CARL E. RAVIN
ADVANCED
IMAGING
LABORATORIES

Technique Optimization in Digital Mammography

Nicole T. Ranger, M.Sc.

NicoleTRangerMSc@gmail.com

Carl E. Ravin Advanced Imaging Labs
Department of Radiology
Duke University Medical Center

Index

1. Introduction to Optimization in Mammography
2. Characteristics of S/F vs. Digital Mammography
3. Technique Optimization Methodology
4. What does this mean to me in the Clinic ?

Part 1

Introduction to Technique Optimization in Mammography

Technique
Acquisition Parameters

1. X-RAY BEAM SPECTRUM

   - *target material*
   - *filter material and thickness*
   - *tube kilovoltage (kVp)*

2. EXPOSURE LEVEL

   - *beam current x time (mAs)*

Optimization

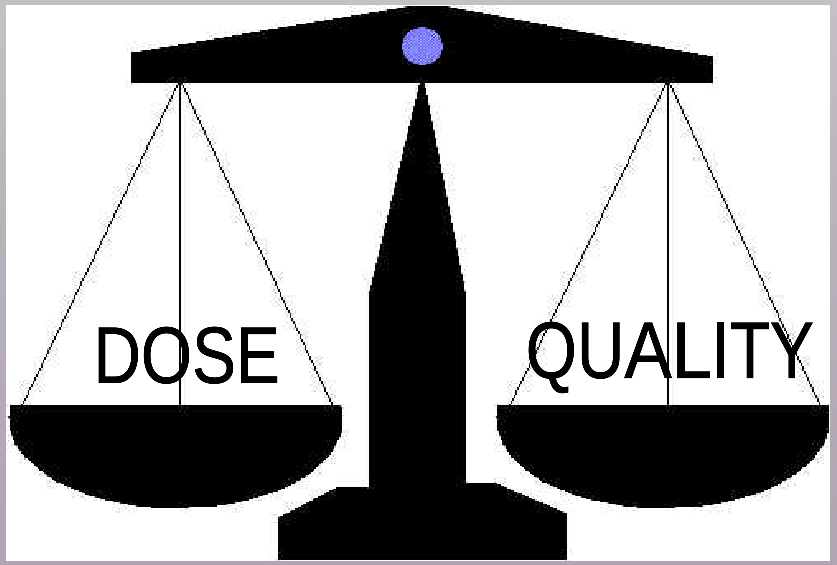
“ Any process or procedure which ensures that doses due to appropriate medical exposure for radiological purposes are kept as low as reasonably achievable (ALARA) consistent with obtaining the required diagnostic information ..”

IAEA-TECDOC-1447 May 2005”

Implications

A mammography image of adequate to superior image quality is NOT acquired using an optimal technique if the dose to the patient was higher than necessary to yield a diagnostic image.

Must find optimum balance between dose & image quality



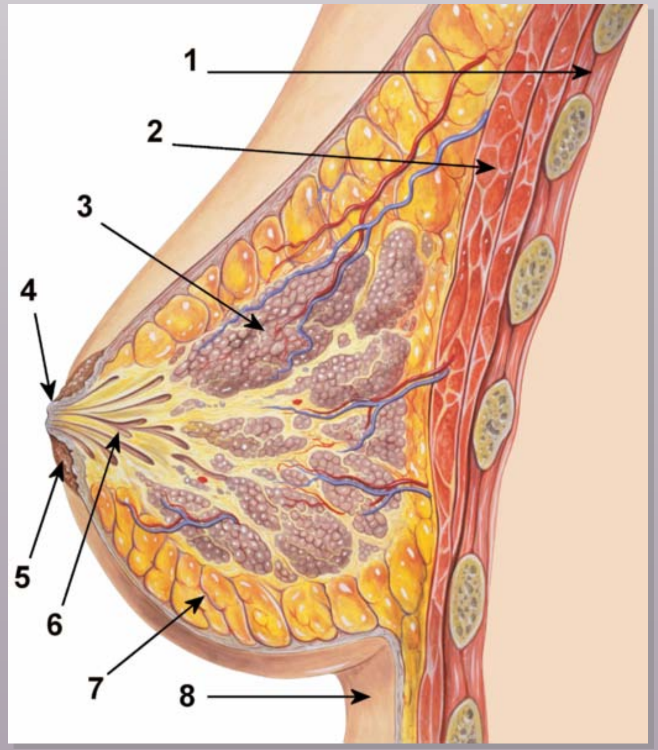
Optimization in Mammography

"In mammography, the objective is to produce images that provide maximum visualization of breast anatomy and the signs of disease without subjecting the patient to unnecessary radiation"

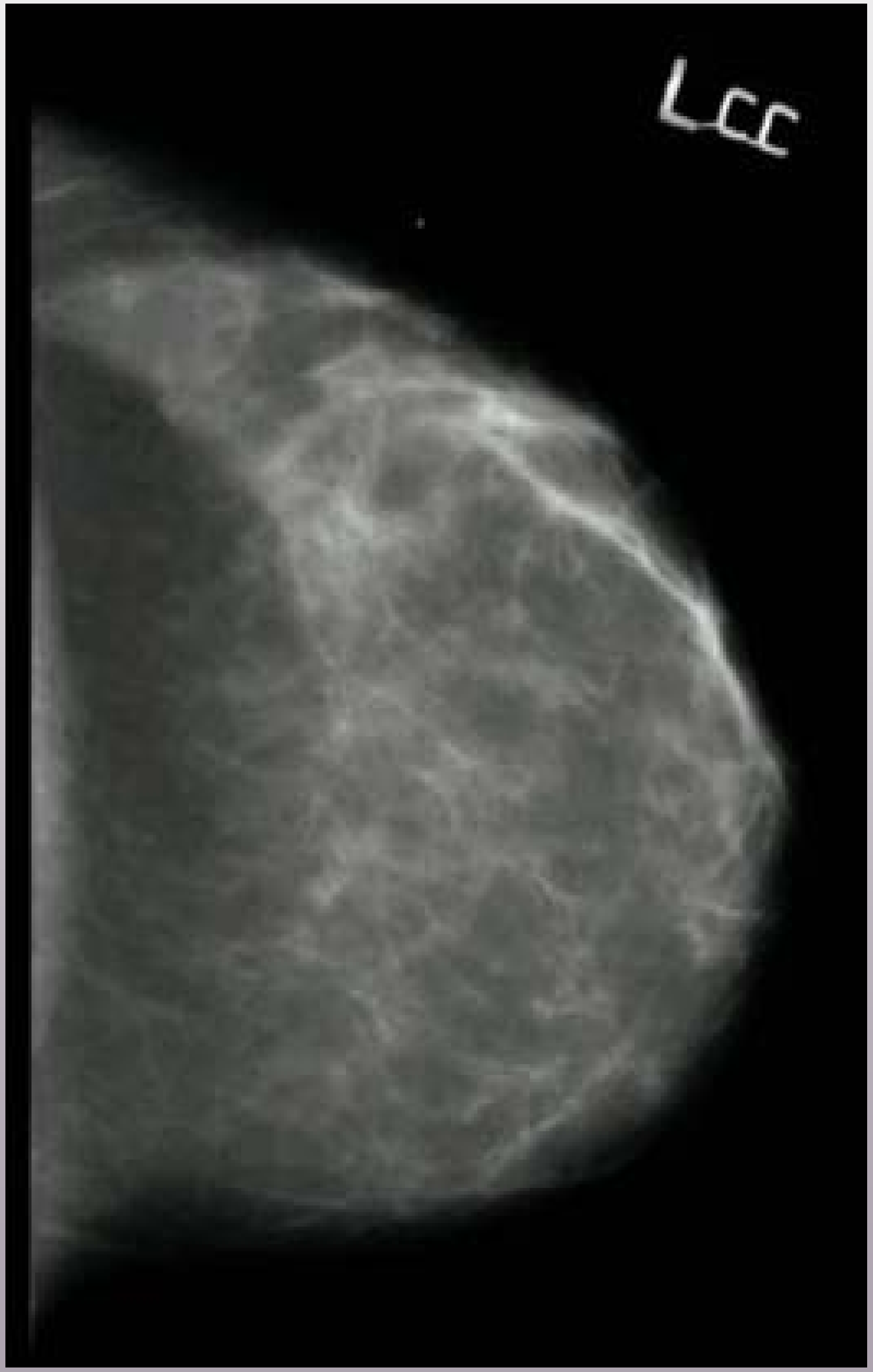
- IAEA

Normal Breast Anatomy

1. Chest wall
2. Pectoralis muscles
3. Lobules
4. Nipple
5. Areola
6. Duct
7. Fatty tissue
8. Skin

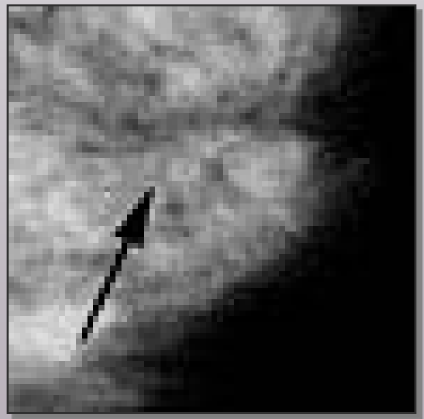


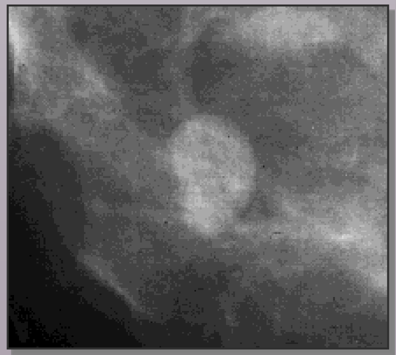
www.wikipedia.com

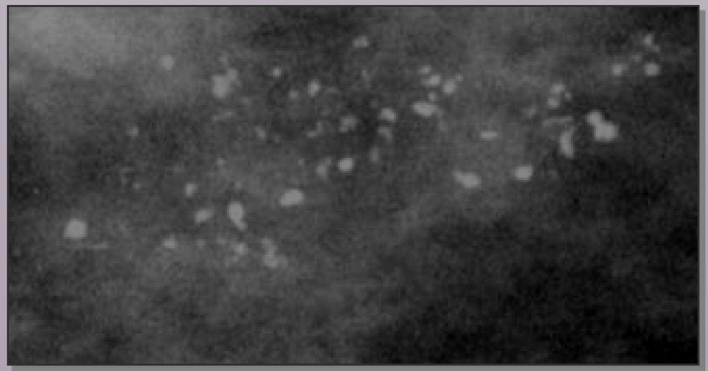


Features of Breast Cancer in Mammography Imaging

- Increased Density (relative to prior exam)
- Architectural Distortion
- Micro-calcifications
- Masses







Optimized Imaging of the Breast

1. DIAGNOSTIC OBJECTIVES

- Detect and characterize microcalcification cluster patterns and morphology
- Visualize breast parenchyma and subtle architectural distortions
- Detect soft tissue masses and assess shape, size, degree of local invasion

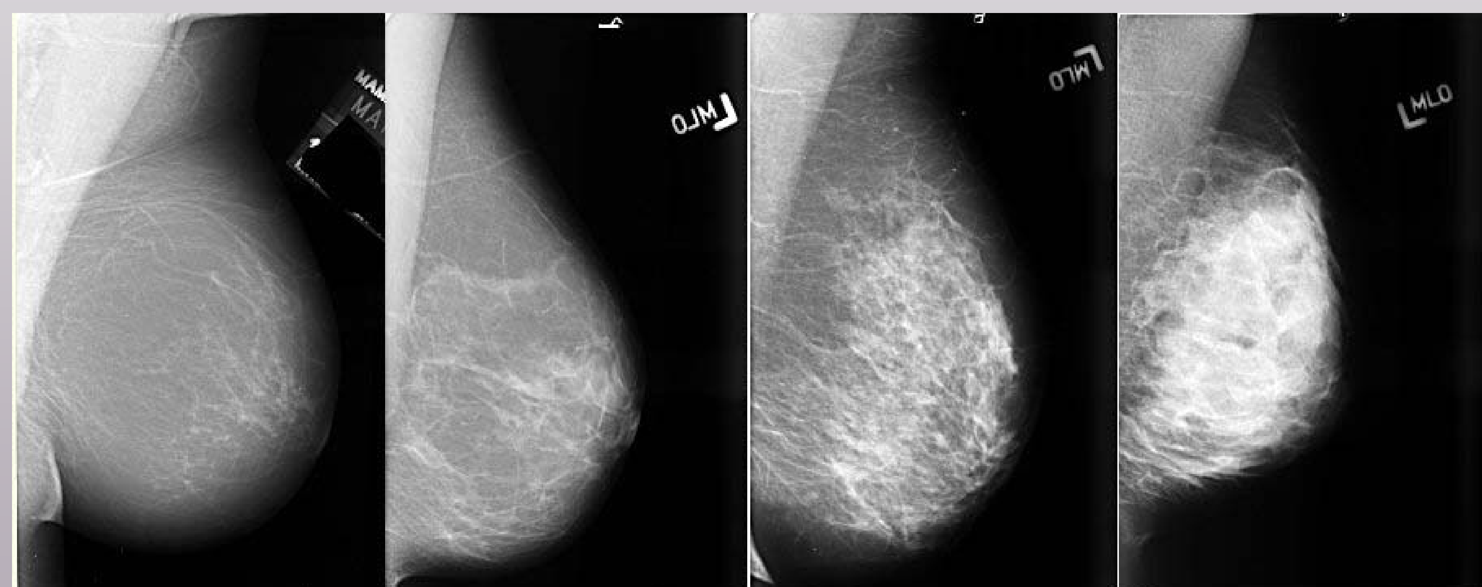
Optimized Imaging of the Breast

II. CHALLENGES

A. NORMAL BREAST DENSITY VARIATIONS

- Age, Genetics, Menstrual cycle (premenopausal women)

ADIPOSE → GLANDULAR



Source: McGill University Department of Medicine Online Mammography Tutorial

For adequate SNR^2 choice of radiographic technique must be patient- and context-specific

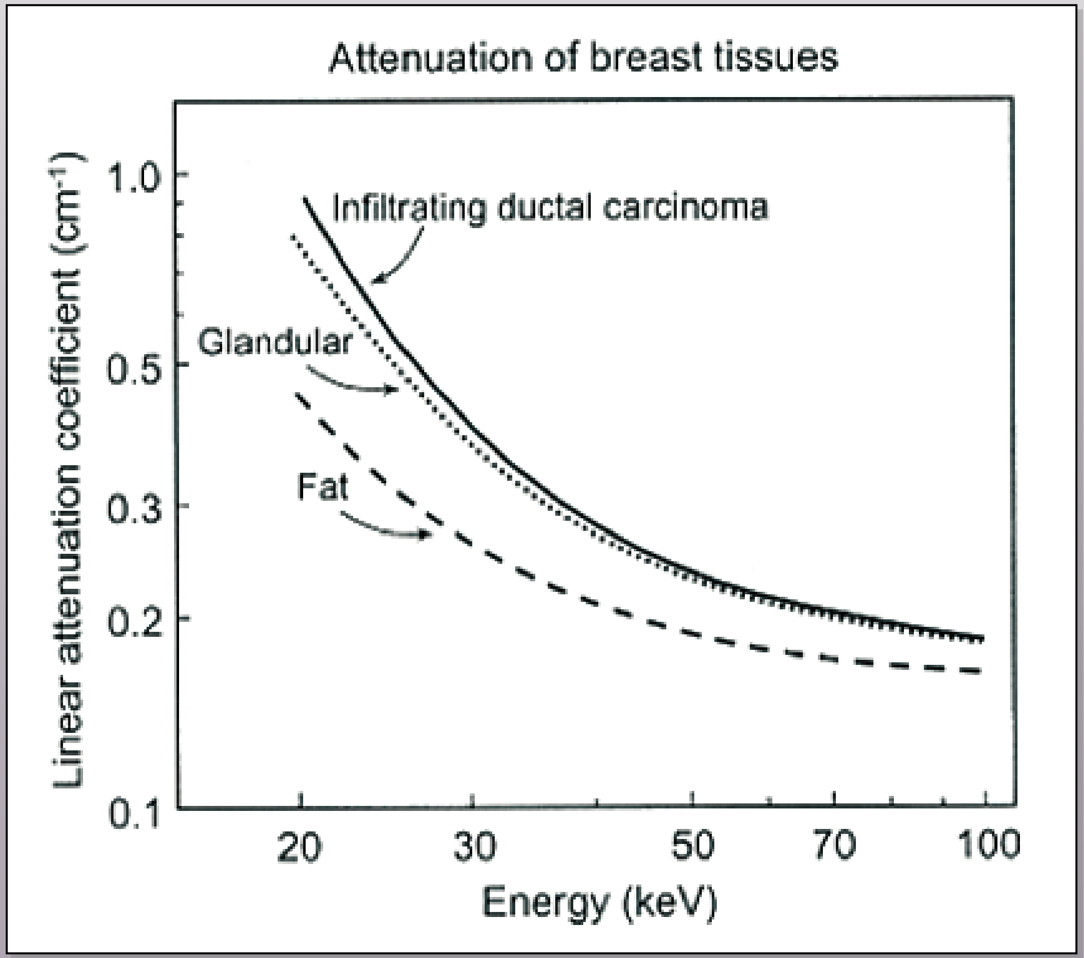
Optimized Imaging of the Breast

II. CHALLENGES

B. HIGH TISSUE CONTRAST RESOLUTION REQUIRED

Fibro-glandular and tumor tissue have similar attenuation properties

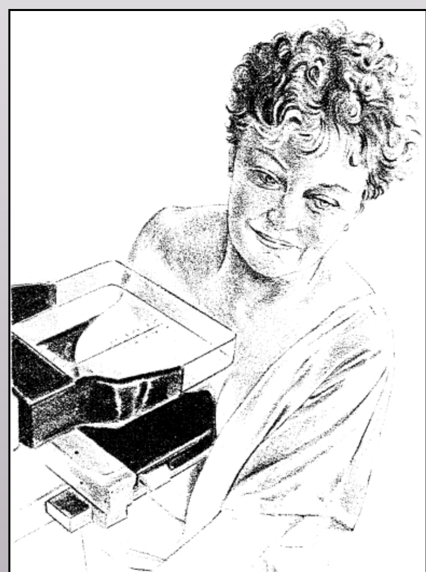
Optimize beam quality to maximize differential absorption and …



