

WEBINAR:

X-ray Technology for NDT Applications (Nondestructive Testing)

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CT Image Courtesy of North Star Imaging

Bio

Andrew Fay is an Application Engineer at Hamamatsu Corporation US HQ in Bridgewater, NJ

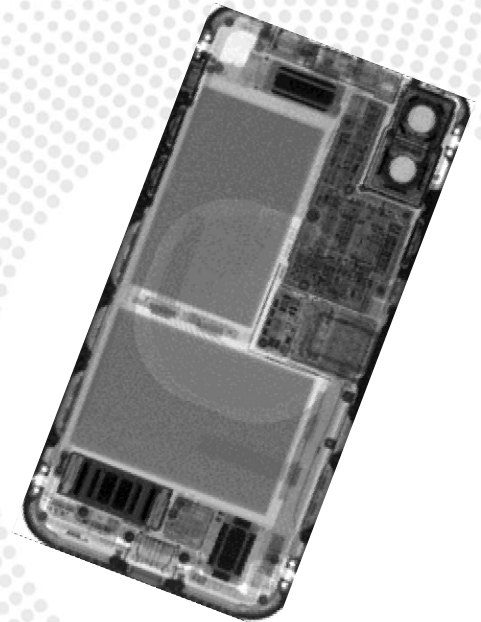


Agenda

- Intro to X-rays
- Source Tubes
- Detectors
- Applications :

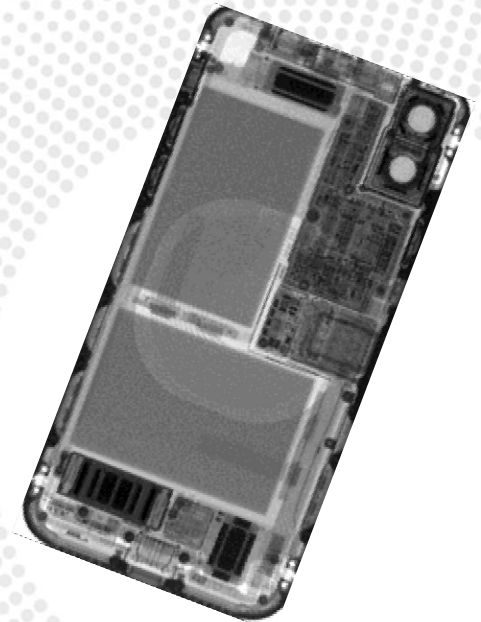
- Industrial CT
- Electronics Inspection
- Food Inspection

~ 35 minutes



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Advancements in X-ray Technology

