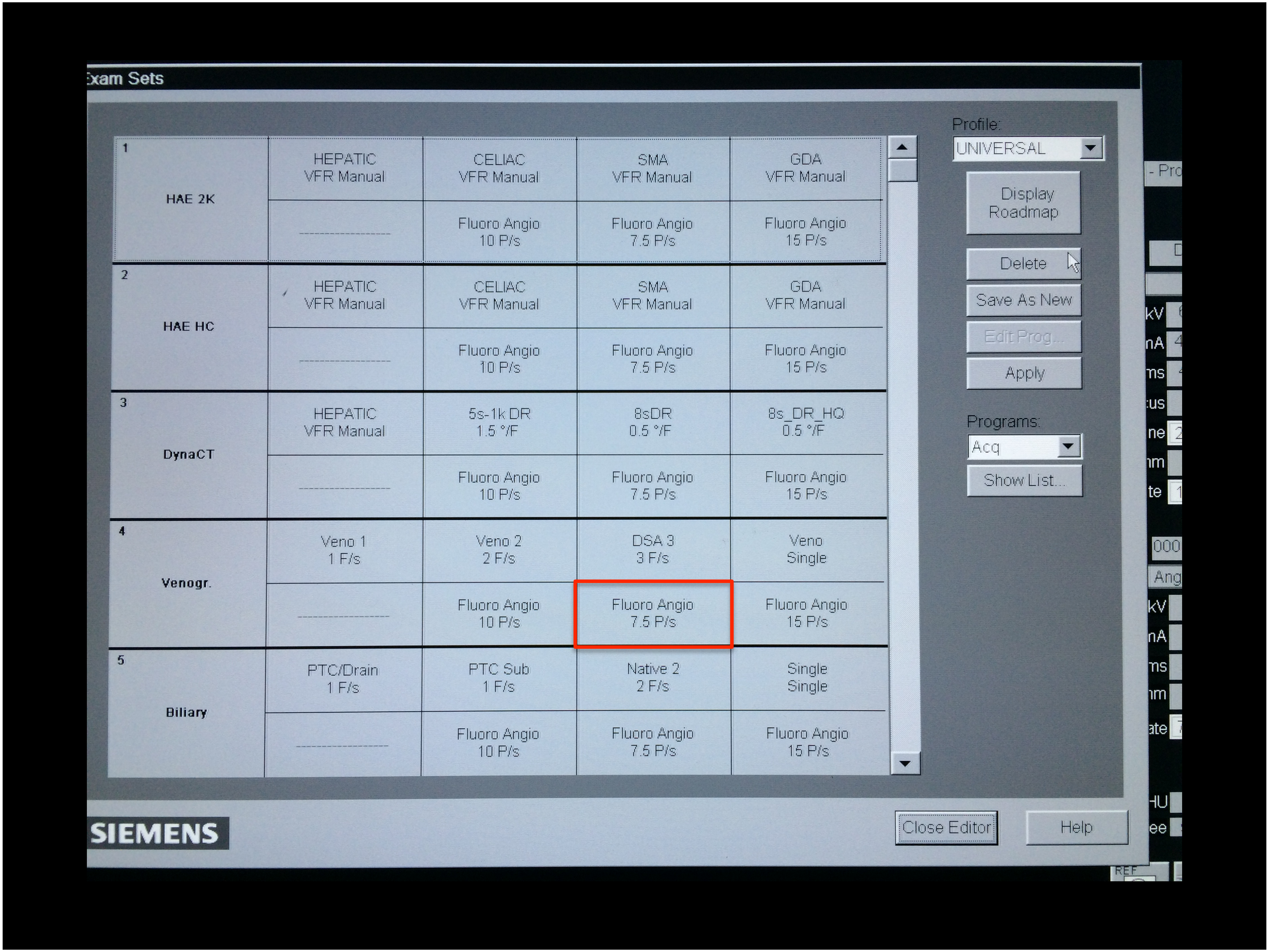
Filming


Exam Sets
Profile:
UNIVERSAL
Display Roadmap
Delete
Save As New
Edit Prog...
Apply
Programs:
Acq
Show List...
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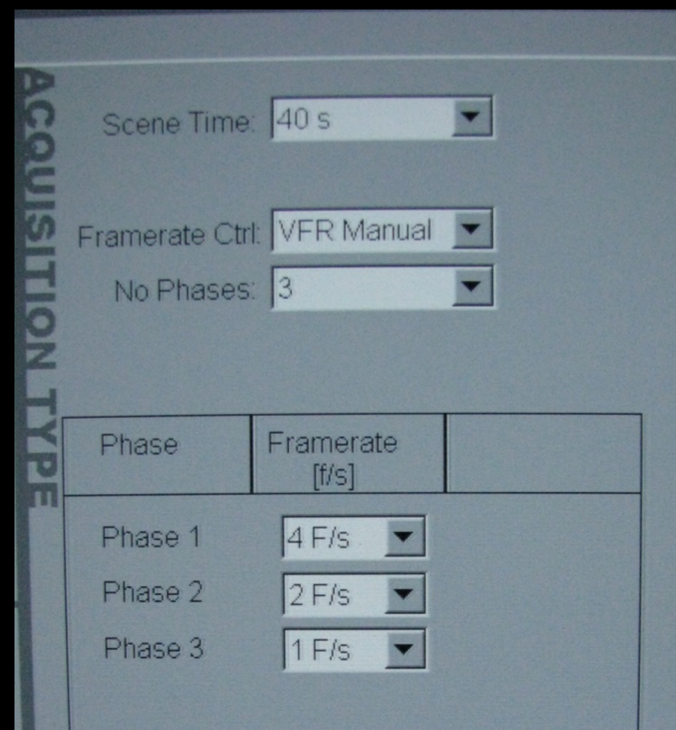
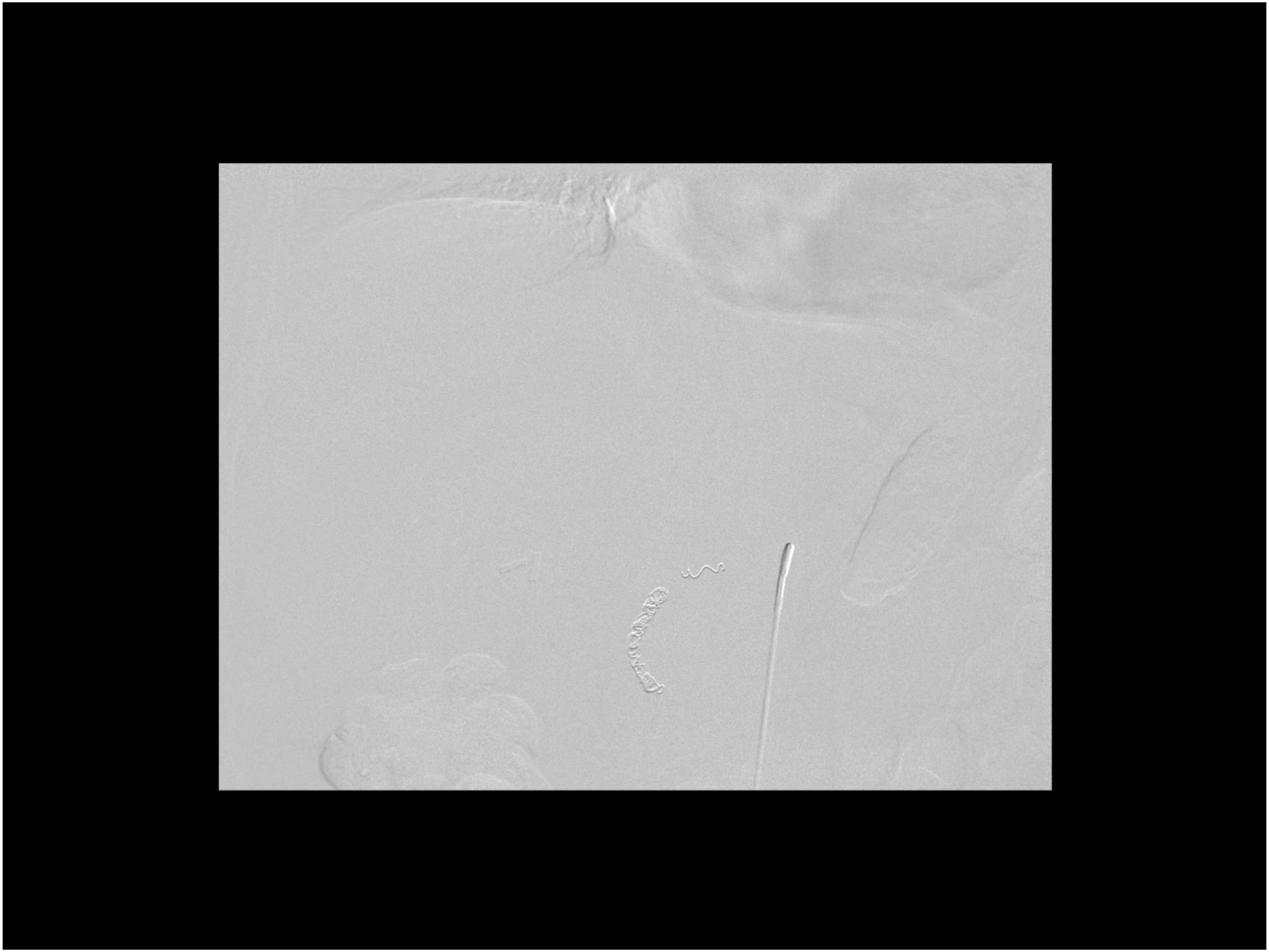
HAE 2K
HEPATIC VFR Manual
CELIAC VFR Manual
SMA VFR Manual
GDA VFR Manual
Fluoro Angio 10 P/s
Fluoro Angio 7.5 P/s
Fluoro Angio 15 P/s
2
HAE HC
HEPATIC VFR Manual
CELIAC VFR Manual
SMA VFR Manual
GDA VFR Manual
Fluoro Angio 10 P/s
Fluoro Angio 7.5 P/s
Fluoro Angio 15 P/s
3
DynaCT
HEPATIC VFR Manual
5s-1k DR 1.5 °/F