Source: Bushberg, The Essential Physics of Medical Imaging

Use COMPRESSION

Craniocaudal (CC) | Mediolateral Oblique (MLO)



Source: Basset LW, Imaging the Breast, Cancer Medicine, 6th ed

Breast Thicknesses:
2 cm - 8 cm

↓ scatter

↓ kVp

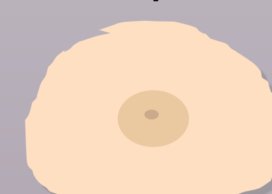
↑ contrast

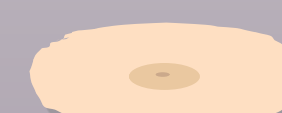
↓ mAs

↓ dose

Scatter Fraction:

0.8 – 1.0 uncompressed	0.4 – 0.5 compressed





Source: Bushberg, The Essential Physics of Medical Imaging

Optimized Imaging of the Breast

II. CHALLENGES

C. NEED FOR DEVICE-SPECIFIC OPTIMIZATION

Different:
- Technology, i.e. Receptor Sensitivity
- Target/Filter options
- Exposure and other controls
- Image Processing

May require different imaging protocols & techniques for different technologies & systems, i.e. SF versus CR, CR versus DR, Direct DR versus Indirect DR, etc…

Optimized Imaging of the Breast

III. IMAGING SYSTEM REQUIREMENTS

- High Receptor Sensitivity ↓ DOSE
- High Spatial Resolution
- High Contrast Resolution
- Low Noise
- Reproducibility
  - Consistent image quality & exposure

Optimized Imaging of the Breast

IV. PRIMARY QUALITY FACTORS

RESOLUTION	Focal Spot Size & Blur Magnification, Pixel Pitch Patient Motion Blur
CONTRAST	Tissue Density, Thickness X-Ray Beam Quality (Target/Filter/kVP)
NOISE	Receptor Sensitivity mAs / Exposure

Optimized Imaging of the Breast

V. TECHNIQUE FACTORS

Contrast	Target (Anode):	Molybdenum (Mo) Rhodium (Rh) Tungsten (W)
Contrast	Filter:	Mo, Rh, Al, Ag
Contrast	Tube Voltage:	kVp
Noise	Exposure:	mAs

▪	CONTRAST
▪	NOISE

Optimized Imaging of the Breast

VI. BREAST DOSIMETRY

Mean or Average Glandular Dose (MGD/AGD)

$$MGD = D_gN \times E$$

D_gN: Exposure normalized glandular dose

(abs. dose / unit exposure)

E: Entrance surface exposure

~ 2.0 mGy (3.0 mGy ACR limit)

TABLE 8-6. DgN CONVERSION FACTOR (mRAD PER ROENTGEN) AS A FUNCTION OF HVL AND kVp FOR Mo TARGET/FILTER: 4.5-CM BREAST THICKNESS OF 50% GLANDULAR AND 50% ADIPOSE BREAST TISSUE COMPOSITION*

	kVp							
HVL (mm)	25	26	27	28	29	30	31	32
0.25	122							
0.26	126	128						
0.27	130	132	134					
0.28	134	136	138	139				
0.29	139	141	142	143	144			
0.30	143	145	146	147	148	149		
0.31	147	149	150	151	152	153	154	
0.32	151	153	154	155	156	158	159	160
0.33	155	157	158	159	160	162	163	164
0.34	160	161	162	163	164	166	167	168
0.35	164	166	167	168	169	170	171	172
0.36	168	170	171	172	173	174	175	176
0.37		174	175	176	177	178	178	179
0.38			179	180	181	182	182	183
0.39				184	185	186	186	187
0.40					189	190	191	192

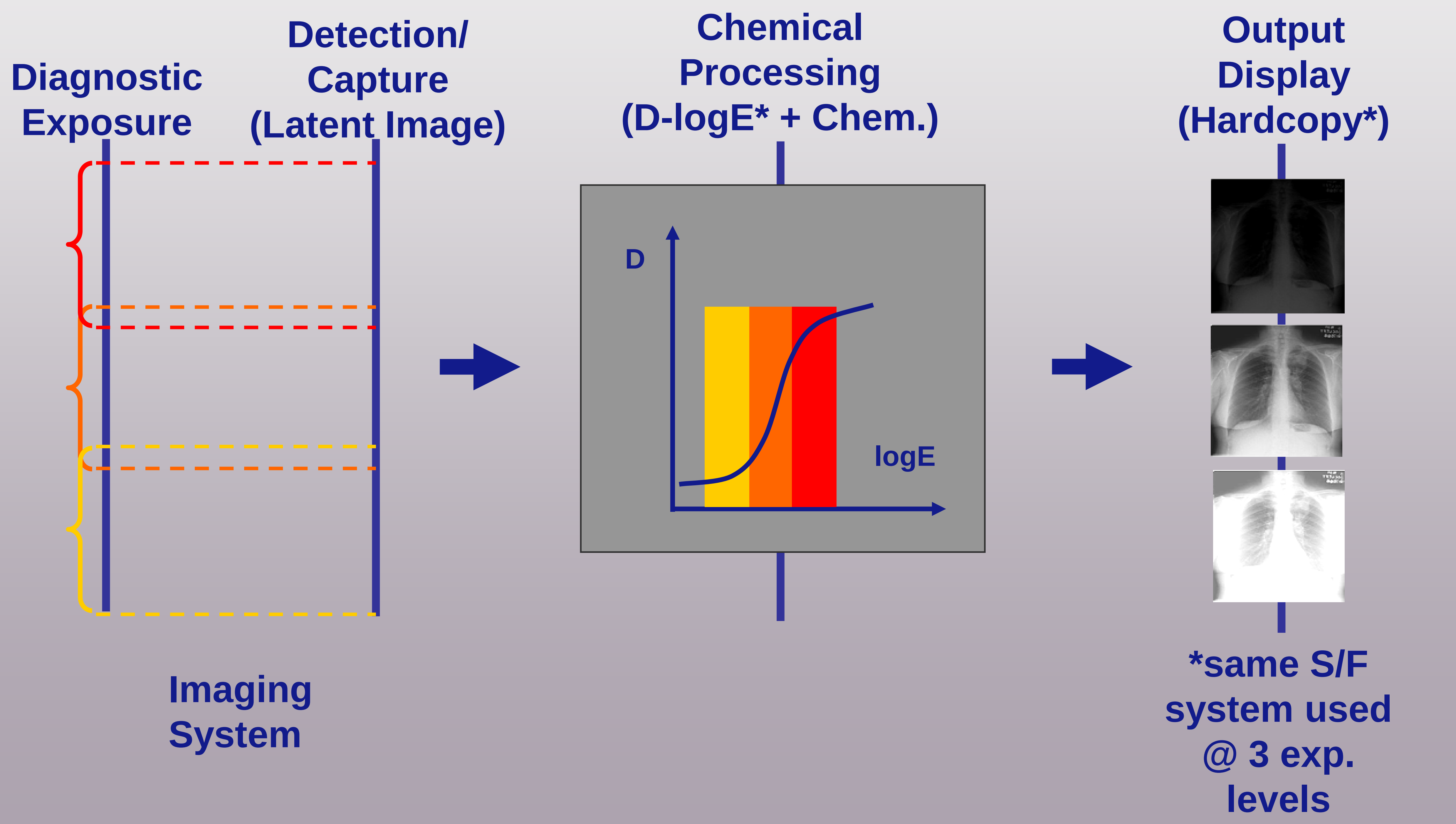
*Adapted from ACR QC Manual, 1999.

Source: Bushberg, The Essential Physics of Medical Imaging

Part 2

The Advantages of Digital Mammography

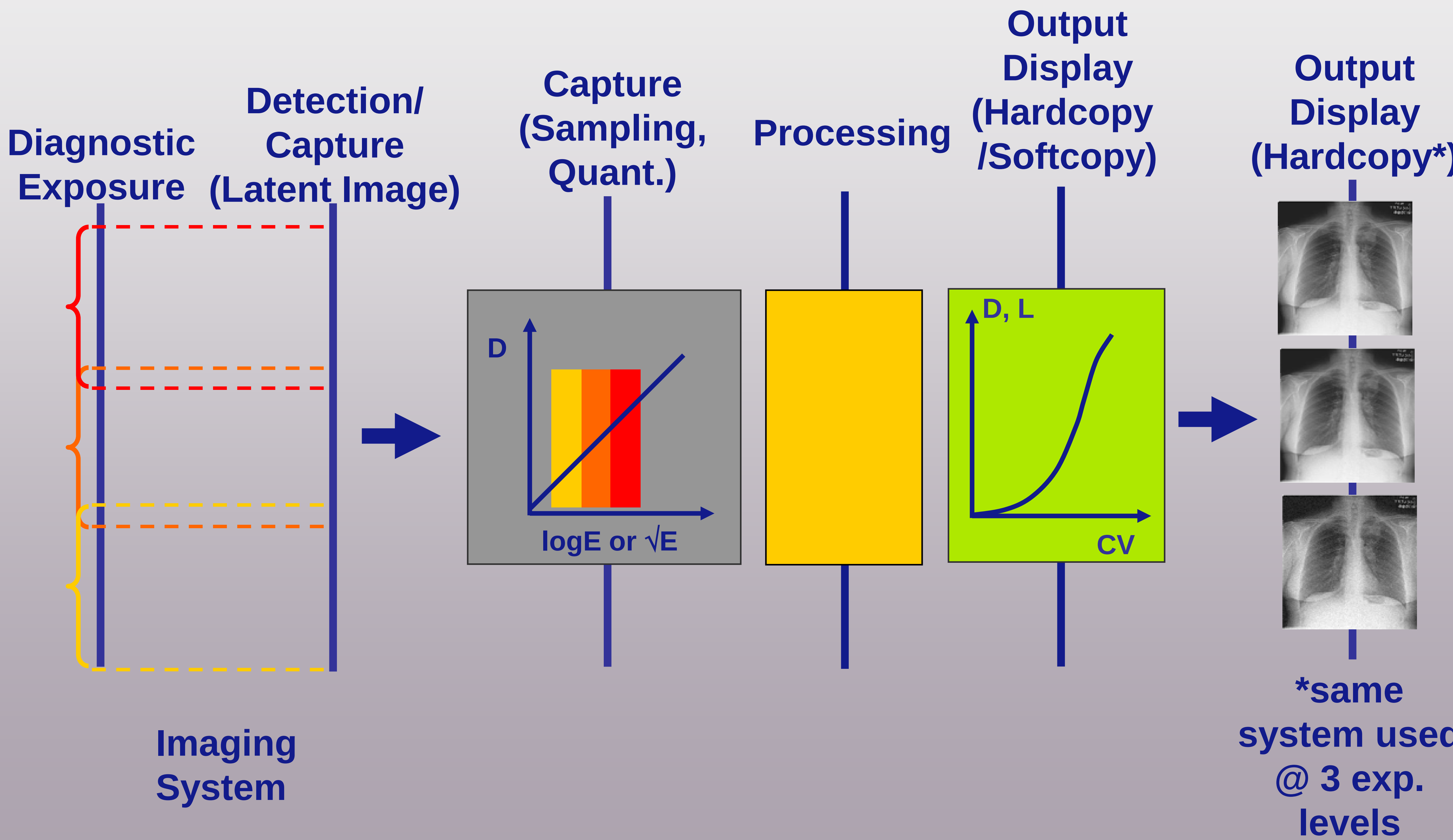
Analog Imaging Chain (Screen-Film)



Technique Optimization
Screen-Film

- Optimization criteria based on film density
- Typical Target/Filter: Mo/Mo or Mo/Rh
- Dependent on film processor performance
- Impacted by speed and latitude of film
- Film is capture, display and storage medium

Digital Imaging Chain (CR, DR)

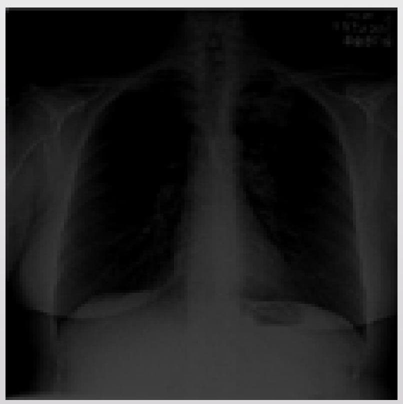


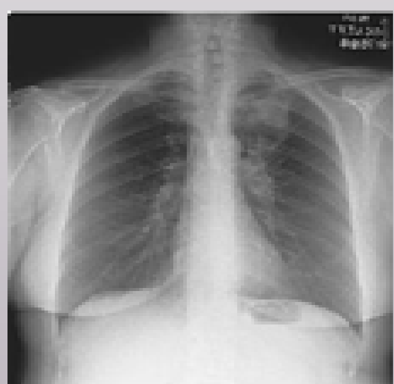
Technique Optimization
Digital Mammography

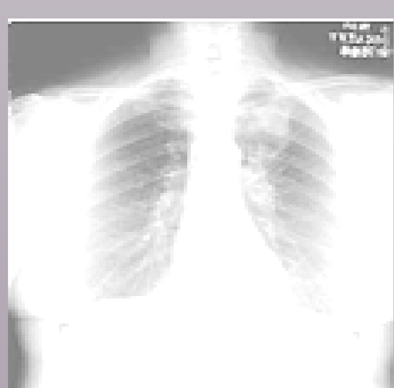
- Optimization criteria can be subjective, semi-objective or objective, e.g. based on a computed figure-of-merit (FOM)
- Prerequisite: Detector calibration & QC
- Typical Target/Filter: W/Rh
- Acquisition, processing and display can and should be optimized separately

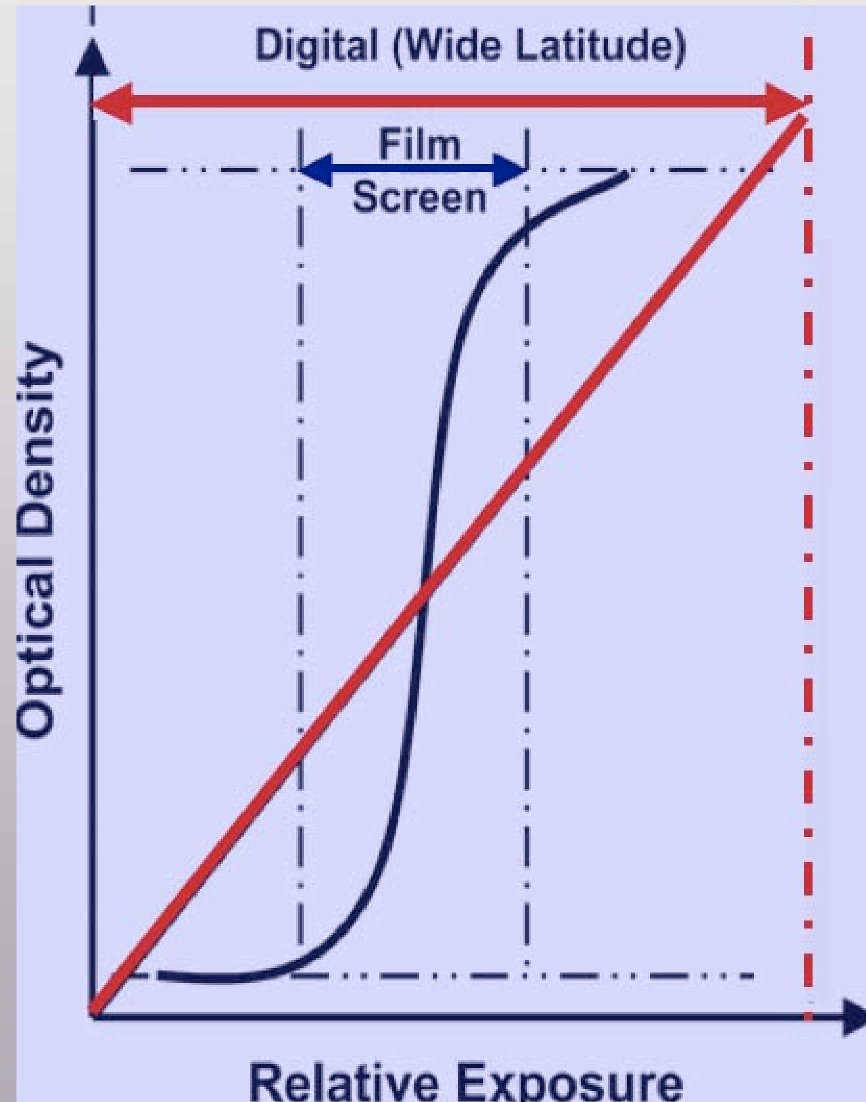
Latitude: S/F vs DR

SF









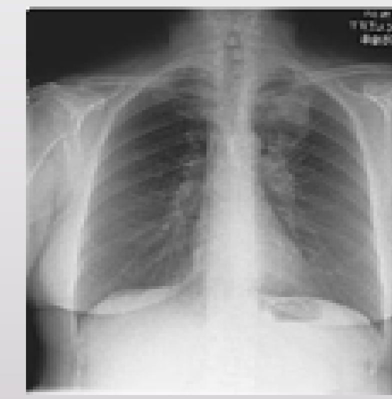
Adapted from: Mahesh M., Radiographics (2004)

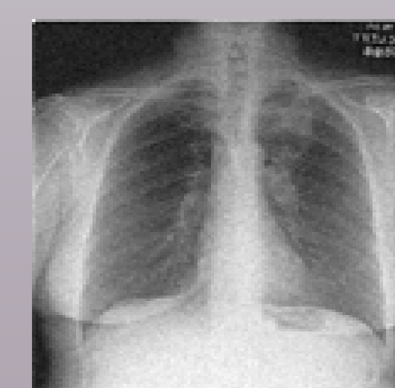
high

SNR^2

low

DR





DIGITAL MAMMOGRAPHY

CR SYSTEM COMPARISONS

CLASS	TYPE /PHOSPHOR*	MODEL	MANUFAC-TURER	PIXEL PITCH* (mm)	ACTIVE AREA (cm^2)	TARGET/ FILTER
CR	PSP BaSrFBrI:Eu	CR35-X CR85-X	AGFA	0.050	18 x 24 24 x 30	?
CR	PSP BaFBrI:Eu	ASPIRE CLEARVIEW	FUJIFILM	0.050	18 x 24 24 x 30	?
CR	PSP BaFBr:Eu	DIRECTVIEW	CARESTREAM	0.0485	18 x 24 24 x 30	?
CR	PSP BaFI:Eu	REGIUS 190	KONICA-MINOLTA	0.04375	18 x 24 24 x 30	?