Roentgen 1896



1895 X-rays Discovered

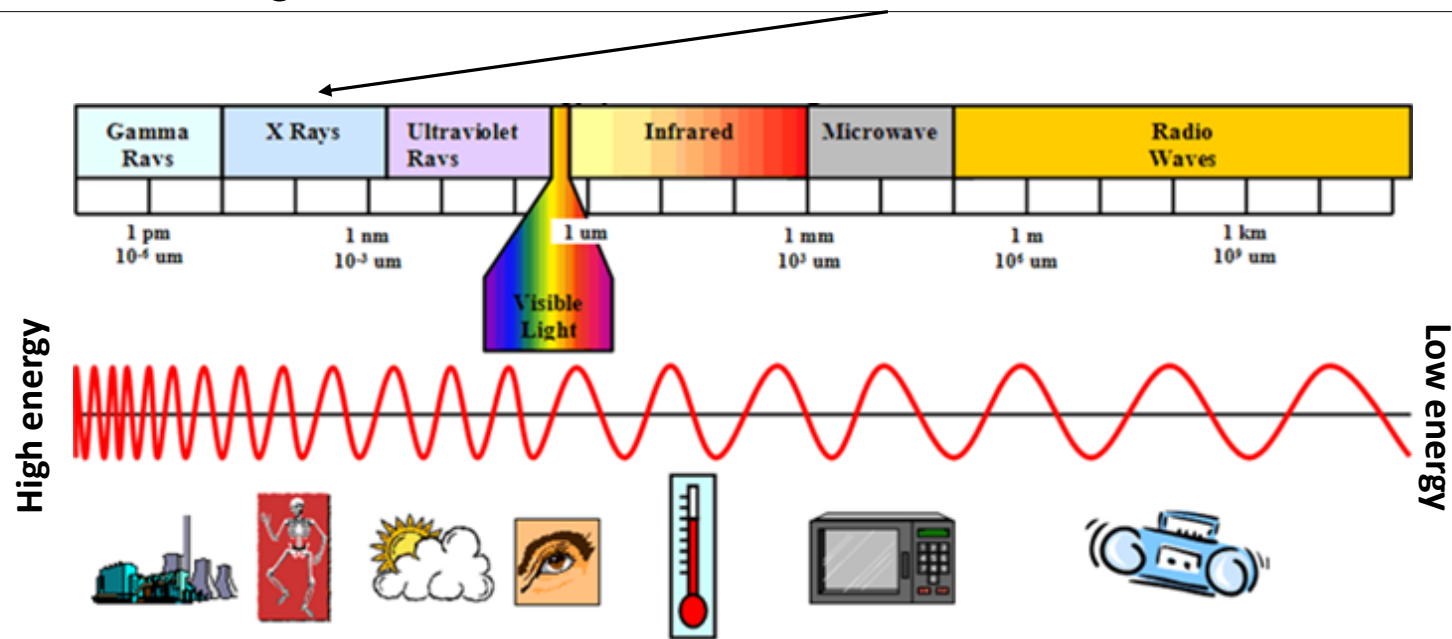
Industrial Cone Beam CT 2020



Courtesy: Pinnacle X-ray Solutions

X-ray : Properties

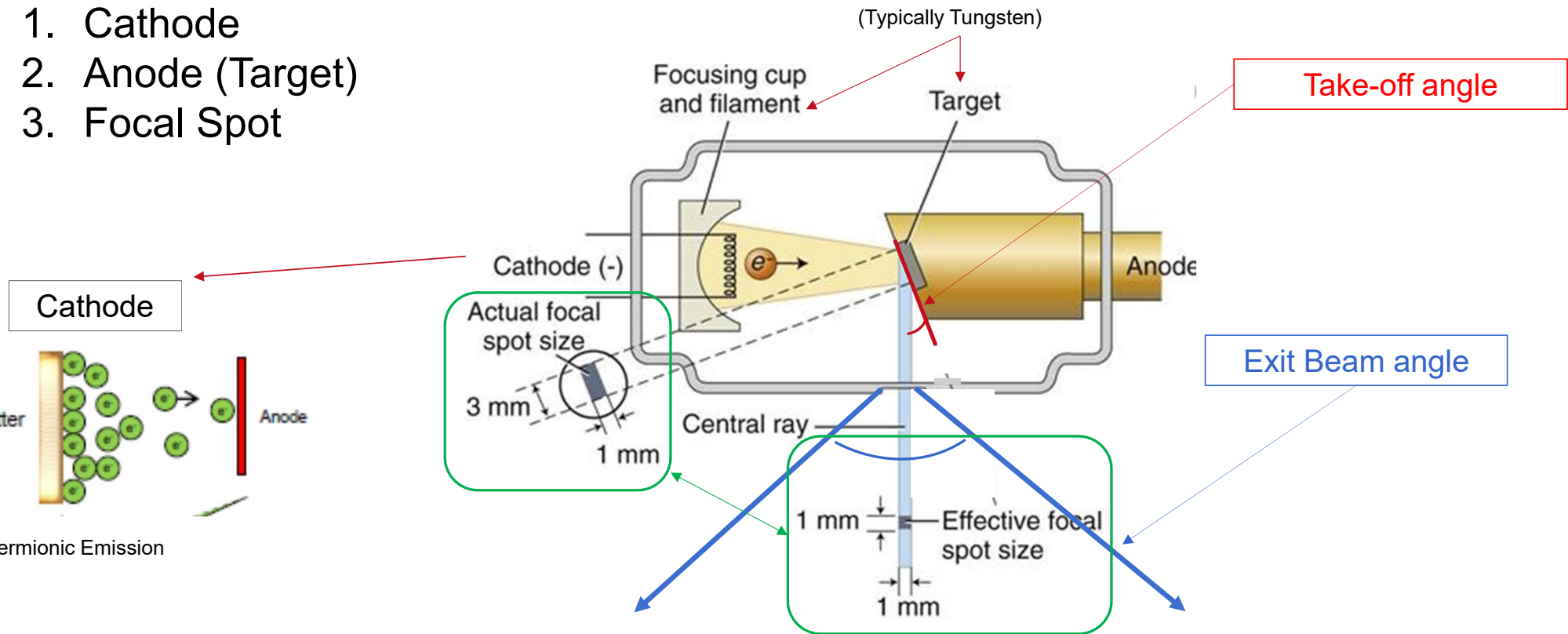
- Energy Range: “Soft x-ray” 5-50keV to “Hard x-rays” 150keV – 1MeV
- Wavelength: 0.01nm – 10nm