8sDR 0.5 °/F
8s_DR_HQ 0.5 °/F
Fluoro Angio 10 P/s
Fluoro Angio 7.5 P/s
Fluoro Angio 15 P/s
4
Venogr.
Veno 1 1 F/s
Veno 2 2 F/s
DSA 3 3 F/s
Veno Single
Fluoro Angio 10 P/s
Fluoro Angio 7.5 P/s
Fluoro Angio 15 P/s
5
Biliary
PTC/Drain 1 F/s
PTC Sub 1 F/s
Native 2 2 F/s
Single Single
Fluoro Angio 10 P/s
Fluoro Angio 7.5 P/s
Fluoro Angio 15 P/s
SIEMENS
Close Editor
Help

Variable frame rate (VFR) imaging

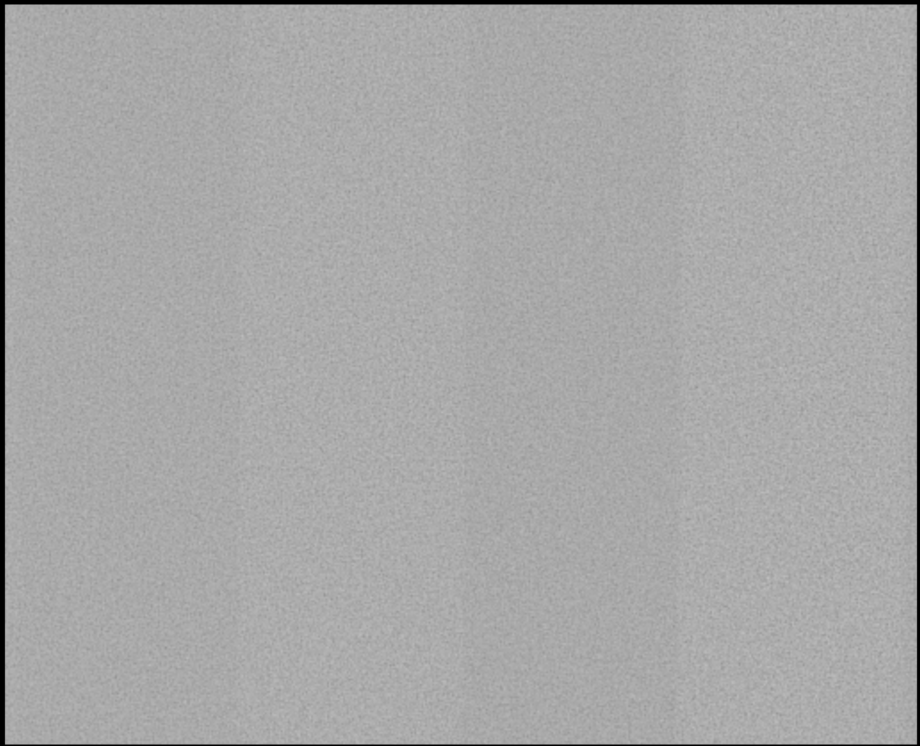
- The concept of this technique is quite simple – by reducing the total number of ACQ frames, dose is reduced
- Frame rate reduction is triggered by
  - Time
  - Manually