* Source: NHS Report 06047 Computed Radiography (CR) Systems for Mammography (2006)

DIGITAL MAMMOGRAPHY

DR SYSTEM COMPARISONS

CLASS	TYPE	MODEL	VENDOR	PIXEL PITCH (mm)	ACTIVE RECEPTOR AREA (cm^2)	TARGET/ FILTER
DR	Indirect CsI Slot-scan CCD	Senoscan	FISCHER/ HOLOGIC	0.054 (0.027)	21 x 29	Mo/Mo Mo/Rh Rh/Rh W/Al
DR	Direct aSe	Aspire HD* (Amulet)	FUJIFILM	0.050	18 x 24 24 x 30	Mo/Mo Mo/Rh Rh/Rh
DR	Direct aSe	Selenia	LORAD/ HOLOGIC	0.070	25 x 29	Mo/Mo Mo/Rh
DR	Indirect aSi:CsI	Nuance Nuance Excel	PLANMED	0.085	17 x 24 24 x 30	W/Ag W/Rh

** NOT FDA APPROVED IN U.S.*

DIGITAL MAMMOGRAPHY

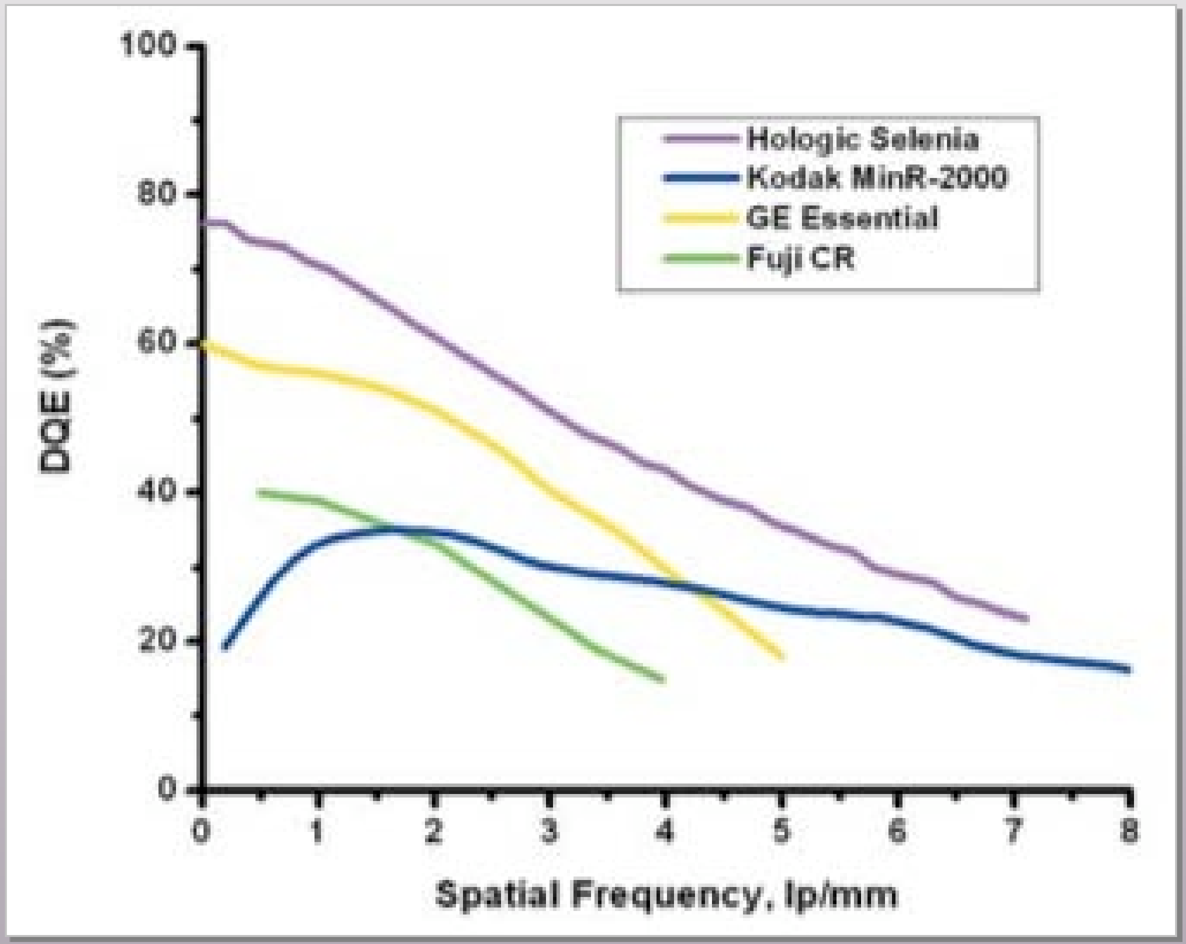
DR SYSTEM COMPARISONS

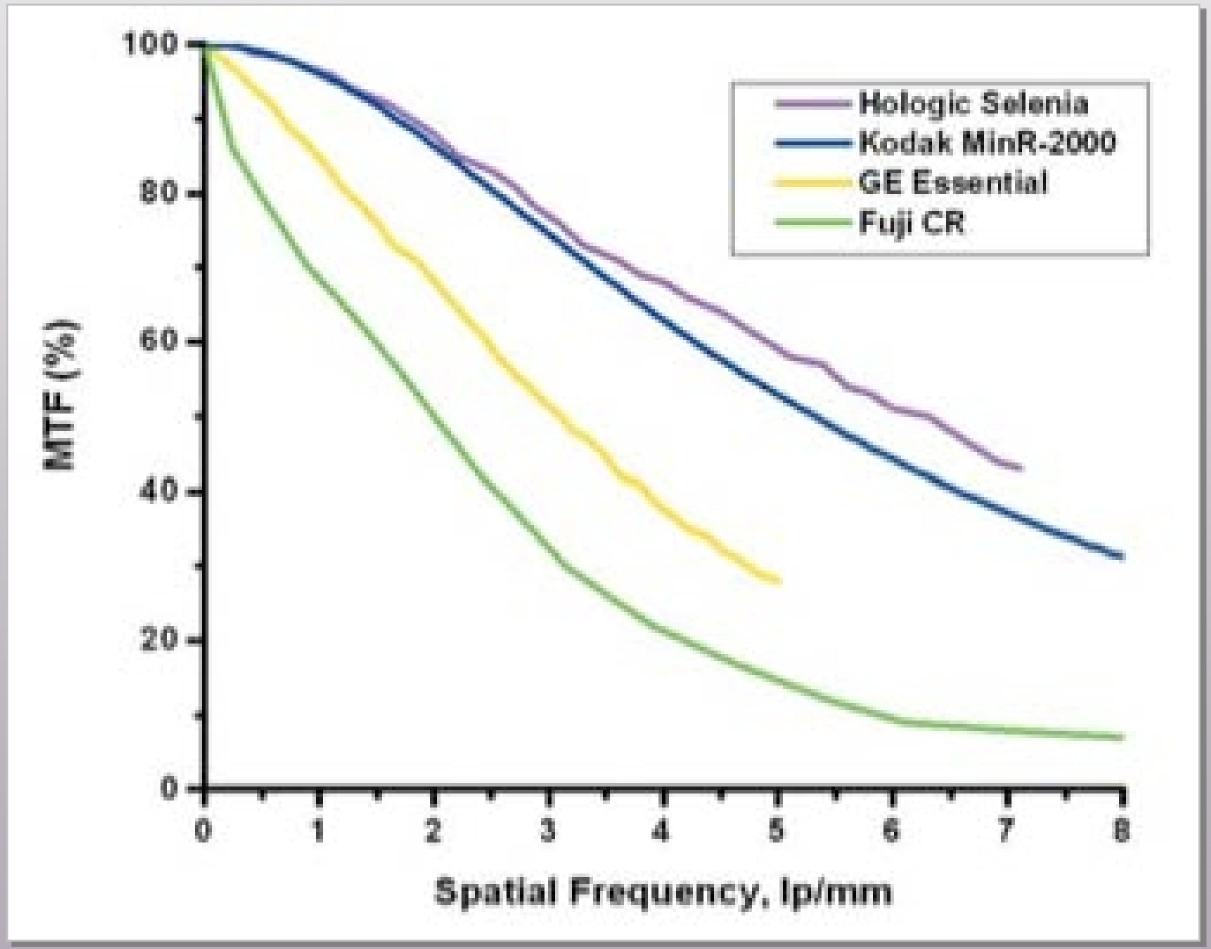
CLASS	TYPE	MODEL	VENDOR	PIXEL PITCH (mm)	ACTIVE RECEPTOR AREA (cm^2)	TARGET /FILTER
DR	Direct aSe	Novation DR Novation S Inspiration	SIEMENS	0.070 0.070 0.085	18 x 23 24 x 29 24 x 30	Mo/Mo Mo/Rh W/Rh
DR	Indirect aSi:CsI Flat Panel	2000D, DS Essential Senographe	GE	0.100 0.100 0.100	19.2 x 23 19.2 x 23 24 x 30.7	Mo/Mo Mo/Rh Rh/Rh

DIGITAL MAMMOGRAPHY

IMAGING PERFORMANCE COMPARISONS

FILM ■ CR ■ INDIRECT DR ■ DIRECT DR ■





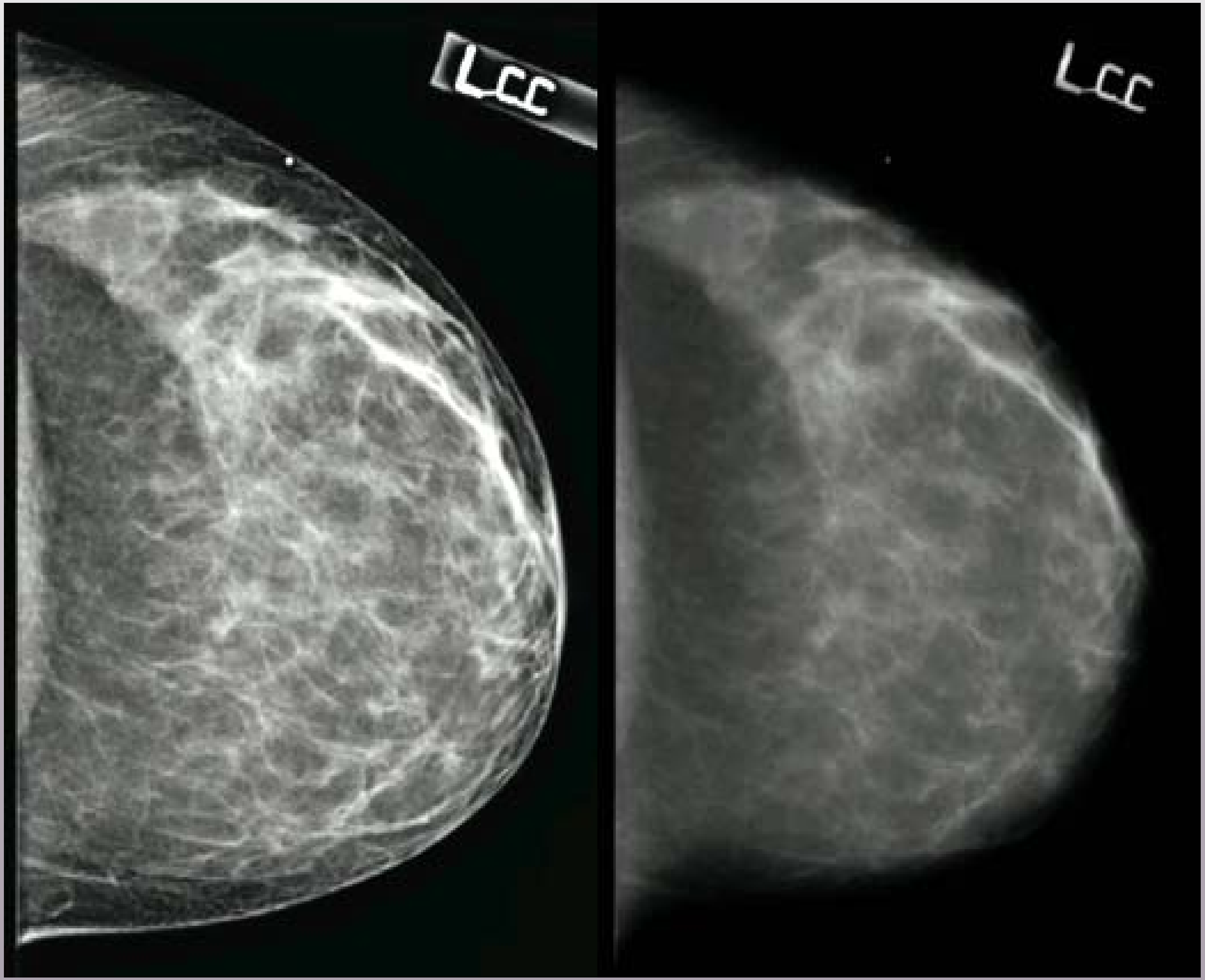
As a class DR systems typically have lower resolution than screen/film

Source: A. Smith white paper

Why go Digital ?

DIGITAL

SCREEN-FILM



Advantages of Digital

- Increased throughput
- Increased sensitivity
- Increased latitude
- Better contrast resolution
- Contrast adjustment
- Image processing
- Advanced applications
- Decreased dose
- Indefinite archival
- Simultaneous access

But ..