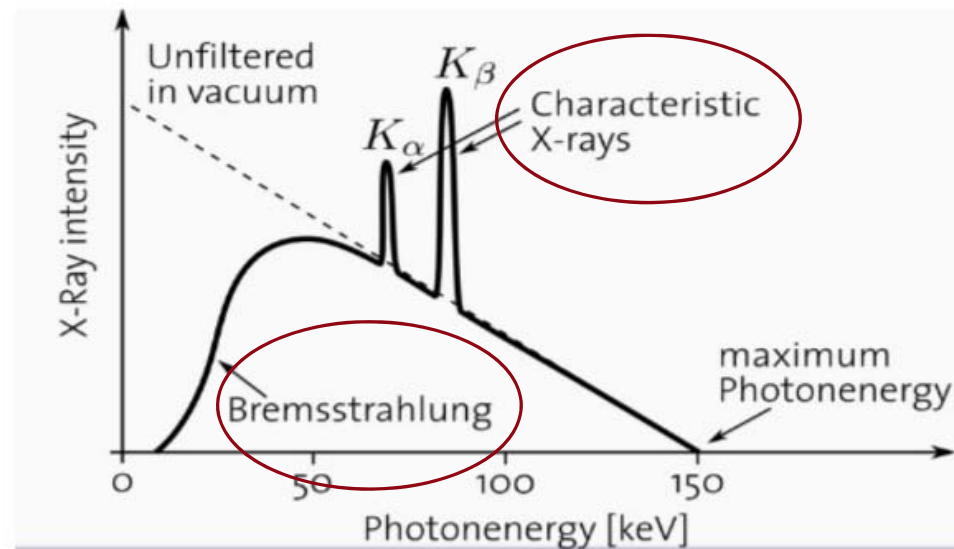
Principle of X-ray Generation

Basic structure of an X-ray tube

1. Cathode
2. Anode (Target)
3. Focal Spot

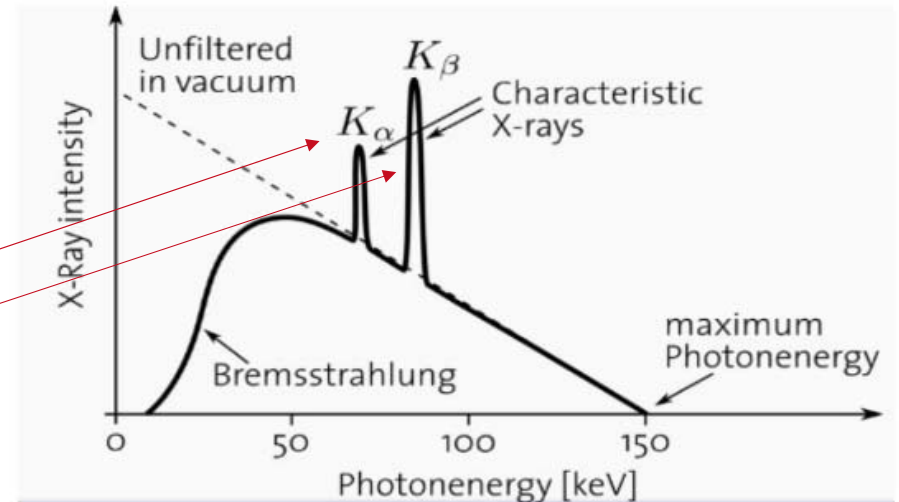
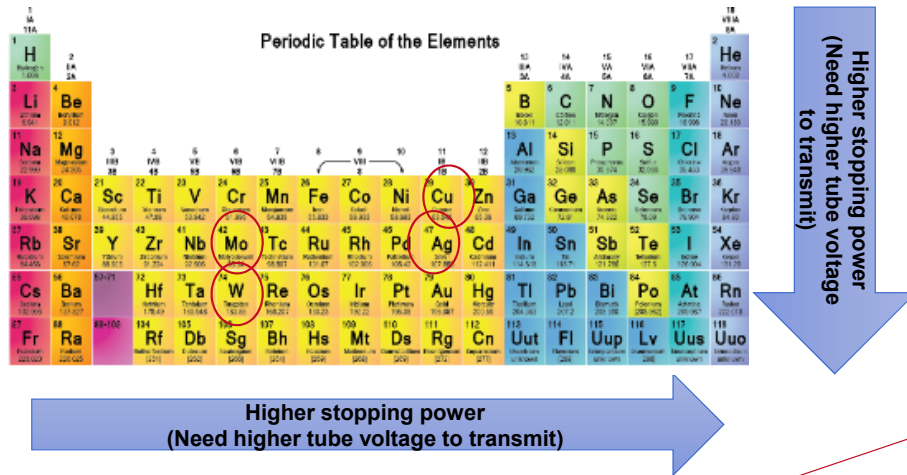