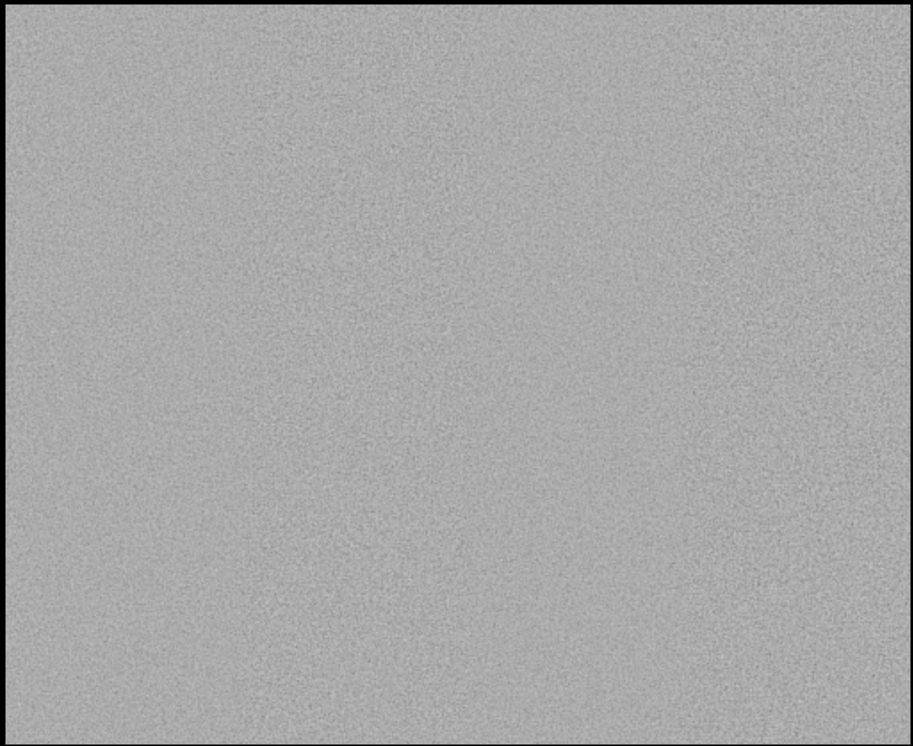


Mask averaging

- Reduction in image noise that can translate directly in to reduction in dose with virtually no impact on image quality
- Unfortunately, in my practice it is rarely used



3.6 uGy/fr



2.4 uGy/fr

Aufrichtig scale for pulsed fluoroscopy

- The human visual system has a finite integration time of approximately 200 ms
- Richard Aufrichtig studied this phenomenon and derived an empirical relationship relating the necessary dose per pulse to the pulse rate
- The use of lower pulse rates results in an LIH image of higher quality

$$\left(\frac{IAKRD_2}{IAKRD_1}\right) = \sqrt{\frac{PPS_1}{PPS_2}}$$

Aufrichtig R, Xue P, Thomas CW, Gilmore GC, and Wilson DL. Perceptual comparison of pulsed and continuous fluoroscopy. Med Phys **21**:245-256 (1994).

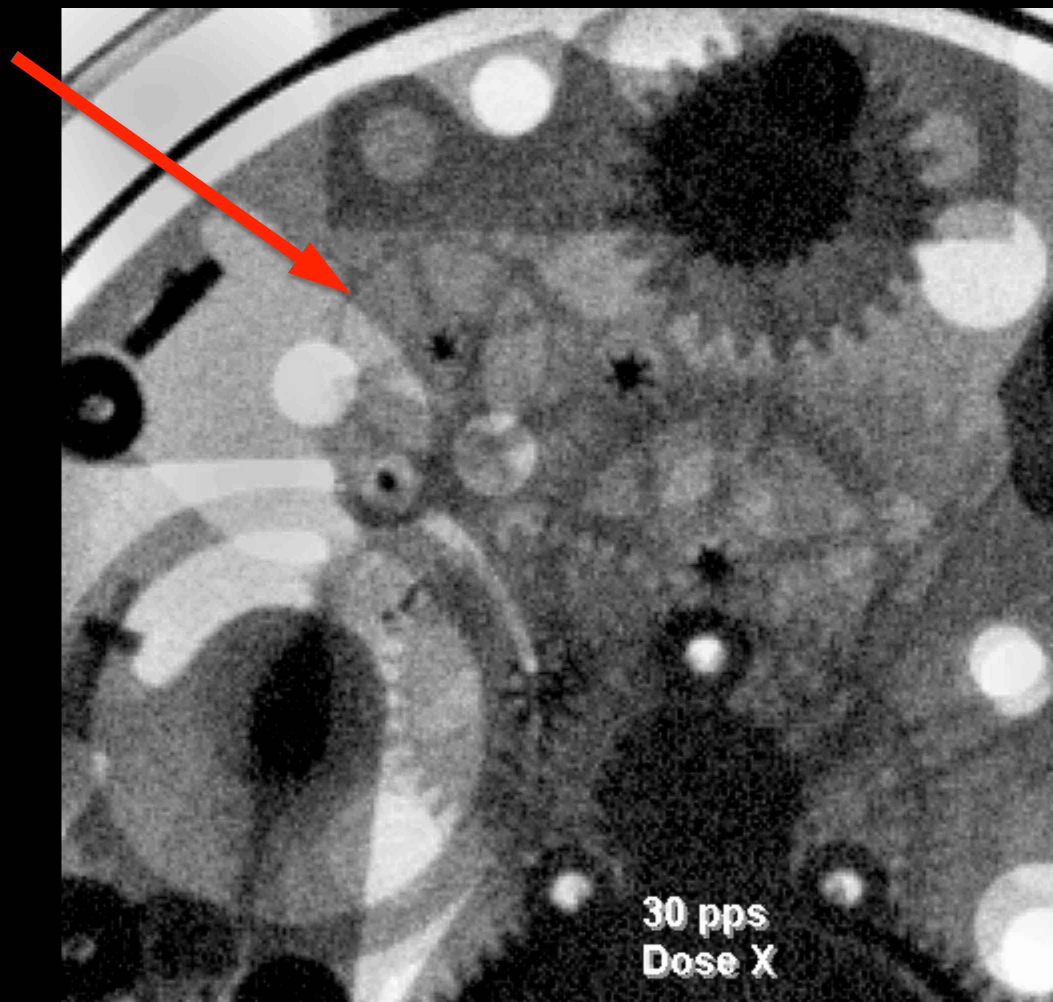


Illustration courtesy of Phil Rauch, M.S.