- Lower spatial resolution (generally)

Digital is the Future

As of 12/2009:

59% of MQSA certified facilities had 1 or more FFDM units

60% of all MQSA certified units were FFDM

New mammography unit sales in US almost exclusively digital

Source: MQSA website

Part 3

Technique Optimization Methodology

Technique Optimization Methods

- Spectral Simulation using Monte Carlo methods
- Experimental Studies using Objective Criteria (Figures-of-Merit)
- Clinically-Relevant Task Based Observer Studies
- Prospective or Retrospective Clinical Studies
- *Subjective Evaluation of Image Quality Phantom Data*

Example

Technique Optimization Protocol

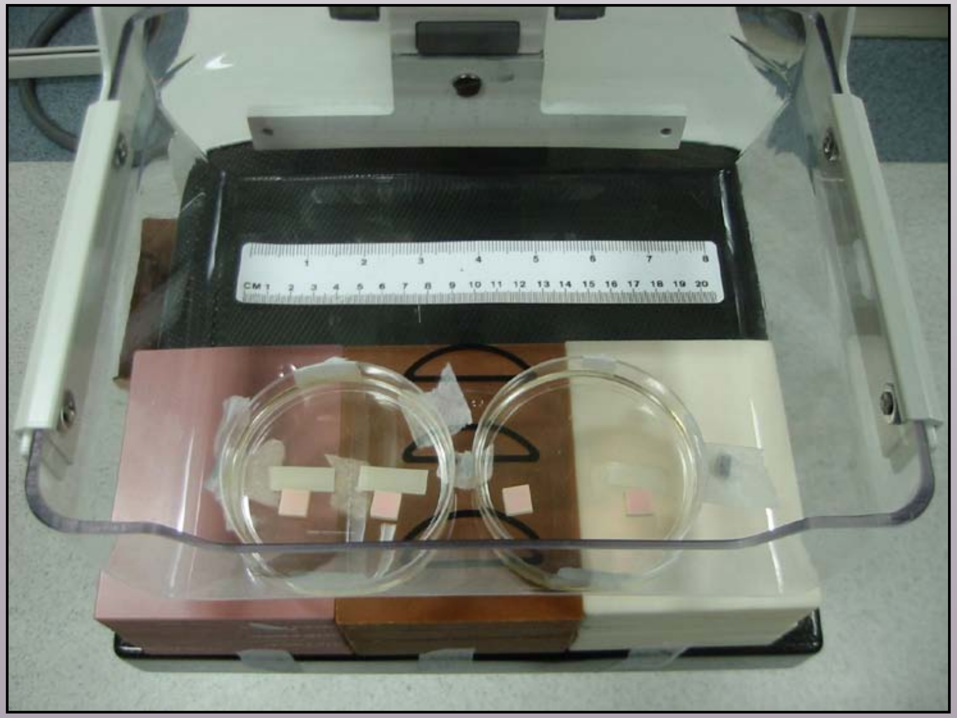
- objective figure of merit (FOM)
- quotient of $SdNR^2$ to MGD
- computed for masses and calcs

Technique Optimization Protocol

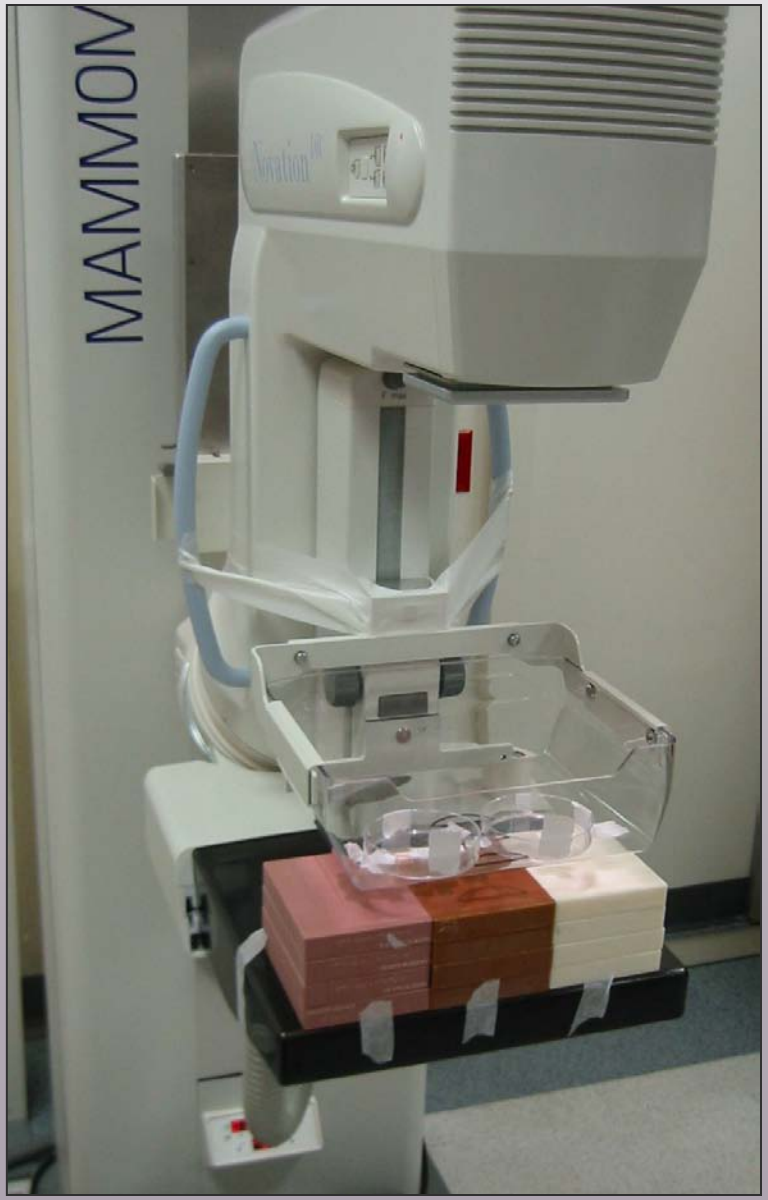
Physical Setup

Siemens Mammomat Novation DR

Mo/Mo vs W/Rh
kVp: 23, 25, 27, 29, 31, 33, 35



Ranger et al, Med Phys 37 (2010



Technique Optimization Protocol

FIGURE – OF – MERIT

$$FOM = \frac{SdNR^2}{MGD}$$

← Quality

← Dose

$SdNR^2$: Signal Difference to Noise Ratio Squared

MGD: Mean Glandular Dose (computed from spectral estimates using Spectra*)

** Boone et al, Radiol 213 (1999)*

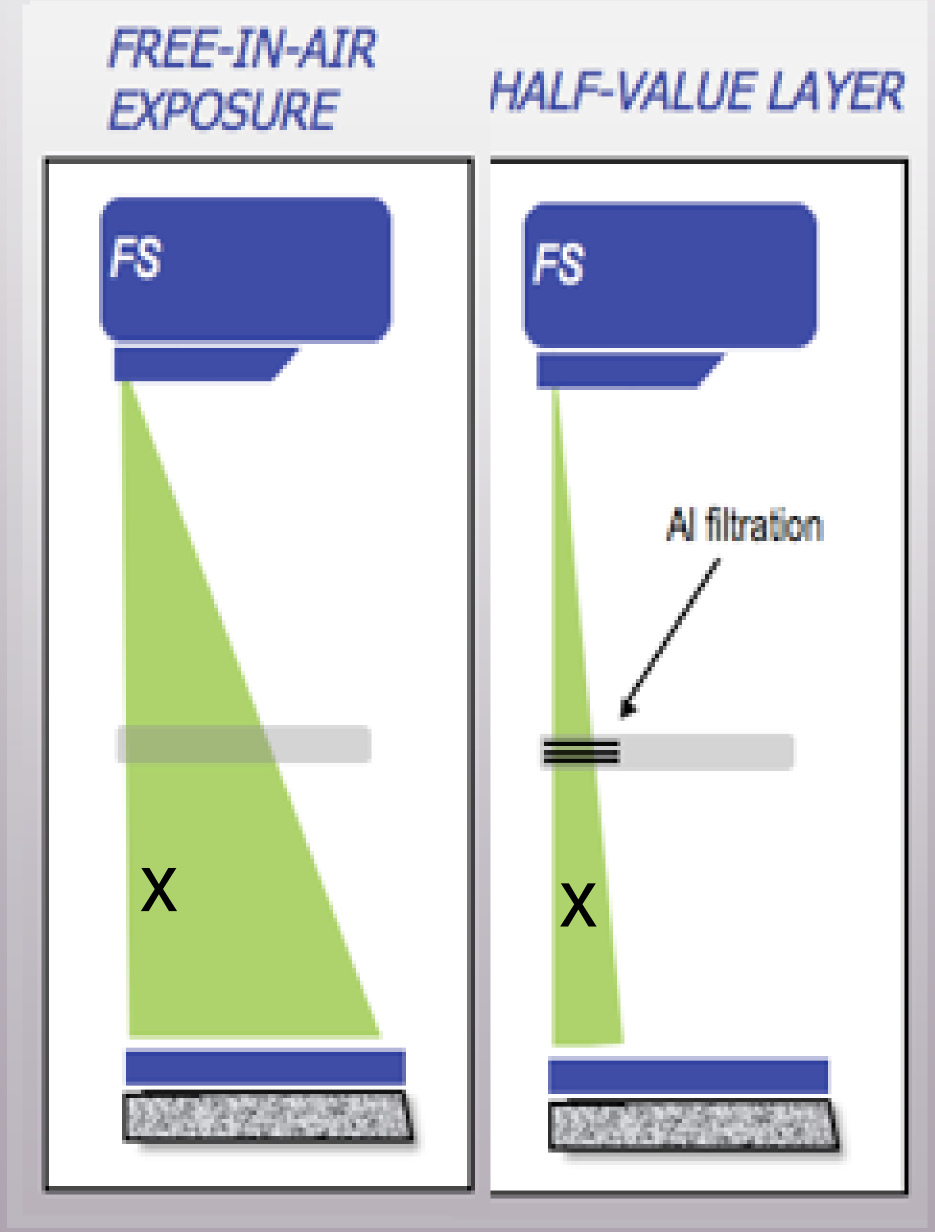
Technique Optimization Protocol

Characterizing the Beam Quality & Exposure

Measure free-in-air exposure at each beam quality: target/filter & kVp

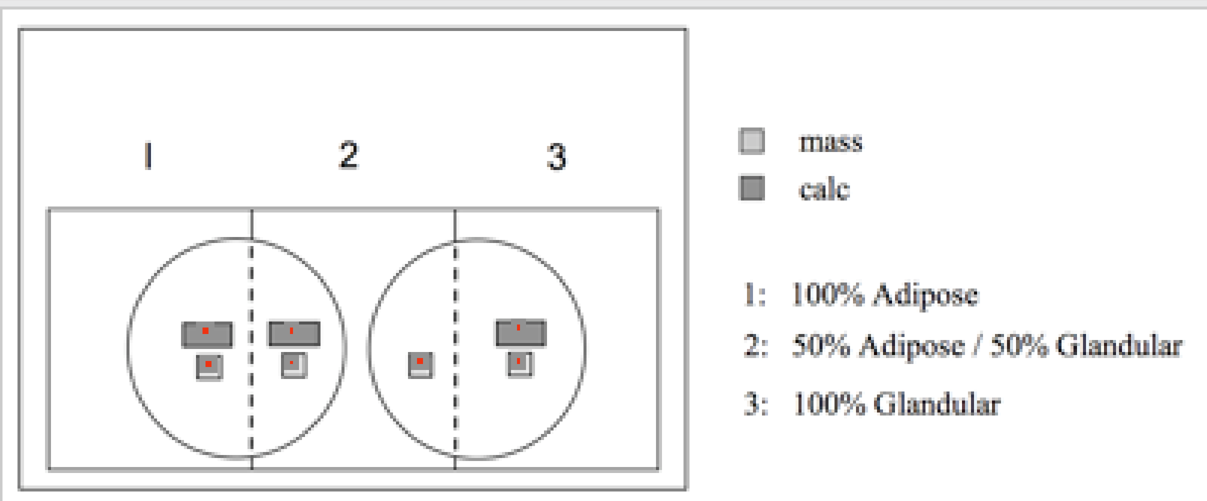
Extrapolate to phantom surface using inverse square law

Measure HVL at each beam quality using narrow beam geometry and calibrated ion chamber fitted with a Mammo probe.

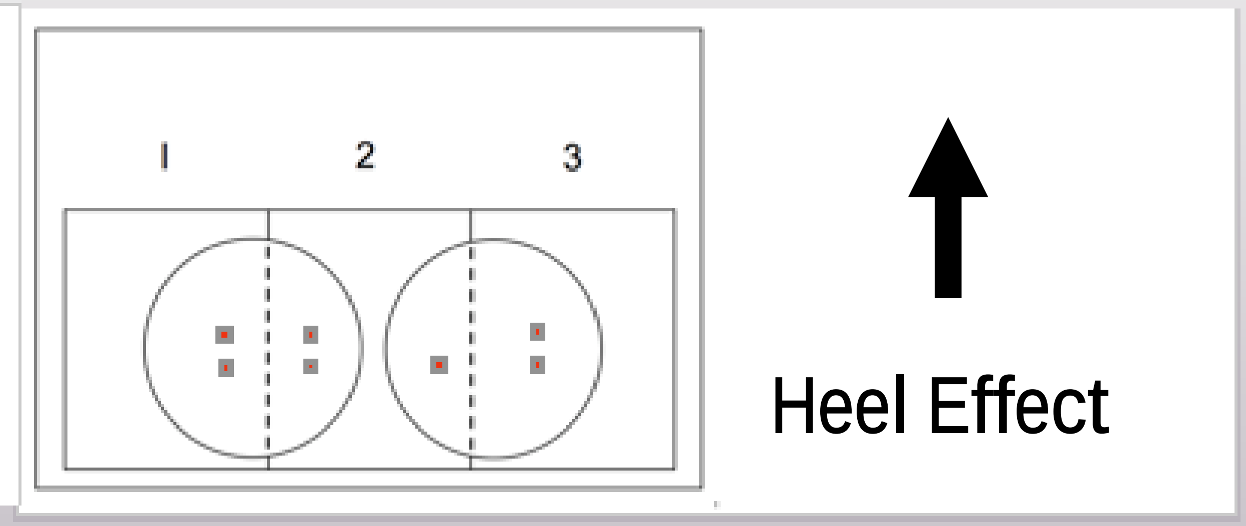


Technique Optimization Protocol

Computation of SdNR²



With Inclusions



Without Inclusions

$\bar{S}_i$: mean signal in ROI overlying inclusion

$\bar{S}_b$: mean signal in ROI in background (same location)