X-rays : tube energy spectrum



Photon spectrum for x-ray tube operating at 150kVp

Factors affecting tube output spectrum : Target Material



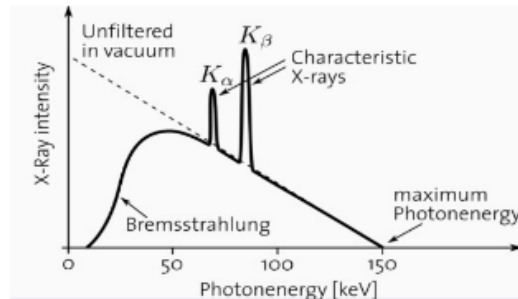
Photon spectrum for x-ray tube operating at 150kVp

Characteristic X-ray emission lines for some common anode materials.^{[68][69]}

Anode material	Atomic number	Photon energy [keV]		Wavelength [nm]	
		$K_{\alpha 1}$	$K_{\beta 1}$	$K_{\alpha 1}$	$K_{\beta 1}$
W	74	59.3	67.2	0.0209	0.0184
Mo	42	17.5	19.6	0.0709	0.0632
Cu	29	8.05	8.91	0.154	0.139
Ag	47	22.2	24.9	0.0559	0.0497
Ga	31	9.25	10.26	0.134	0.121
In	49	24.2	27.3	0.0512	0.455

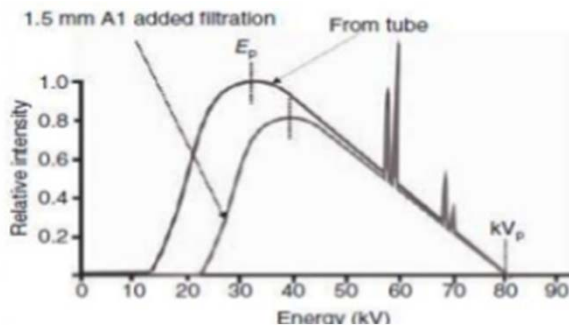
Factors affecting tube output spectrum :