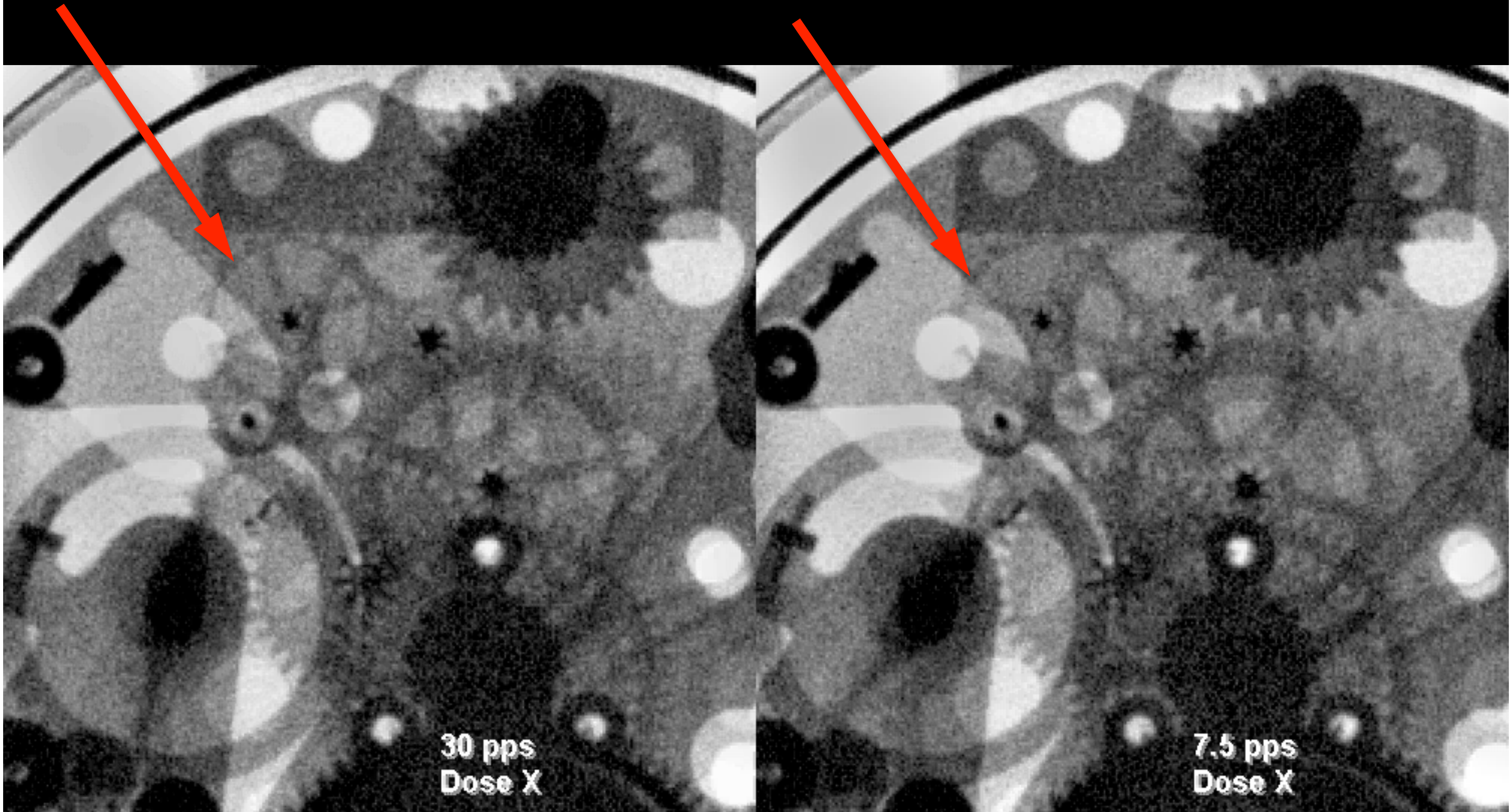


Illustration courtesy of Phil Rauch, M.S.

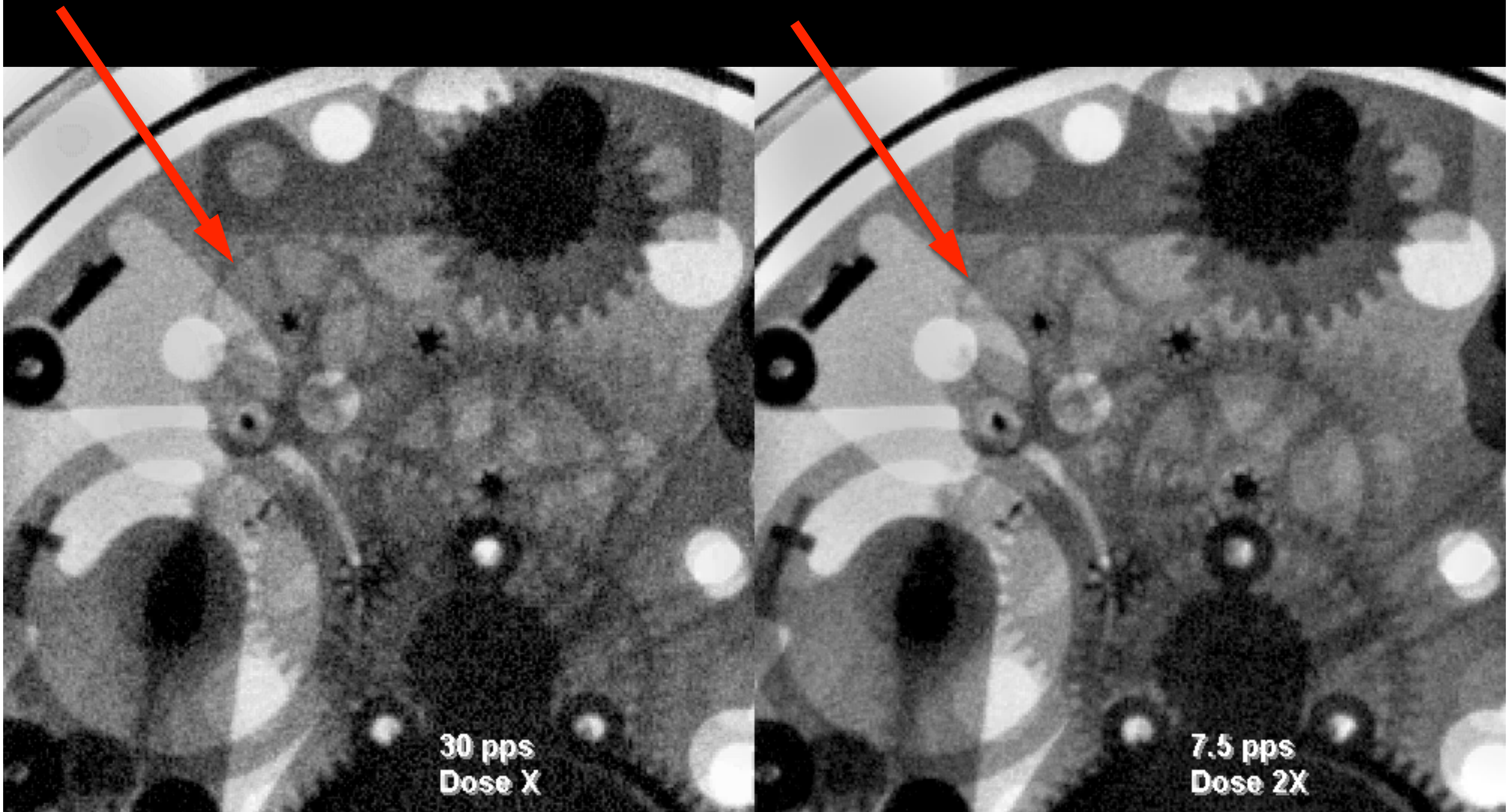


Illustration courtesy of Phil Rauch, M.S.