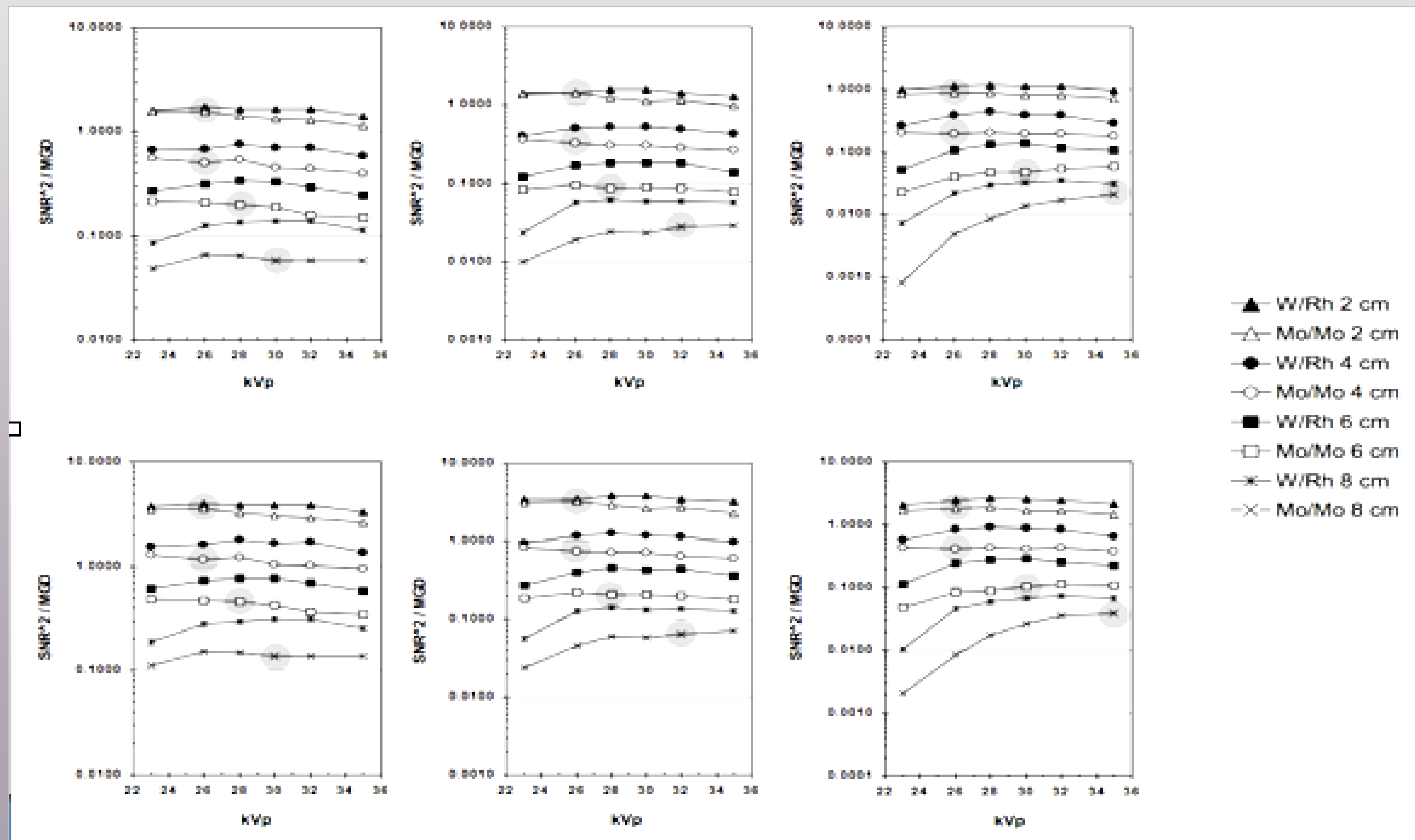
Technique Optimization Protocol

FOM Results

0% Gland | 50% Gland | 100% Gland

MASSES

CALCS



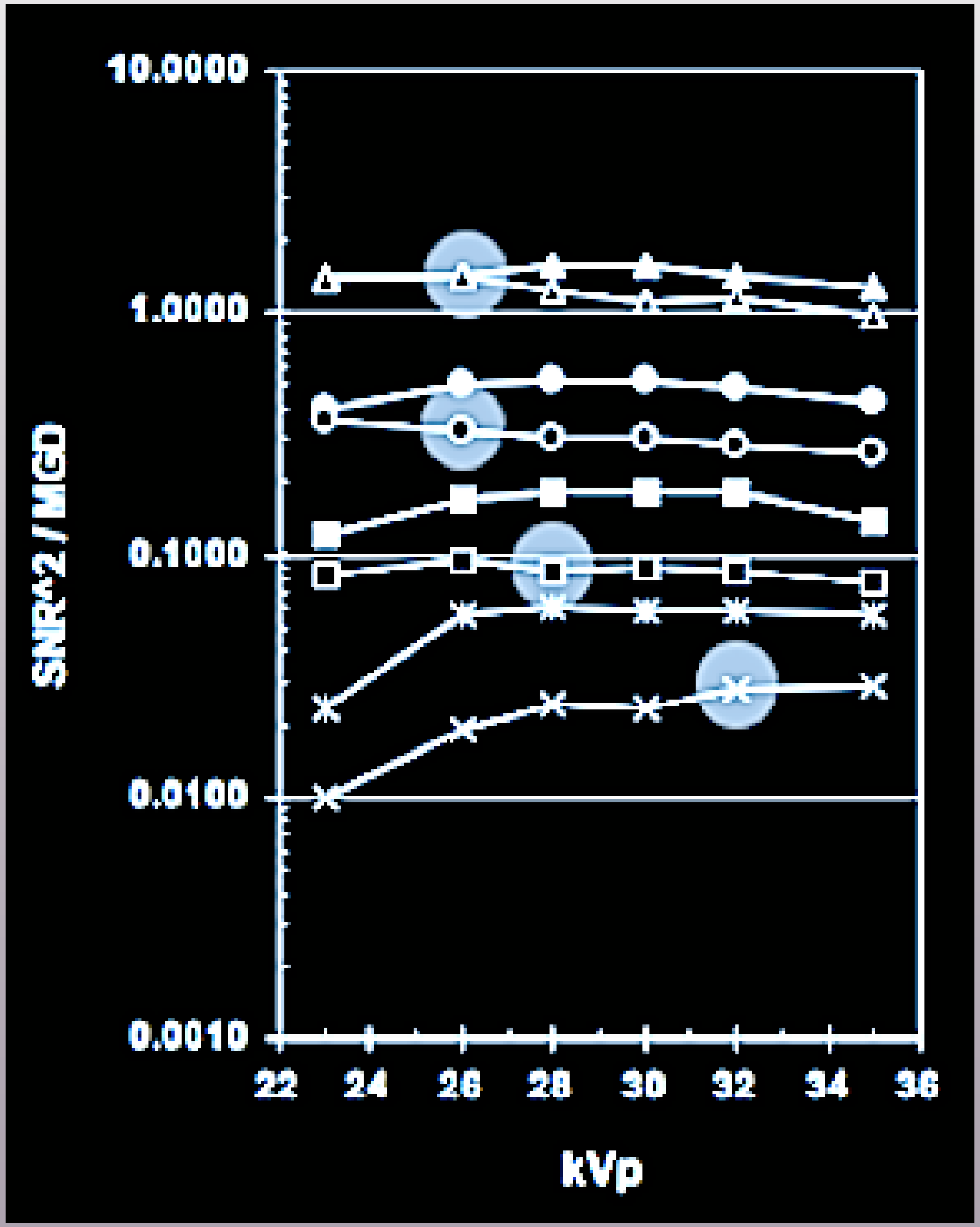
Technique Optimization Protocol

Computation of the FOM^R and Dose Savings

Relative FOM (FOM^R) gives the image quality improvement at the new technique (W/Rh) in comparison to the optimized reference technique (Mo/Mo ●) for the equivalent glandular dose

$$FOM^R = \frac{FOM_{EVAL}}{FOM_{REF}}$$

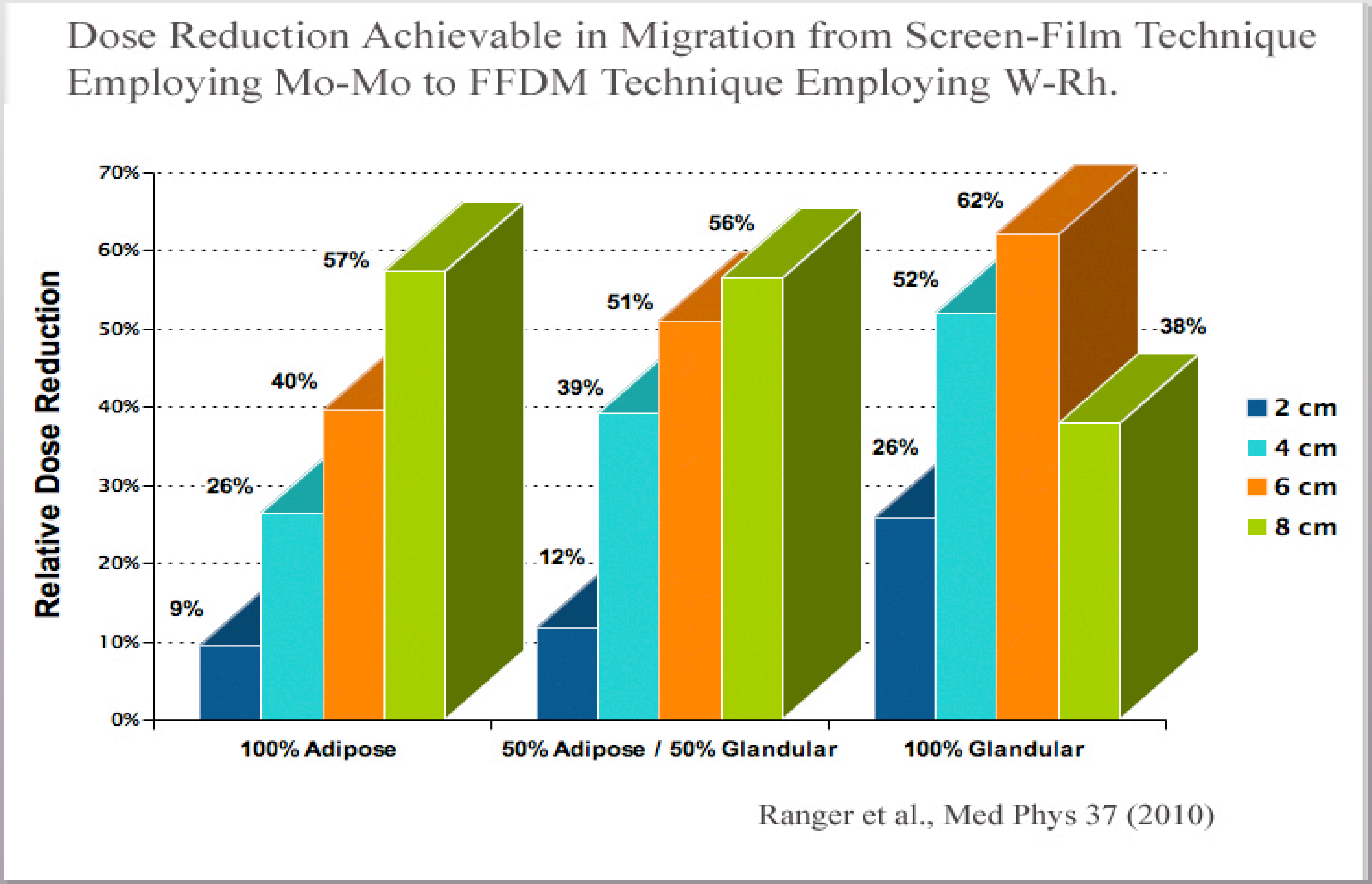
RELATIVE DOSE SAVINGS ⟶ $\left(FOM^R\right)^{-1}$



Technique Optimization Protocol

Relative Dose Savings

Siemens Novation DR



Dose savings likely to be much more conservative ....

WHY?

Breast Density:
What is typical or average ?

Common misconception that average breast density is 50% adipose tissue to 50% fibroglandular or “50-50”

The myth of the 50-50 breast

M. J. Yaffe[a)]
Sunnybrook Health Sciences Centre, University of Toronto, Toronto, Ontario M4N 3M5, Canada

J. M. Boone and N. Packard
UC Davis Medical Center, University of California-Davis, Sacramento, California 95817

O. Alonzo-Proulx
Sunnybrook Health Sciences Centre, University of Toronto, Toronto, Ontario M4N 3M5, Canada

S.-Y. Huang
UC Davis Medical Center, University of California-Davis, Sacramento, California 95817

C. L. Peressotti
Sunnybrook Health Sciences Centre, University of Toronto, Toronto, Ontario M4N 3M5, Canada

A. Al-Mayah and K. Brock
University Health Network, University of Toronto, Toronto, Ontario M5G 2M9, Canada

(Received 30 April 2009; revised 23 September 2009; accepted for publication 29 September 2009; published 5 November 2009)

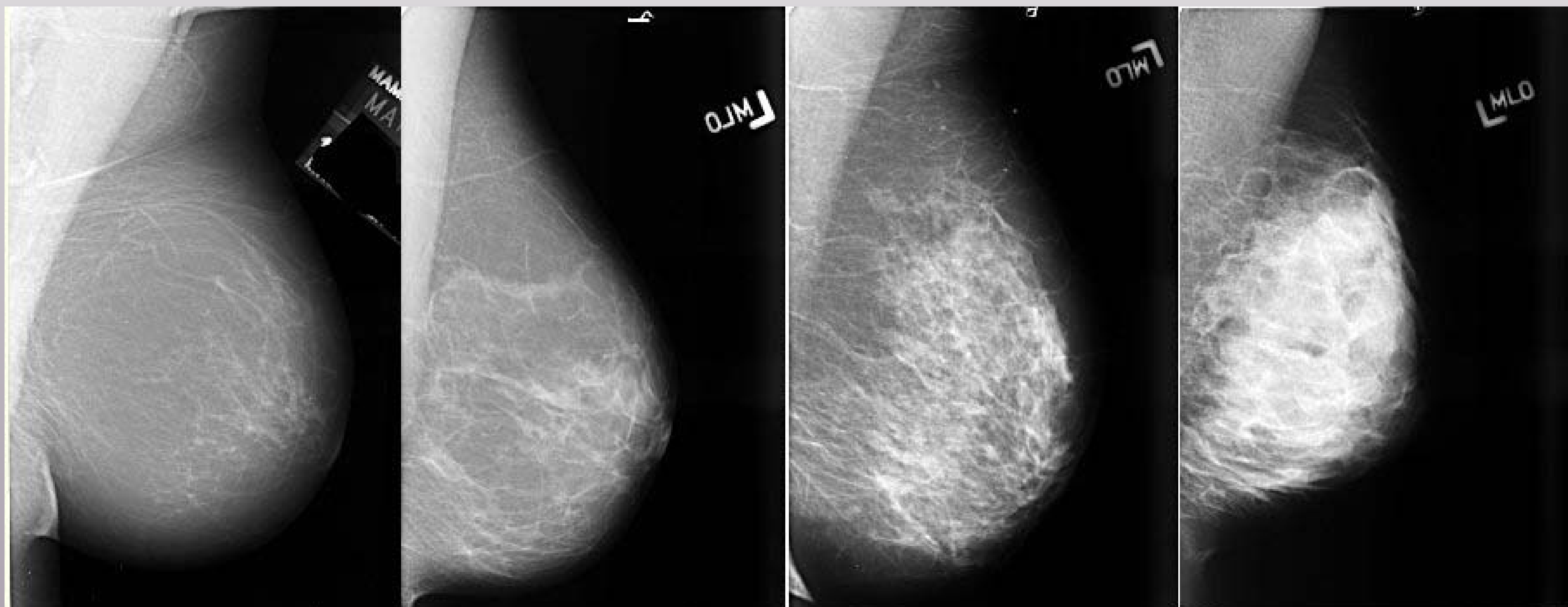
Ref: Yaffe et al, The Myth of the 50-50 Breast

Normal Density Variations

ACR BI-RADS BREAST DENSITY CLASSIFICATION SCHEME

Category 1 | Category 2 | Category 3 | Category 4

ADIPOSE → GLANDULAR



Source: McGill University Department of Medicine Online Mammography Tutorial

Part 4

What does all this mean in the clinic ?

Summary Key Concepts

Image quality must be optimized in the context of the COST (RISK) associated with the patient's EXPOSURE (DOSE) and that is accomplished via Technique Optimization

- Tradeoff between QUALITY and DOSE

- Optimization must be patient- and application-specific, i.e. tailored to patient size, exam type and other relevant factors

Recommendations

1. Automatic exposure (and other controls, e.g. automatic kVp, Target-Filter selection, etc..) controls should be verified as part of routine acceptance testing and checked on a routine basis.

2. AEC cells in conventional mammo units are located beneath the grid. CR cassette structure/sensitivity varies from vendor to vendor. Must calibrate the AEC for the intended CR casette type and only use those cassettes

3. Newer FFDM systems employ a virtual AEC in conjunction with a short prescan to determine the exposure termination conditions. Make sure it works as intended

Recommendations

4. An imaging QA program must include monitoring of the system in the context of its intended clinical use
   a PROPERLY OPERATING imaging system is
   NOT the same as one OPERATED PROPERLY

   - *Validate vendor-recommended techniques/protocols*
   - *Establish written imaging protocols and SOPs*
   - *Mandate ongoing staff training and in-services*
   - *Conduct routine audits to ensure compliance*

ACKNOWLEDGMENTS

Information or Assistance Provided by:

DUKE

Joseph Y. Lo, PhD

Ehsan Samei, PhD

Jay A. Baker, MD

Anne Jarvis

SIEMENS

Thomas M. Mertelmeier, PhD

OTHER

Eric Gingold, PhD

SAM Question #1

Which of the following is NOT an advantage of digital mammography over screen film mammography:

20%	a)	improved throughput
20%	b)	improved latitude
20%	c)	higher spatial resolution
20%	d)	decreased dose for comparable image quality
20%	e)	image processing and digital archival

10

SAM Question #1

Which of the following is NOT an advantage of digital mammography over screen film mammography:

(a) improved throughput
(b) improved latitude
(c) higher spatial resolution
(d) decreased dose for comparable image quality
(e) image processing and digital archival

Answer: (c)

Ref: Williams, M.B., Fajardo L.L., Digital Mammography: Performance Considerations and Current Detector Designs, Acad Radiol 3:429-437 (1996)

SAM Question #2

The technique factor that has the strongest impact on digital mammography image quality as reflected in a Figure-of-Merit (FOM) computed from the ratio of CNR2 or SdNR2 to MGD is:

20%	a)	focal spot size
20%	b)	mAs
20%	c)	field size
20%	d)	kVp
20%	e)	target / filter combination

10

SAM Question #2

The technique factor that has the strongest impact on digital mammography image quality as reflected in a Figure-of-Merit (FOM) computed from the ratio of SNR^2 or $SdNR^2$ to MGD is:

(a) focal spot size
(b) mAs
(c) field size
(d) kVp
(e) target / filter combination

53

Answer: (e)

Ref1: "Optimization of Exposure Factors in Full Field Digital Mammography", Williams et al, Med. Phys. 35: 2414-23 (2009)

Ref2: "A Technique Optimization Protocol and the Potential for Dose Reduction in Digital Mammography", Ranger NT, Lo JY, Samei E, Med. Phys. 37: 962-9 (2010)

SAM Question #3

In digital mammography, the approximate Mean Glandular Dose (MGD) for a 5 cm thick average density breast imaged using automatic exposure control with a W/Rh target/filter combination would be closest to:

20%	a) 0.02 mGy
20%	b) 0.2 mGy
20%	c) 2.0 mGy
20%	d) 20.0 mGy
20%	e) 200.0 mGy

10

SAM Question #3

In digital mammography, the approximate Mean Glandular Dose (MGD) for a 5 cm thick average density breast imaged using automatic exposure control with a W/Rh target/filter combination would be closest to:

(a) 0.02 mGy
(b) 0.2 mGy
(c) 2.0 mGy
(d) 20.0 mGy
(e) 200.0 mGy

Answer: (c)

Ref: "Comparison of Acquisition Parameters and Breast Dose in Digital Mammography and Screen-film Mammography in the American College of Radiology Imaging Network Digital Mammographic Imaging Screening Trial", Hendrick RE, Pisano E, Averbukh A, Moran C, Berns EA, Yaffe MJ, Herman B, Acharyya S, Gatsonis C, AJR 194: 362-369 (2010)

SAM Question #4

For a 4 cm breast with a composition ratio of 50% glandular to 50% adipose, the magnitude of dose reduction achievable for comparable image quality in the transition from screen/film to digital mammography is approximately:

20%	a)	10 %
20%	b)	20 %
20%	c)	40 %
20%	d)	60 %
20%	e)	80 %

10

SAM Question #4

For a 4 cm breast with a composition ratio of 50% glandular to 50% adipose, the magnitude of dose reduction achievable for comparable image quality in the transition from screen/film to digital mammography is approximately:

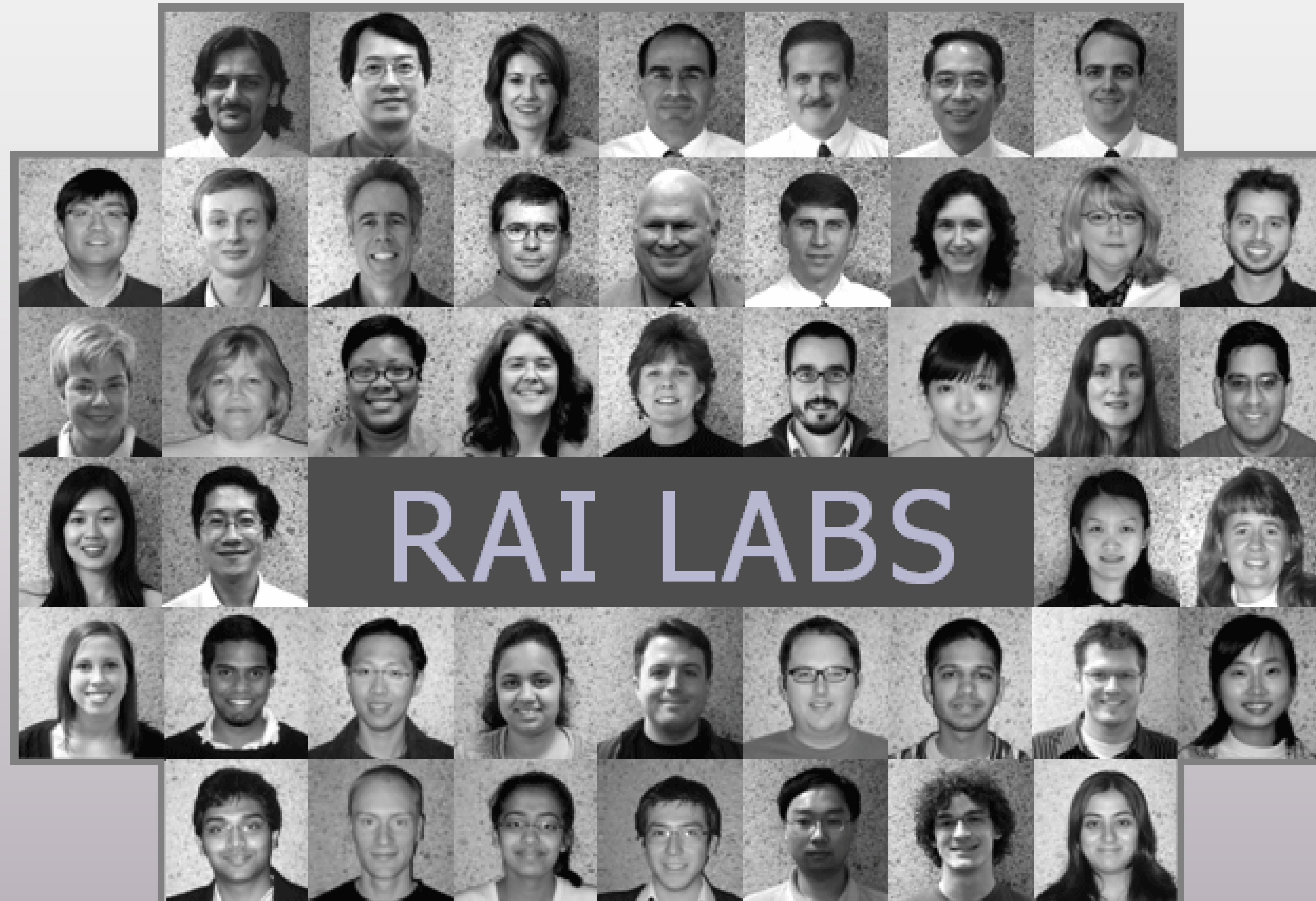
(a) 10 %
(b) 20 %
(c) 40 %
(d) 60 %
(e) 80 %

Answer: (c)

Ref: "A Technique Optimization Protocol and the Potential for Dose Reduction in Digital Mammography", Ranger NT, Lo JY, Samei E, Med. Phys. 37: 962-9 (2010)

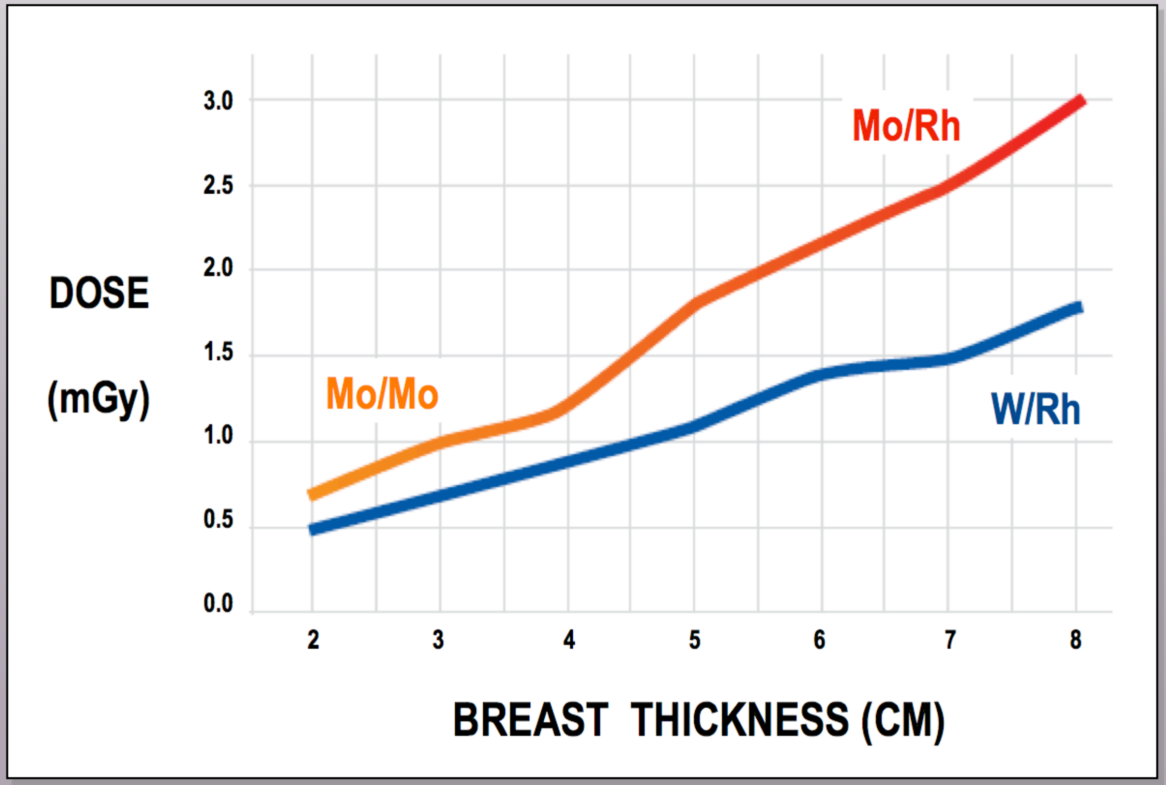
DUKE
ADVANCED
IMAGING
LABORATORIES

Thank you for your attention.



Email: NicoleTRangerMSc@gmail.com

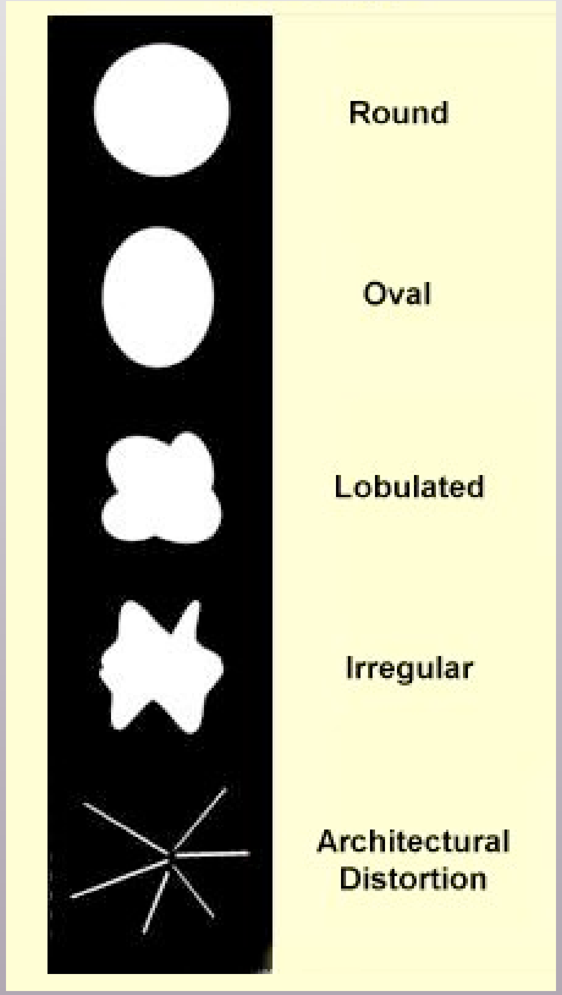
OLD SLIDES



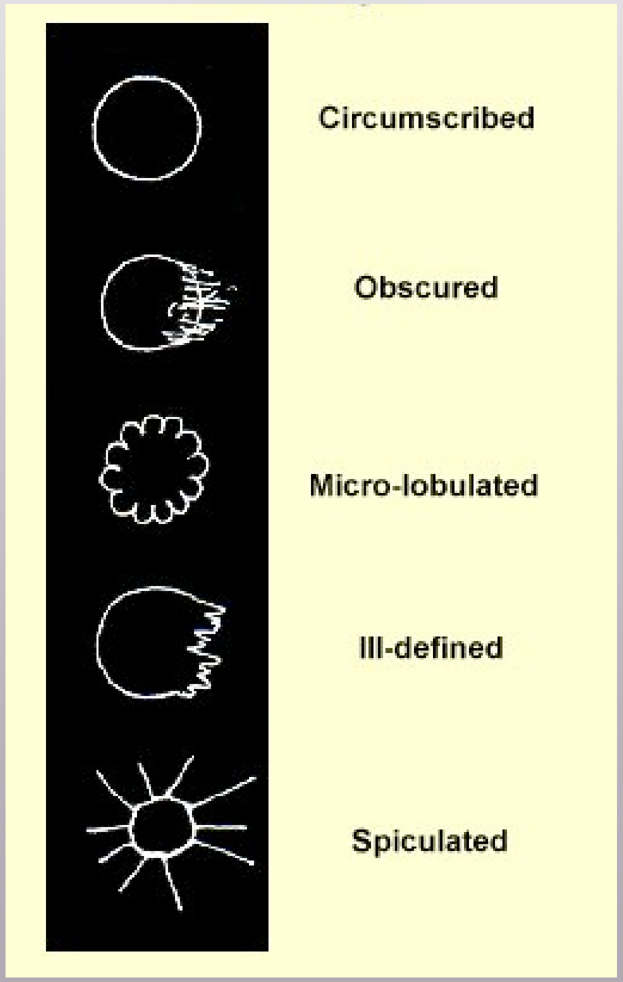
Source: IMS Giotto 3D brochure

Characterizing Breast Masses

Mass Shape



Mass Margins



Characterizing Microcalcifications

Low Probability or Typically Benign

Skin calcifications, lucent, polygonal shape
Vascular calcifications
Coarse, larger calcifications

NEED EXAMPLE IMAGES/FIGURES

Intermediate Probability

Indistinct or amorphous microcalcifications

High Probability

Clusters of heterogeneous or pleomorphic calcifications, irregular size & shape & < 0.5 mm diameter are suspicious

Fine linear or branching calcifications < 1 mm in with are associated with necrotic cancer cells

Need a image quality- & dose-sensitive metric to objectively assess optimization

Typical Calibrations (DR)

Correction for bad detector elements (dels)

Flat-field correction

Correction for radiation field non-uniformity (i.e.Heel Effect)

Gain and offset correction for each del

Correction for velocity variation during scan (CR)

Correction for geometric distortion *

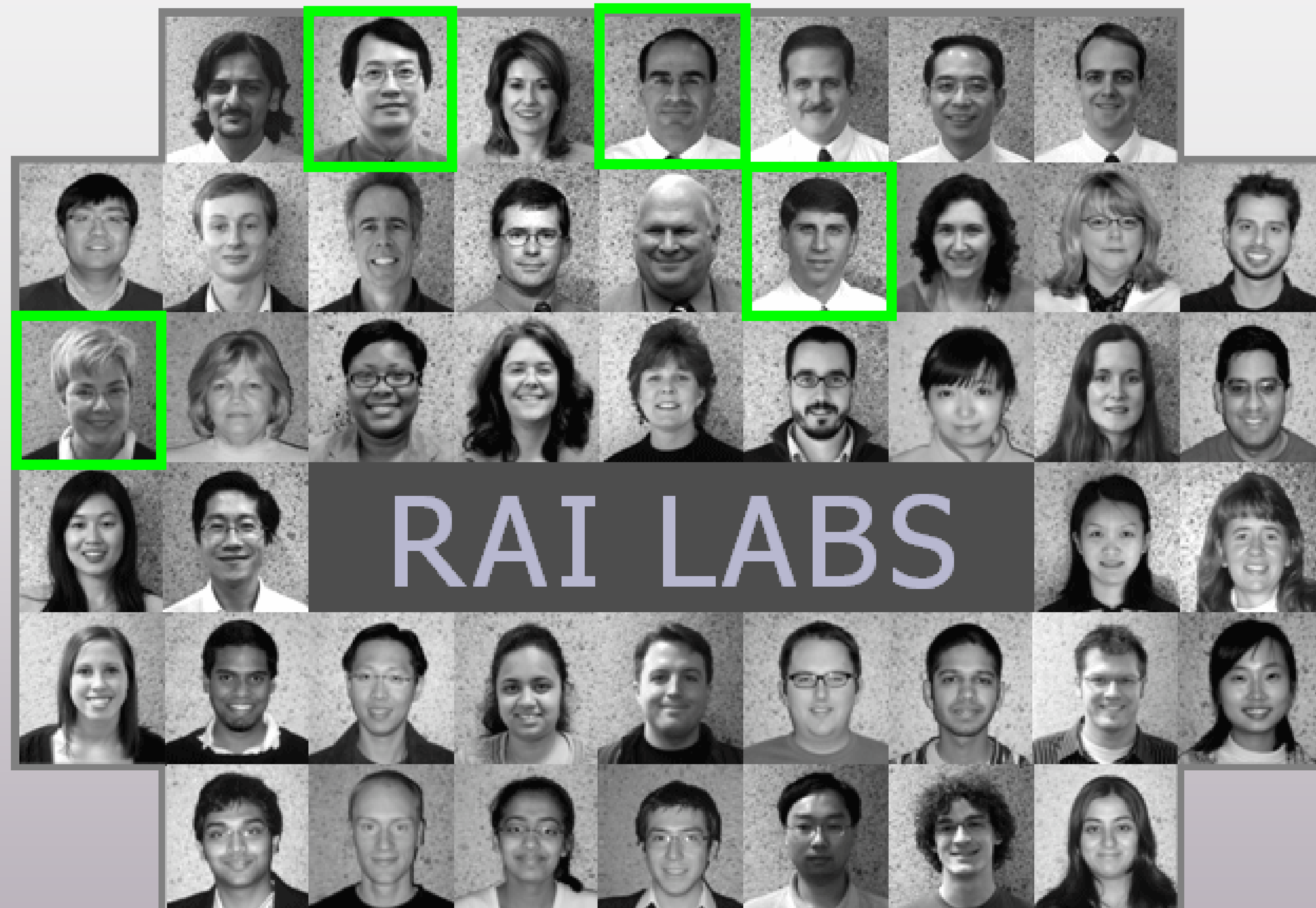
* Primarily in CCD lens-based imaging systems

study published in September 2005 in the *New England Journal of Medicine compareddigital mammograms to film mammograms. The study involved 49,000 women in North America with no known signs of breast cancer. The women were screened using both digital and film mammograms at the beginning of the study and again one year later. Breast cancer was found in 335 of the women. The researchers determined that digital mammograms were superior to film mammograms for three groups:women under 50 years of agewomen with dense breastswomen who have not yet gone through menopause, or who have been in menopause less than one year.Digital mammograms did not prove to be more beneficial for post-menopausal women over age 50 that do not have dense breasts. Additionally, both forms of mammogram had the same rate of false positives.*

Recommendations

- Take advantage of the free resources available
- Invest in a high quality IEC-compliant edge device
- Use lower purity “legacy” Al not the ≥ 99.9% purity Al specified by the standard (test Al before use)
- Review the fundamentals of DQE physics
- Study the body of literature on DQE testing
- Obtain the IEC standards for reference
- Recruit a “DQE Mentor”

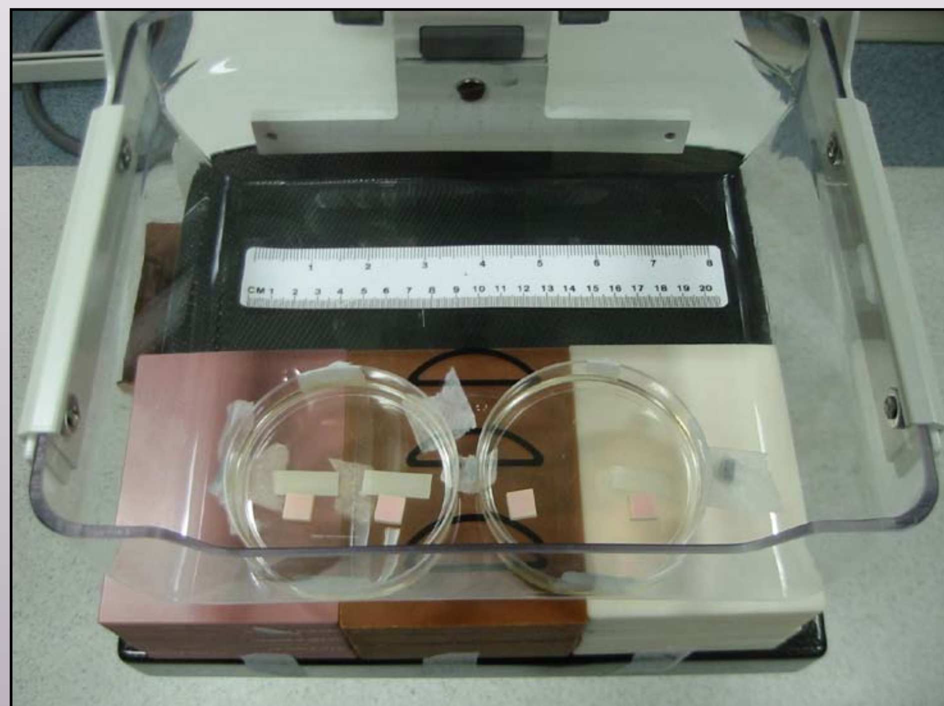
Thank you for your attention.