Filters, Tube Potential, Tube Current

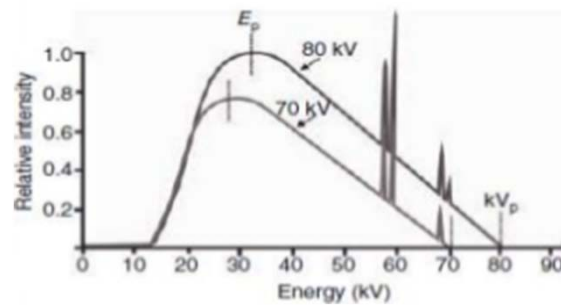


Photon spectrum for x-ray tube operating at 150kVp

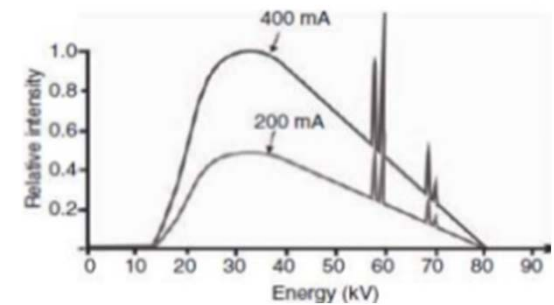
Add **Filters** at tube



Adjust **tube Potential** kV



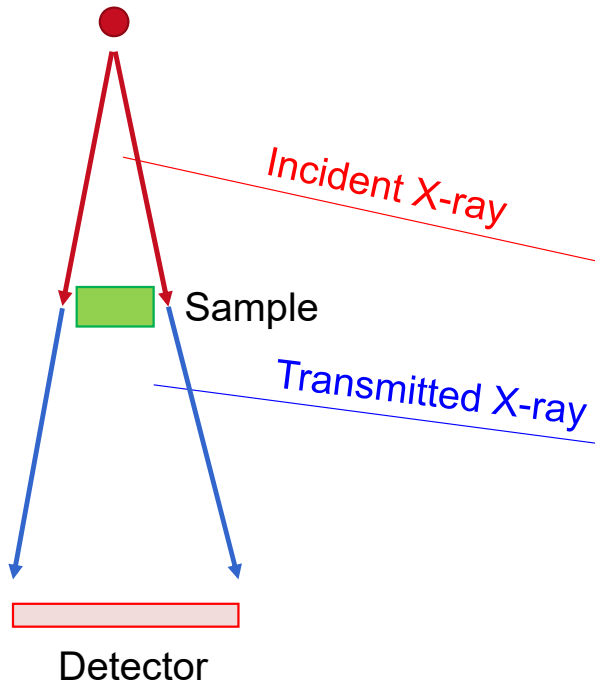
Adjust **tube current**



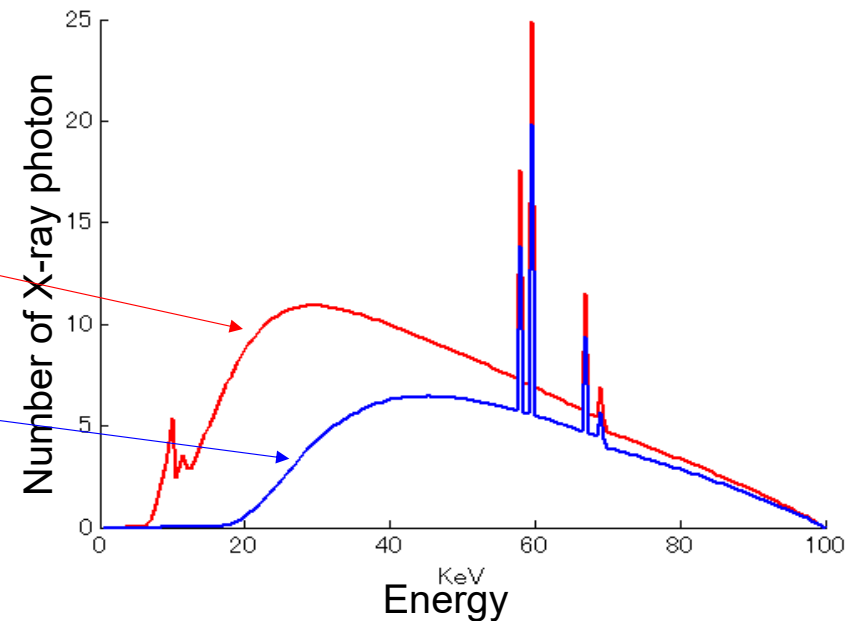
X-rays interact with materials differently

Scatter and Sample Material Attenuation Coefficients

X-ray source



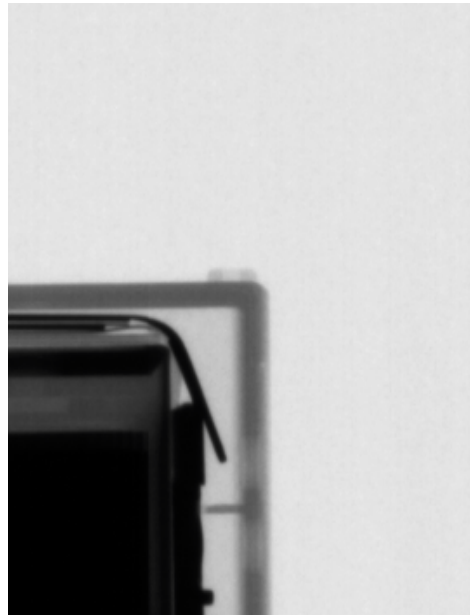
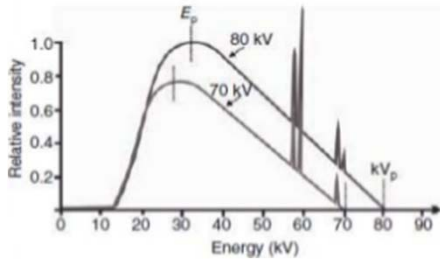
X-ray Production / Spectra