PHYSICIAN PRACTICE

Physician practice

- Physicians have plenty on their mind during a complex FGI
- We cannot expect them to also retain detailed knowledge of equipment settings and apply this knowledge during a case
- We should provide simple instructions and configure protocol defaults with this in mind
- ***Speak their language***

Key aspects

- The Tetrad
- Notification levels and associated actions
- Dose audits

The "Tetrad"

1. Raise the patient table to the highest comfortable working height.

2. Lower the image receptor as much as practicable.

3. Take one small step back or down the table away from the patient.

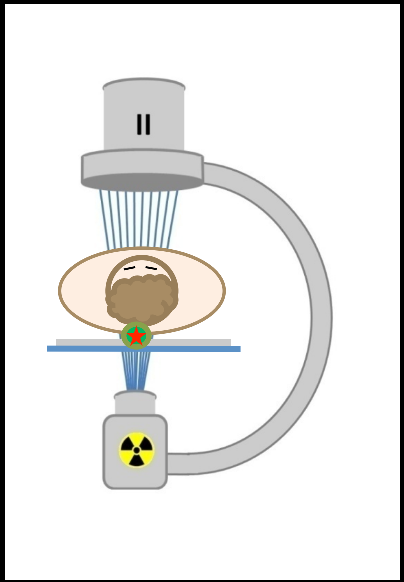
4. Collimate the X-ray field to the area of interest.

Order is important!

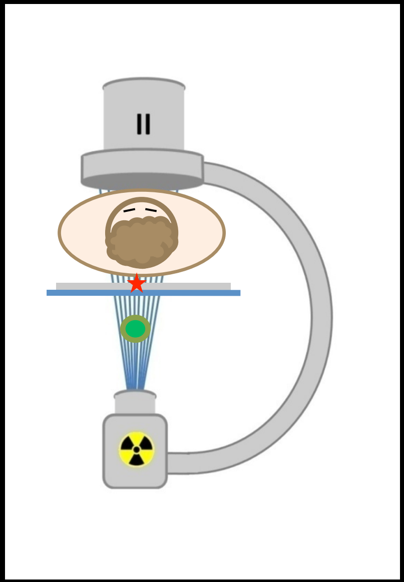
Procedural geometries

Using Good Practice is essential during fluoroscopic procedures, including maintaining the patient as far from the X-ray source as practical. This is common in vascular and interventional procedures, and results in a *non-isocentric* geometry.

The dose rate at the skin surface will be lower in a non-isocentric geometry than in an isocentric geometry.



Isocentric geometry



Non-isocentric geometry

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TABLE 4.7–*Suggested values for first and subsequent notifications and the SRDL.*

Dose Metric	First Notification	Subsequent Notifications (increments)	SRDL
$D_{skin,max}$	2 Gy	0.5 Gy	3 Gy
$K_{a,r}$	3 Gy	1 Gy	5 Gy[a]
P_{KA}	300 Gy cm^2 [b]	100 Gy cm^2 [b]	500 Gy cm^2 [b]
Fluoroscopy time	30 min	15 min	60 min

[a] See additional discussion concerning the value 5 Gy in Section 4.3.4.2.

[b] Assuming a 100 cm^2 field at the patient's skin. For other field sizes, the P_{KA} values should be adjusted proportionally to the actual procedural field size (*e.g.*, for a field size of 50 cm^2, the SRDL value for P_{KA} would be 250 Gy cm^2).

NCRP 168

Notification levels by lab/fluoroscope type

Differences in notification levels reflect differences, technical and geometric, in how fluoroscopically-guided procedures are performed. A number of factors influence the ratio of peak skin dose (PSD) to RAK: procedural geometry, backscatter, and attenuation by the patient support and pad.

Each notification level should involve a procedural pause and communication of the radiation dose status to the operator.

Lab/fluoroscope type	Typical ratio of PSD to RAK (PSD/RAK)
Vascular/interventional radiology	1.0
Cardiac catheterization	1.3-1.4
Interventional neuroradiology	1.0-1.3
Mobile C-arm	1.0-1.5

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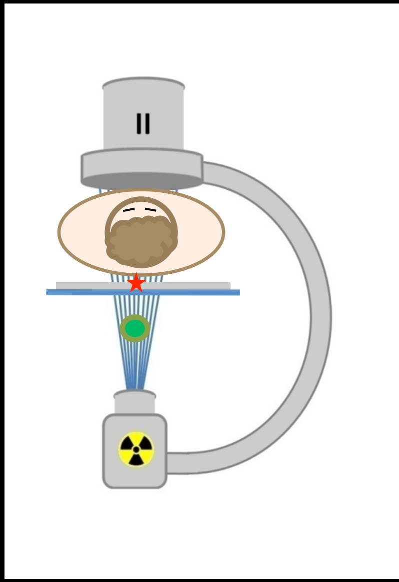
Example – Vascular/Interventional Radiology

RAK notification level (mGy)	Corresponding PSD (mGy)	Suggested action
2,500	2,500	Verify Good Practice is being used.
5,000	5,000	Substantial radiation dose level. Flag patient for f/u. Measure and record table height.
7,500	7,500	Verify Good Practice. Re-evaluate risk/benefit pace of procedure, entering range of potential skin injury.
10,000	10,000	Verify Good Practice. Re-evaluate risk/benefit pace of procedure. Skin injury more likely.

**And every 1,000 mGy above 10,000 mGy*. *These notification levels are for illustration purposes only and the numbers are approximate.*



The use of a non-isocentric geometry means that PSD is often similar to RAK for VIR procedures.

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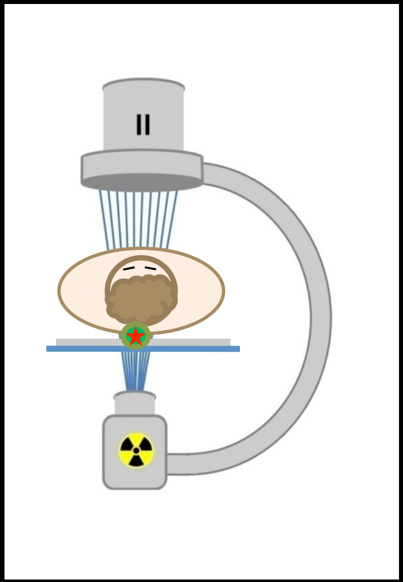
Example – Interventional cardiology

RAK notification level (mGy)	Corresponding PSD (mGy)	Suggested action
1,800	2,500	Verify Good Practice is being used.
3,600	5,000	Substantial radiation dose level. Flag patient for f/u. Measure and record table height. Consider rotating C-arm.
5,400	7,500	Verify Good Practice. Re-evaluate risk/benefit pace of procedure, entering range of potential skin injury.
7,200	10,000	Verify Good Practice. Re-evaluate risk/benefit pace of procedure. Skin injury more likely. Consider rotating C-arm.