DUKE
ADVANCED IMAGING LABORATORIES

Email: nicole.ranger@duke.edu

EXTRA STUFF




MAMMOM
Novation

ACKNOWLEDGMENTS

Information &/or Assistance Provided by:

DUKE

Joseph Y. Lo, PhD

Ehsan Samei, PhD

Jay A. Baker, MD

Anne Jarvis

SIEMENS

Thomas M. Mertelmeier, PhD

Introduction

CONTEXT

1 in 8 women (13%) will be diagnosed with breast cancer in their lifetime

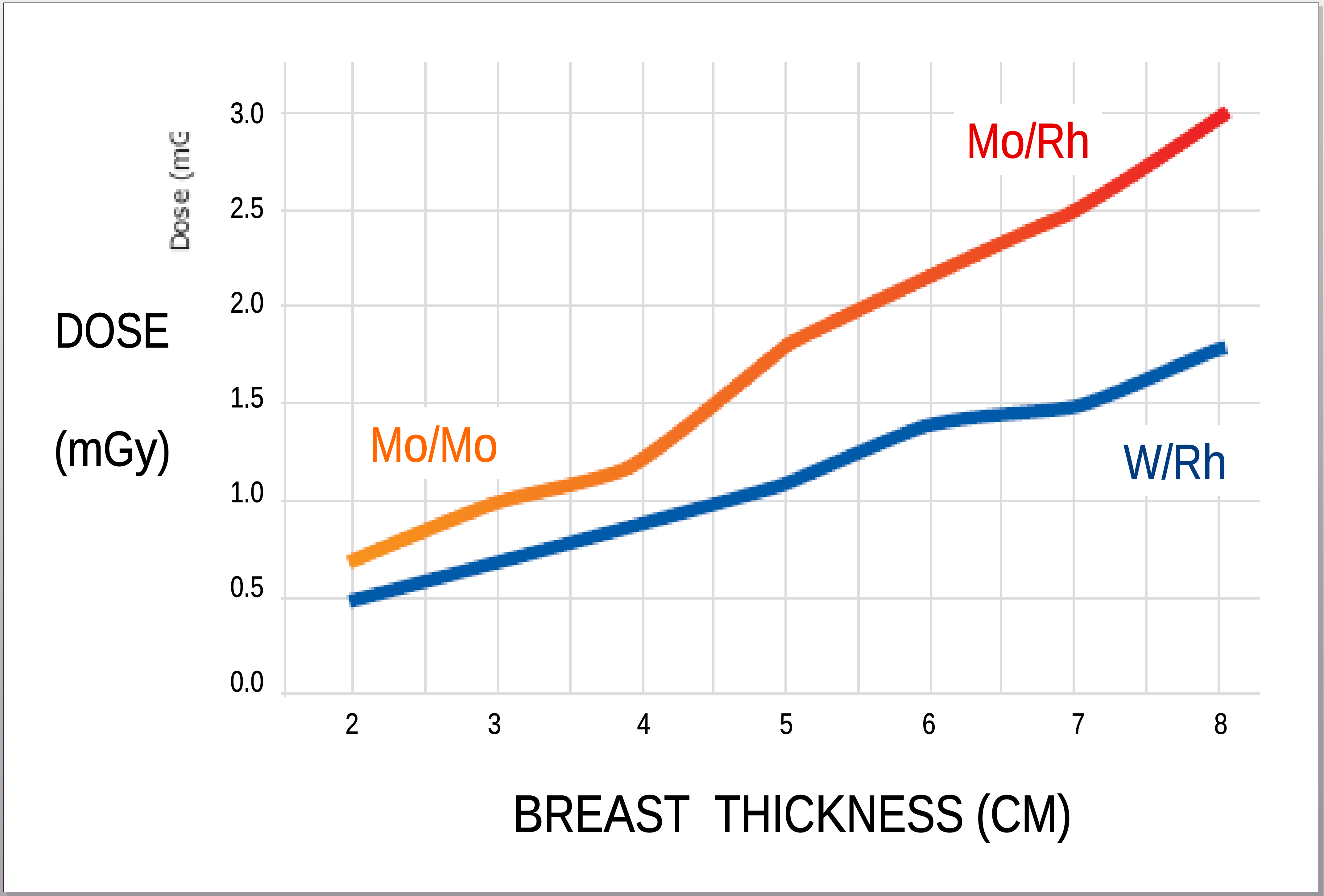
In 2006, 191,410 new breast cancer cases

In 20__ , __ screening mammography exams were conducted in the US and __% were performed using a digital mammography imaging system

Characteristic Photons:

Moly: 17.9, 19.5
Rhodium: 20.2, 22.7

Best spectra with kVp set 5-10 kVp above K-edge



Source: IMS Giotto 3D brochure

Radiographic Characteristics of Breast Tissue

Tissue Type	Density	Atomic #
Adipose		
Glandular		
Calcification		

Breast Imaging Statistics

Breast cancer #__ cause of death in women aged XX-YY

Lifetime risk: 1 in 8 women will be diagnosed

In 2006, ____ new cases of breast cancer were diagnosed; approx. half of which were diagnosed as a result of screening mammography

Risk of inducing a breast cancer as a result of exposures associated with lifetime of screening mammography: ____

In 20__ , ____ screening mammography exams were conducted in the US and ___% of those studies were performed using a digital mammography imaging system

Sources: http://apps.nccd.cdc.gov/uscs/

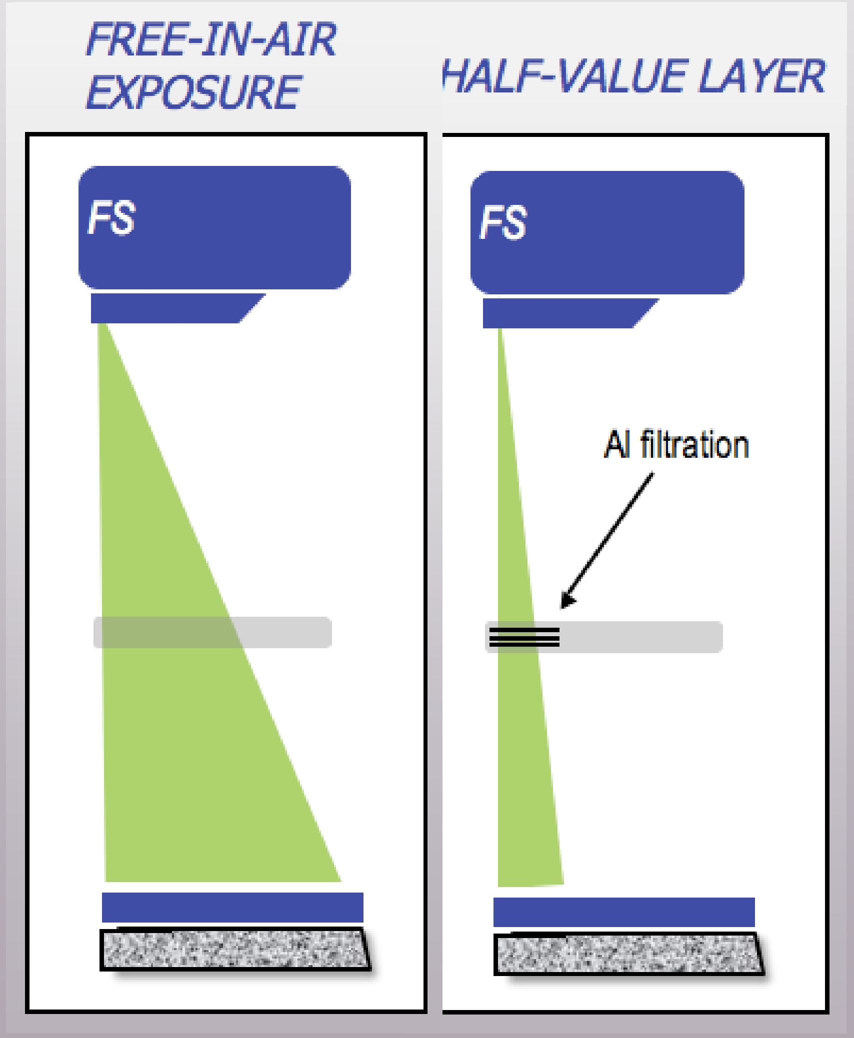
Technique Optimization Protocol

Characterizing the Beam Quality & Exposure

Measure free-in-air exposure at each beam quality: target/filter & kVp

Extrapolate to phantom surface using inverse square law

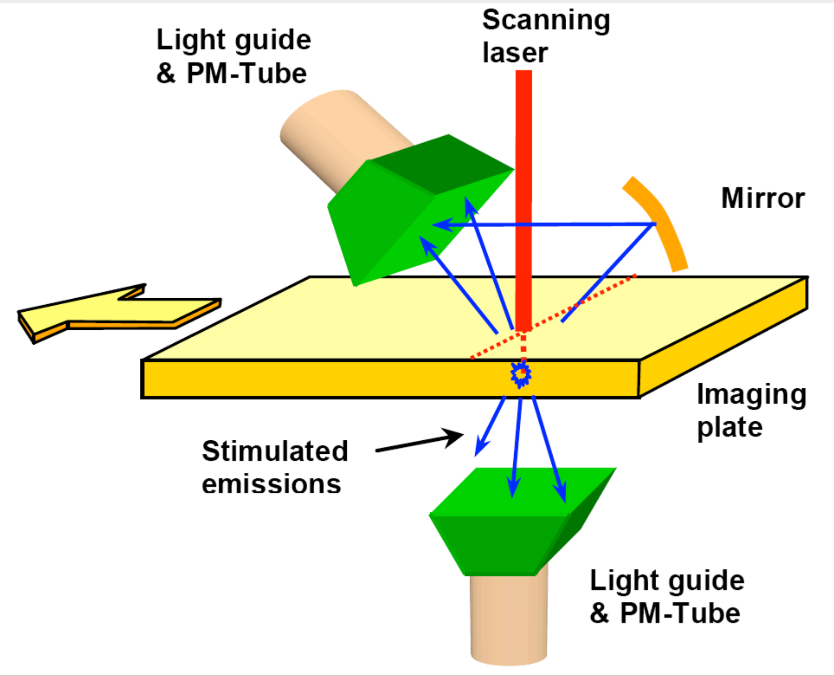
Measure HVL at each beam quality using narrow beam geometry and calibrated ion chamber fitted with a Mammo probe