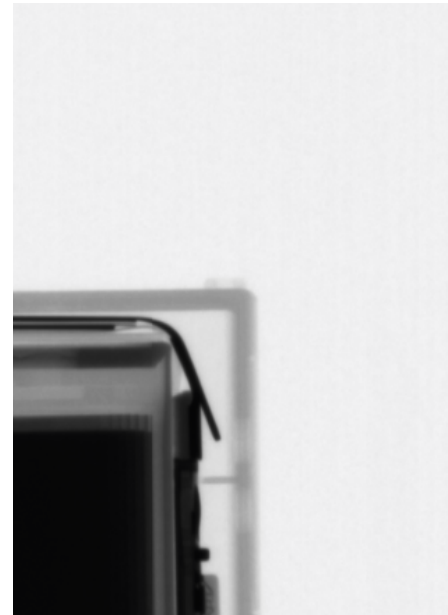
Factors for Image Quality: Tube Potential (Voltage kV) Variation

Tube Potential (kV) : Defines the intensity of X-ray energy

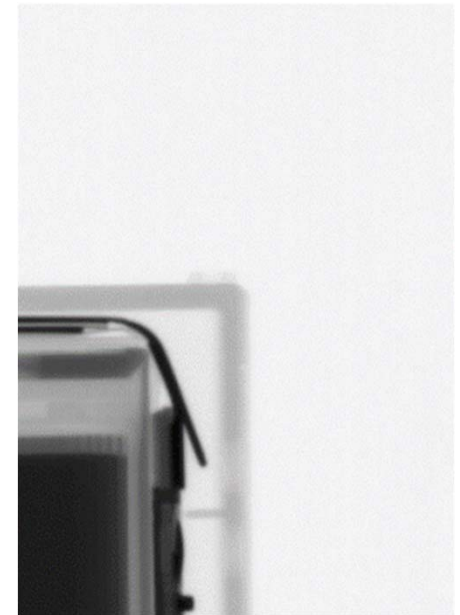
Change tube kV



30kV 300uA



60kV 300uA