**And every 700 mGy above 7,200 mGy. These notification levels are for illustration purposes only and the numbers are approximate.*



The use of an isocentric geometry means that PSD is often greater than RAK for interventional cardiology procedures.

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Dose audits

- The simple act of beginning to record dose metrics will often on its own trigger practice changes
- Stratification of the data can identify specific targets for improvement
- Compare to normative data sets
  - E.g., RAD-IR study

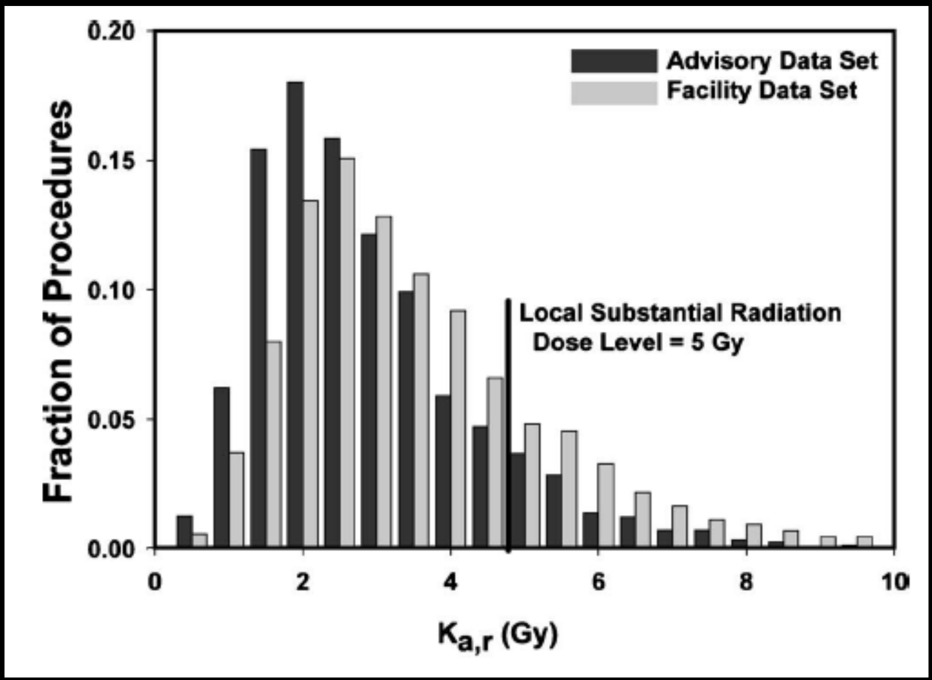
Recommendation 19

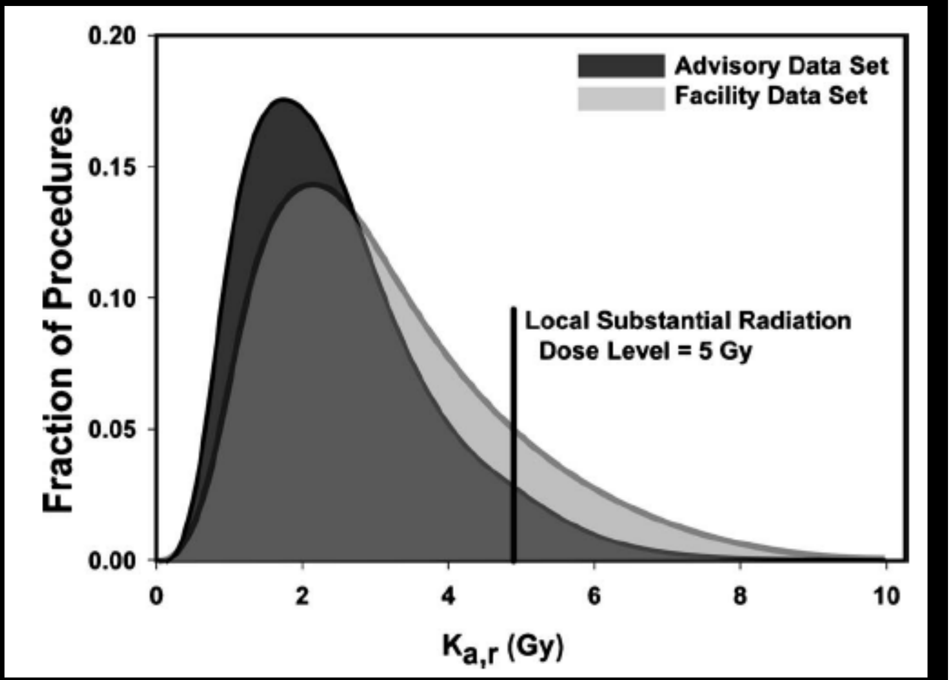
Facilities *shall* have a process to review radiation doses for patients undergoing FGI procedures.

Advisory data based on measured dosimetric quantities (in particular P_{KA} or $K_{a,r}$ to manage overall performance, and $K_{a,r}$ to manage deterministic effects) *should* be used for quality assurance purposes.