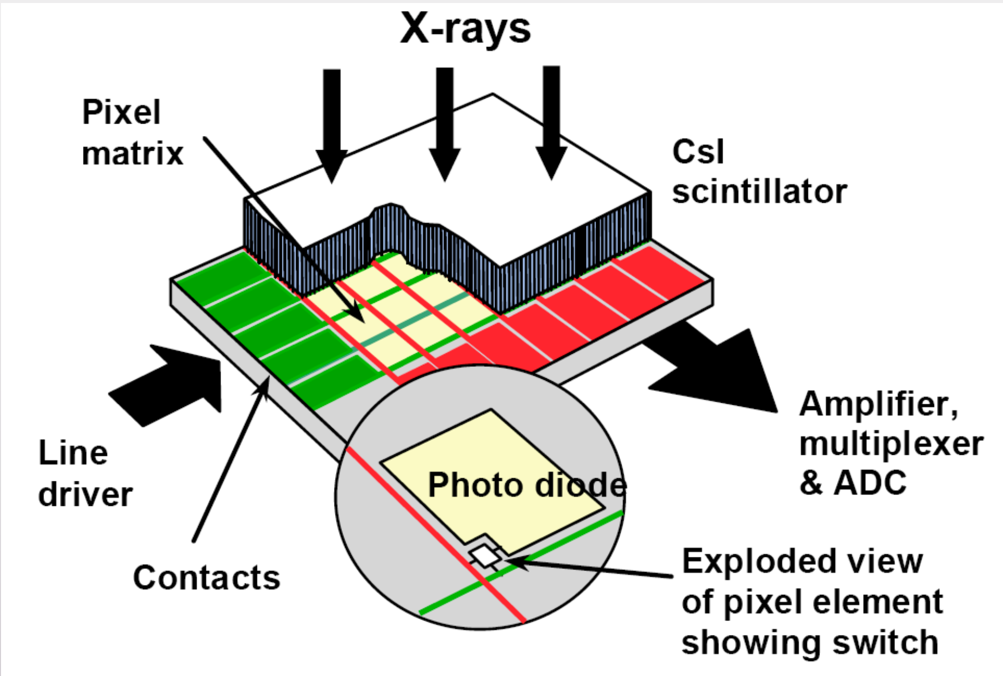


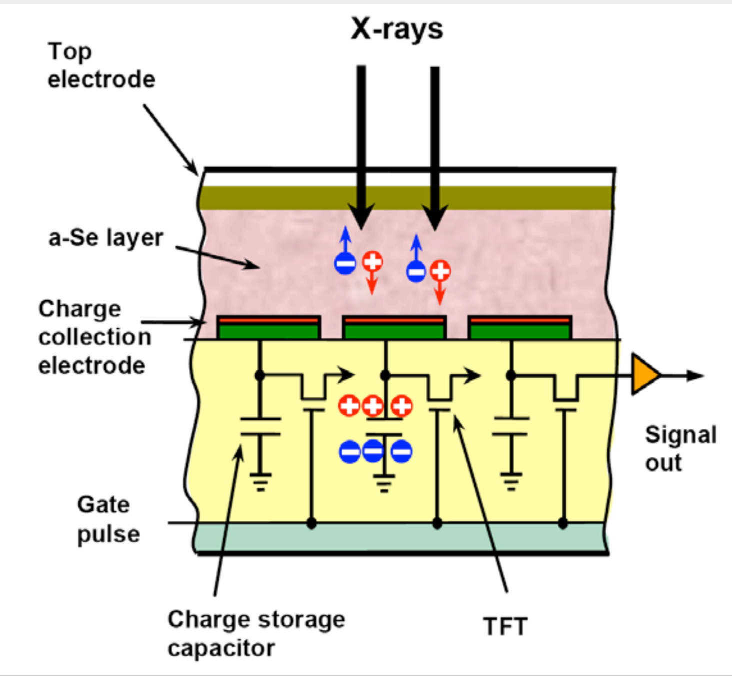
CR: PSP

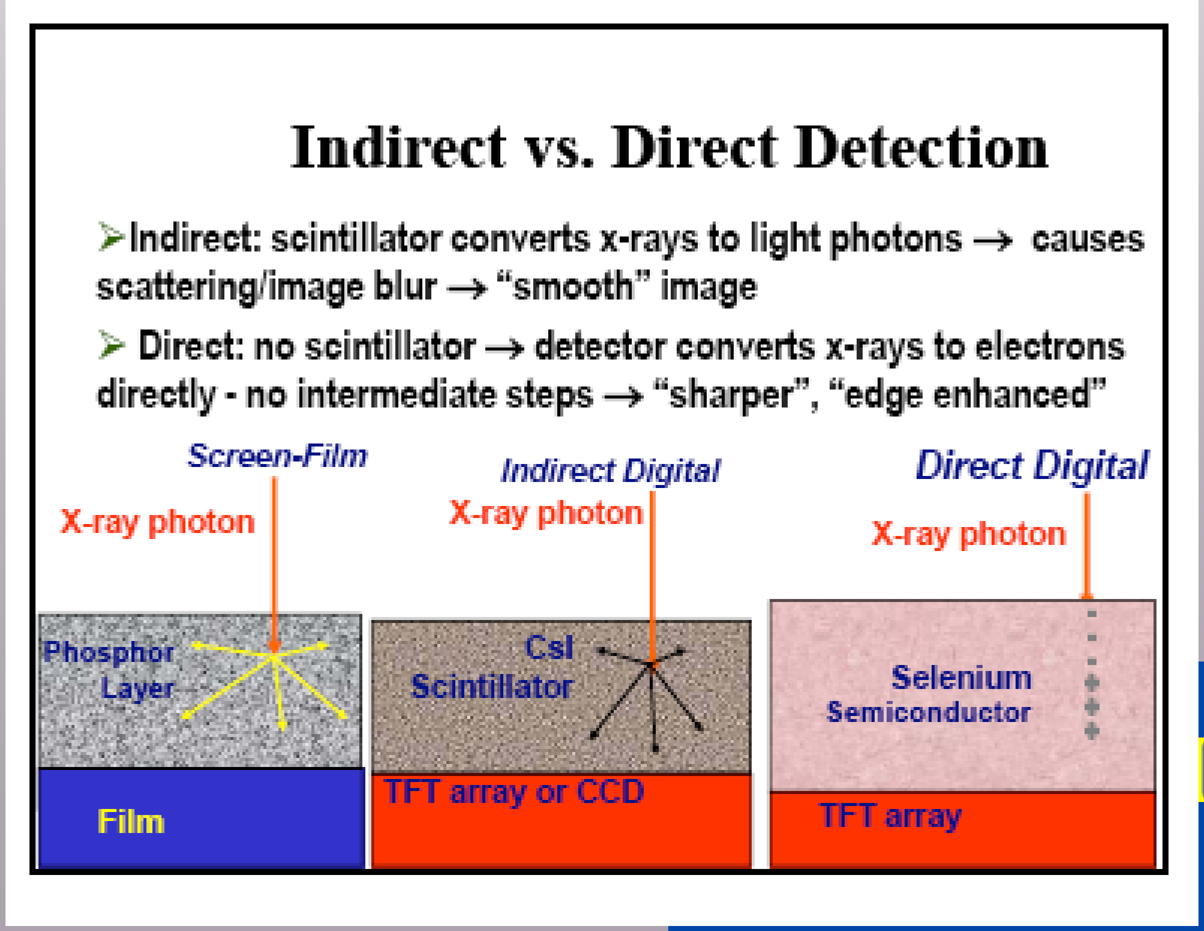
GE Senographe
Indirect DR: Cs(I) TFT

Hologic Selenia
Direct DR: aSe TFT

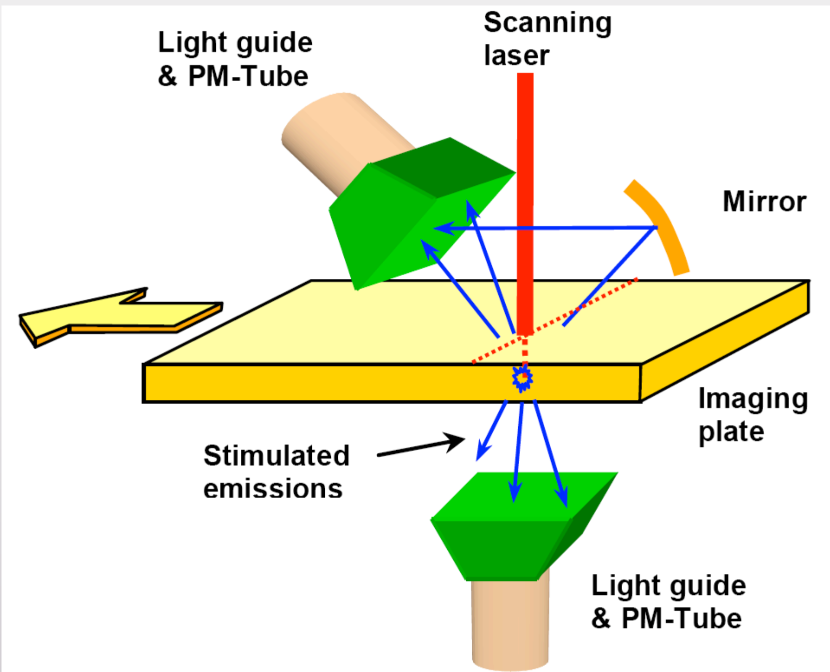




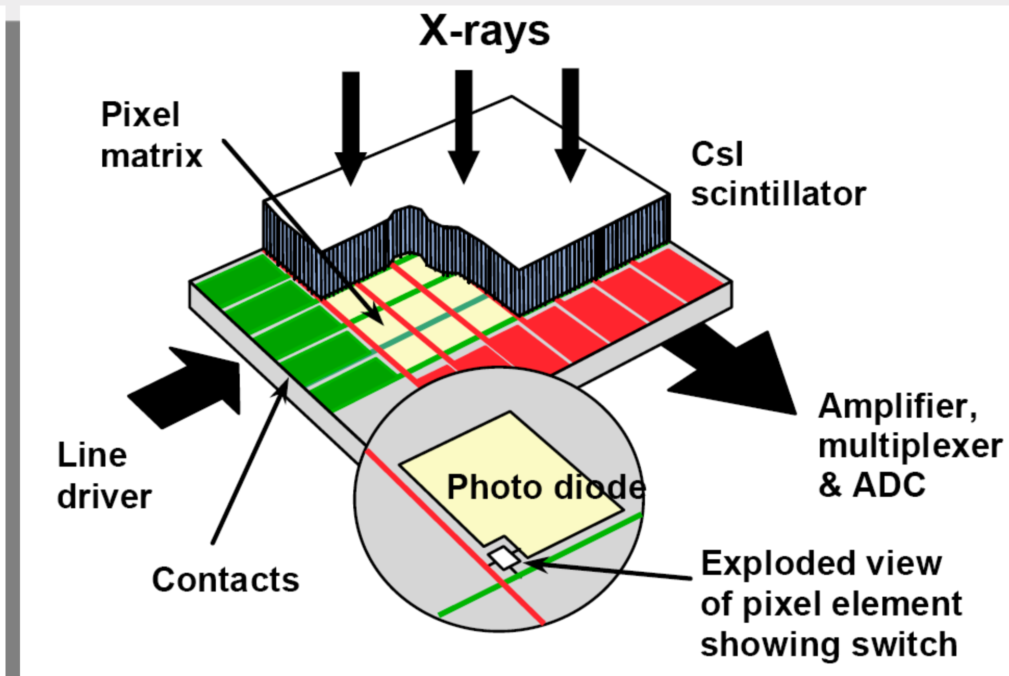




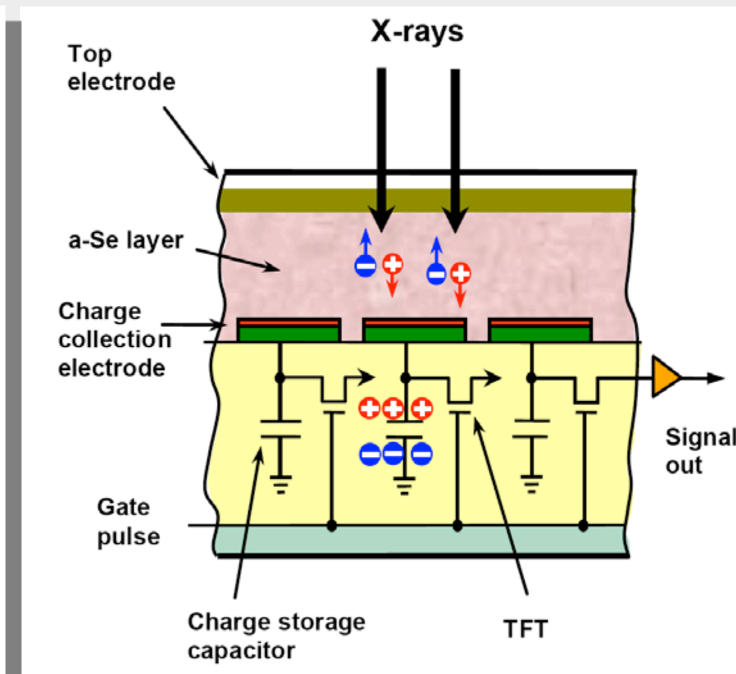
CR: PSP



GE Senographe
Indirect DR: Cs(I) TFT



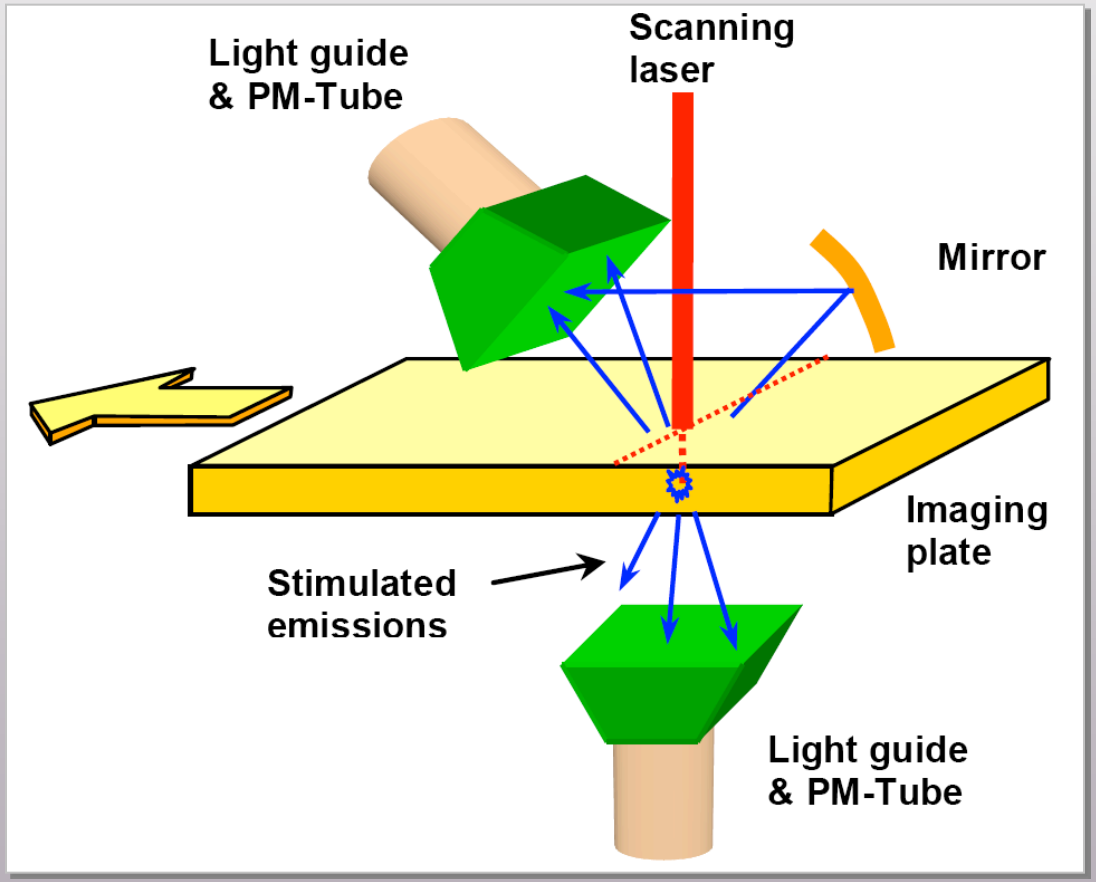
Hologic Selenia
Direct DR: aSe TFT



INDIRECT DETECTION

DIRECT DETECTION

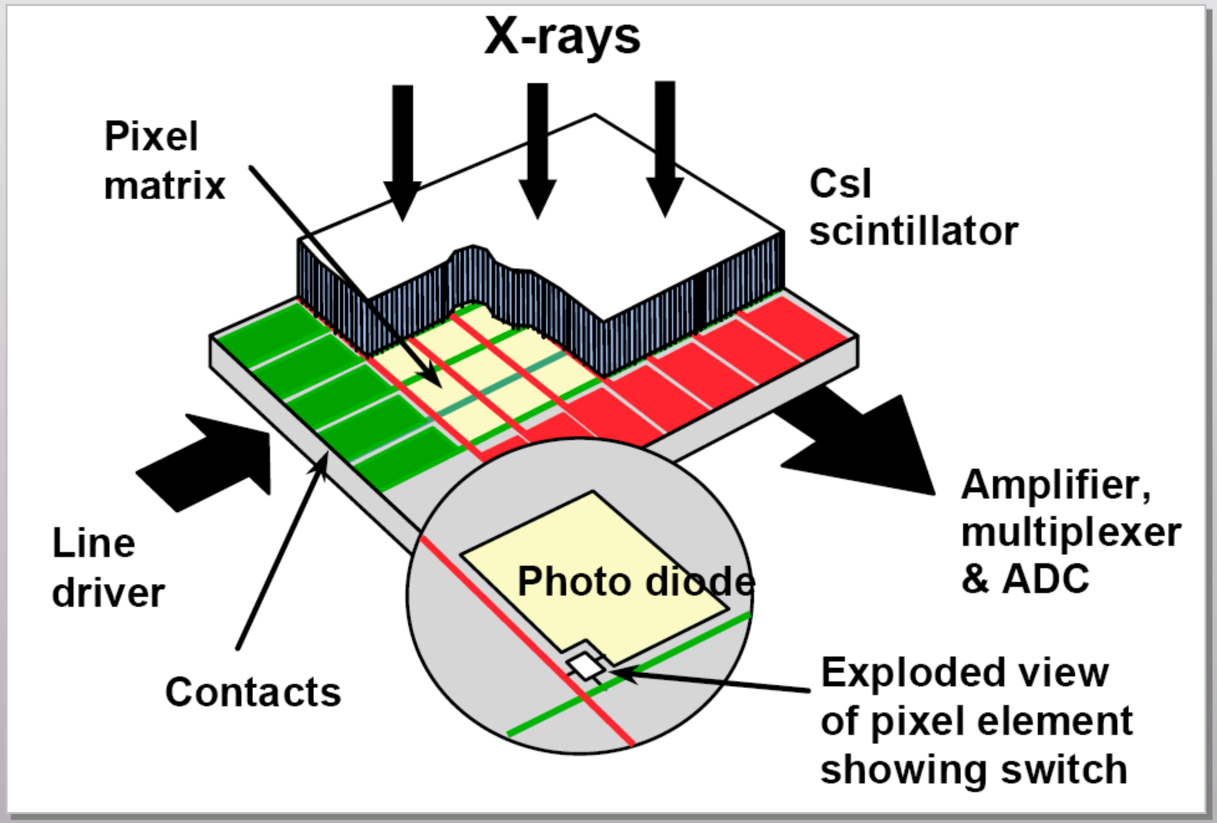
Computed Radiography



Source: Basset LW, Imaging the Breast, Cancer Medicine, 6th ed

Indirect DR

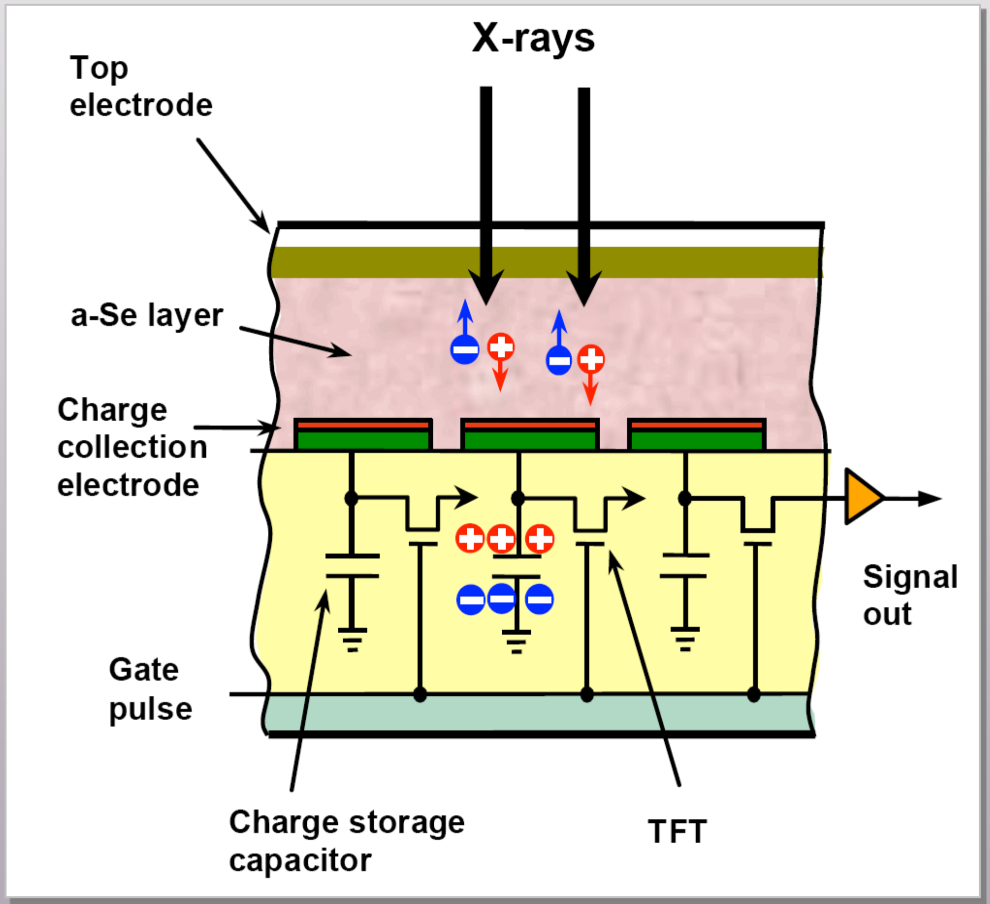
Cs(I) TFT Array



Source: Basset LW, Imaging the Breast, Cancer Medicine, 6th ed

Direct DR

aSi TFT Array



Source: Basset LW, Imaging the Breast, Cancer Medicine, 6th ed