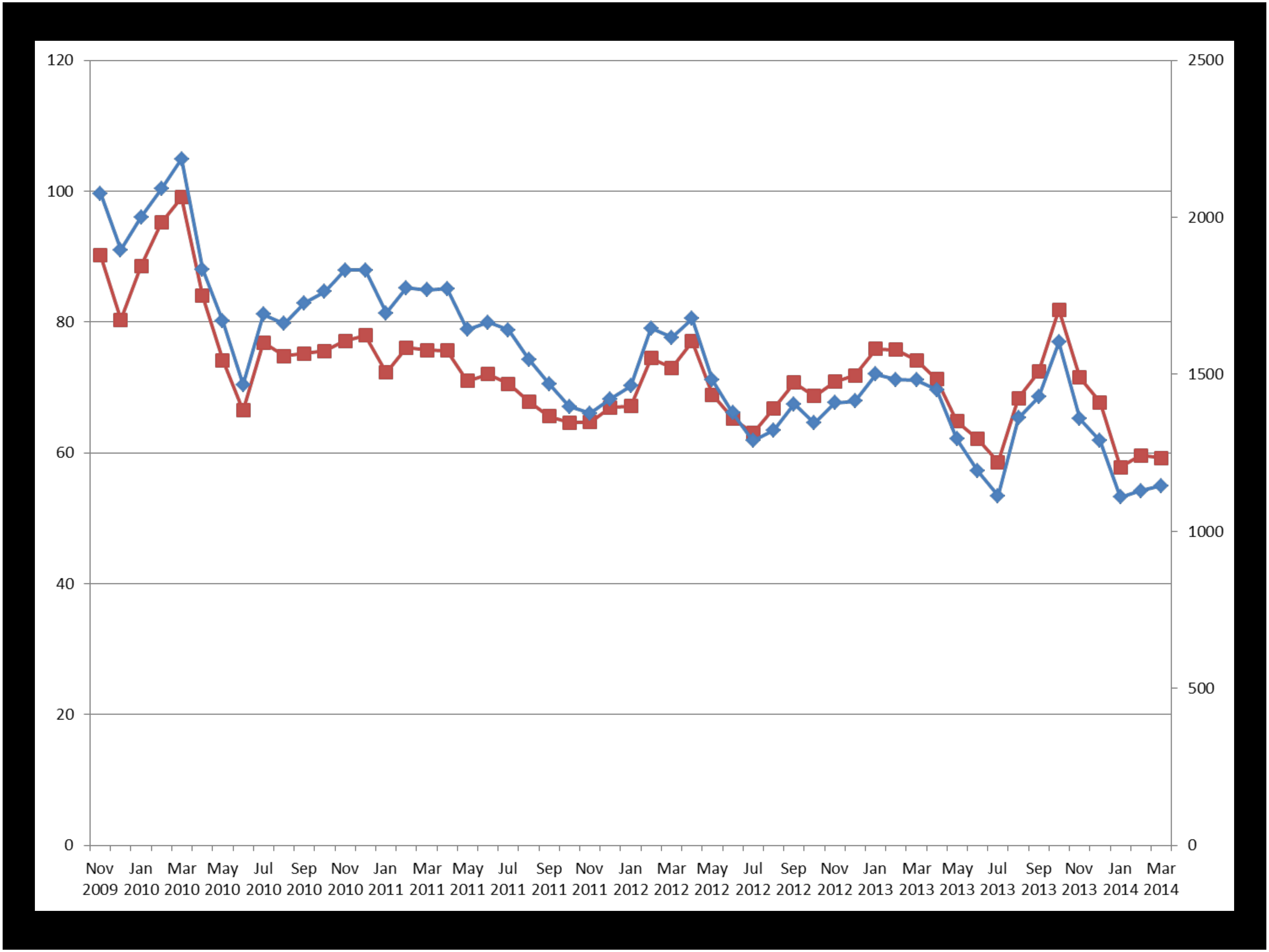
NCRP 168

Radiation dose audits





Balter S et al. Patient radiation dose audits for fluoroscopically guided interventional procedures. Med Phys 38(3):1611-18, 2011.



120
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Nov 2013
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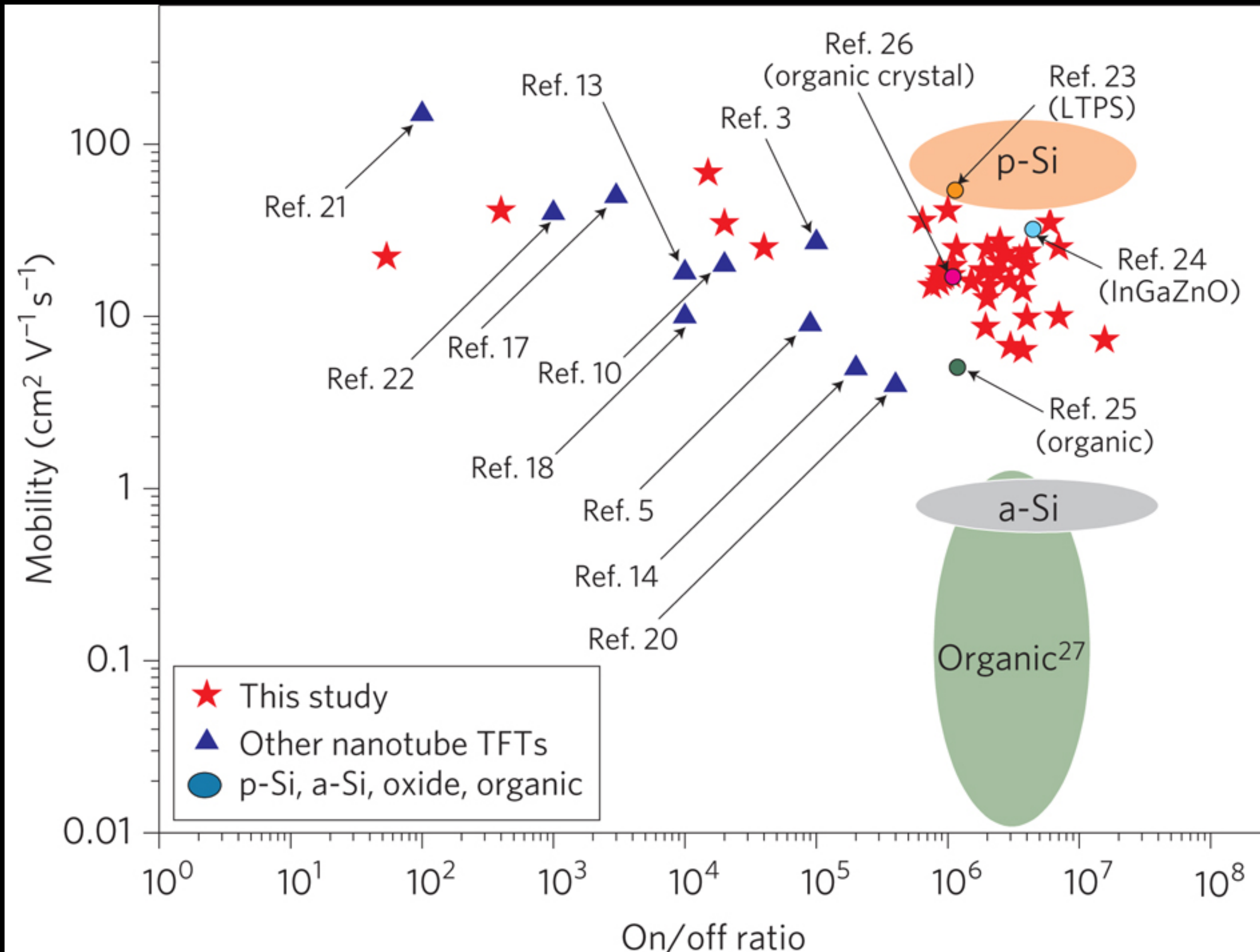
Mar 2014

TECHNOLOGY

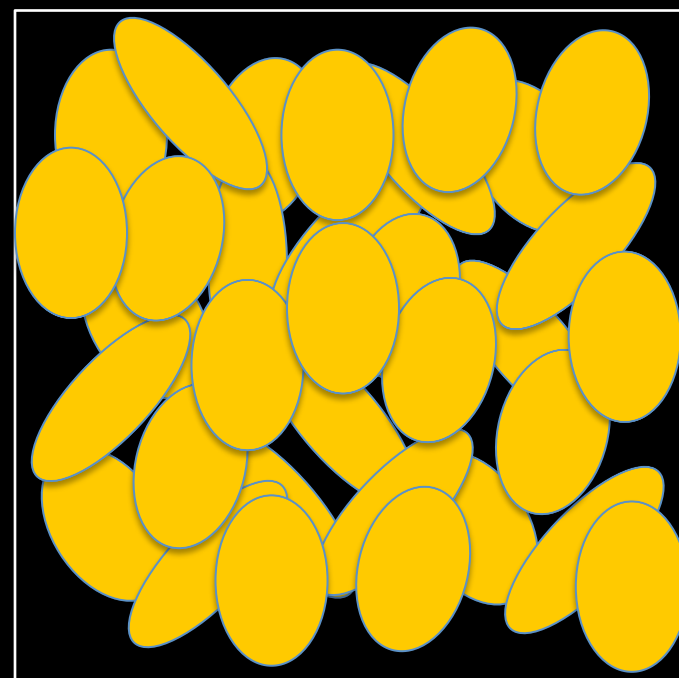
Technological advances

- Detector technology
  - Higher acquisition bit depth
  - Crystalline silicon
    - Electron mobility
    - Active pixel sensors
- X-ray tube technology
  - Flat emitter

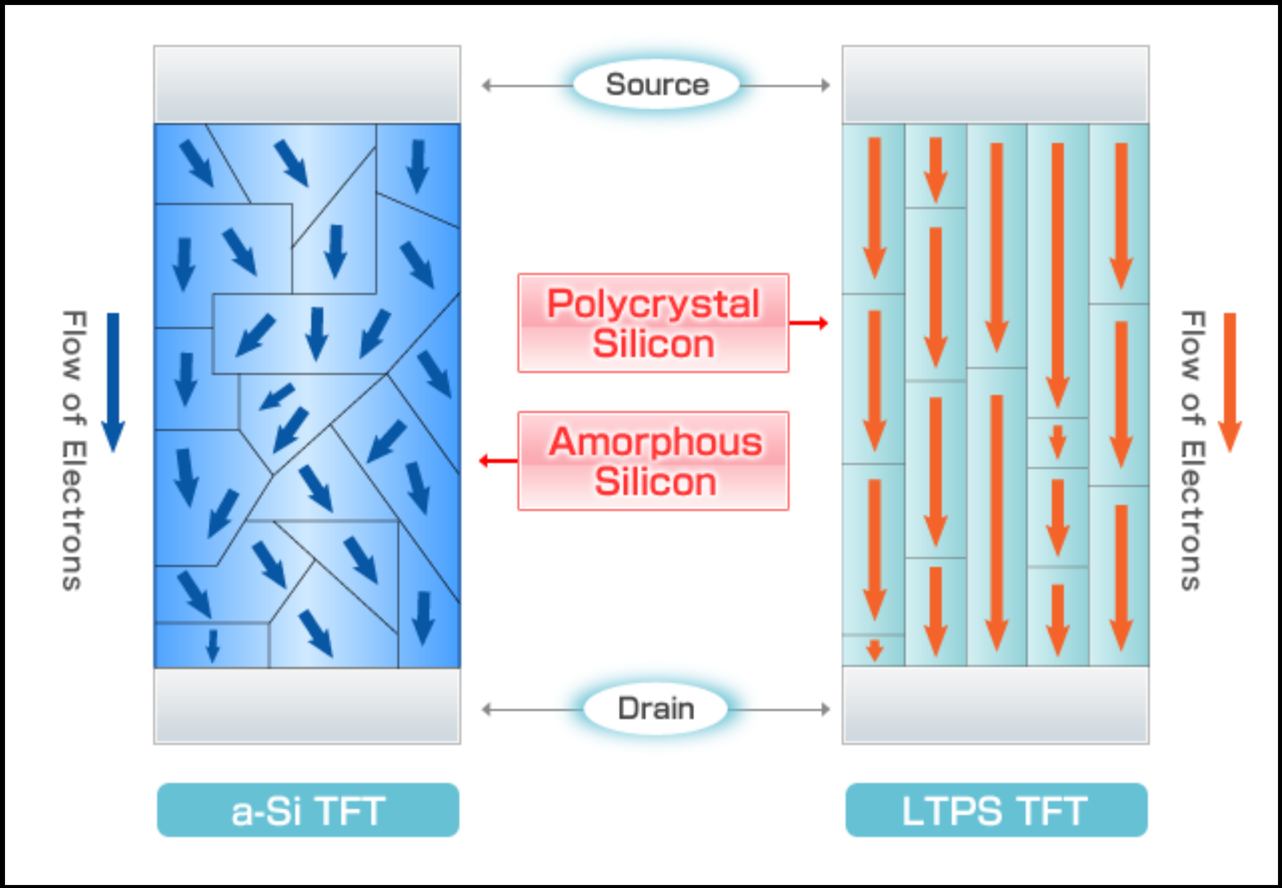


Sun D et al. Flexible high-performance carbon nanotube integrated circuits. Nat Nanotechnol **6**:156-161 (2011).

a-Si



poly-Si



Nissin Ion Equipment Co, Ltd. http://www.nissin-ion.co.jp/en/prd/id/

Backplane	a-Si:H	poly-Si	mono-Si
Monolithic array size	Large	Medium	Small
e^- mobility	1 cm^2/V-s	100 cm^2/V-s	1000 cm^2/V-s
TFT mask steps	4-5	5-11	5-11
Leakage current	Low	Higher	Higher
Radiation hardness	Excellent	Good/Fair	Poor
Large scale uniformity	Good	Fair	Poor
Cost/yield	Low/High	High/Low	High/Low

Further reading

- Miller et al., Quality improvement guidelines for recording patient radiation dose in the medical record. *J Vasc Interv Radiol* **15**:423–429, 2004.
  - SIR Standards of Practice Committee
- Miller DL, Balter S, Noonan PT, Georgia JD, Minimizing radiation-induced skin injury in interventional radiology procedures. *Radiology* **225**:329–336, 2002 .
- Stecker et al., Guidelines for patient radiation dose management. *J Vasc Interv Radiol* **20**:S263–S273, 2009.
  - SIR Safety and Health Committee
  - Discharge/consenting examples
- Archer BR and Wagner LK, Protecting patients by training physicians in fluoroscopic radiation management. *J Appl Clin Med Phys* **1:**32-37, 2000.
- Wagner LK and Archer BR, Minimizing Risks from Fluoroscopic X Rays, 2nd ed., R.M. Partnership, The Woodlands, TX.
- Balter S, et al. Fluoroscopically guided interventional procedures: A review of radiation effects on patients' skin and hair. Radiology, 254:326-341
- NCRP Report 168