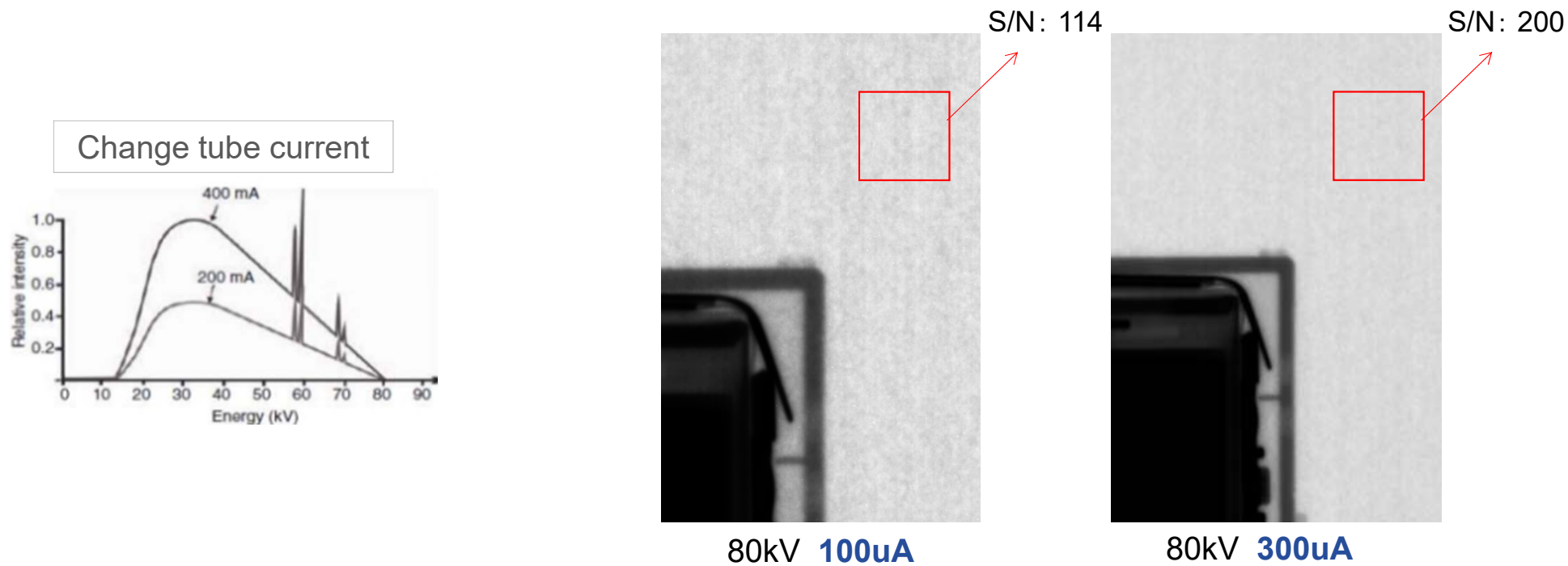


90kV 300uA

Higher Tube potential kV gives better material penetration

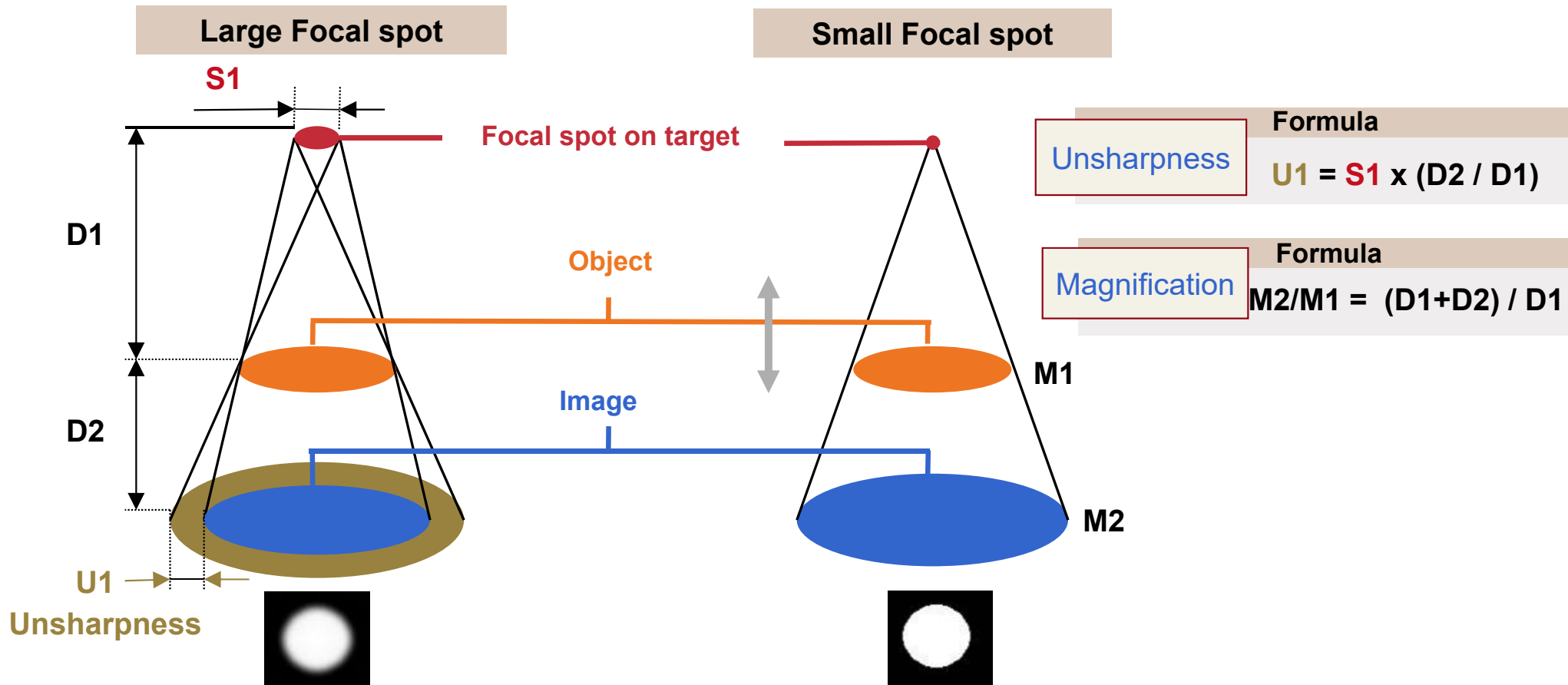
Factors for Image Quality: Tube Current (μA) Variation

Tube current: Determines the amount of x-ray photons (“Brightness” of image)



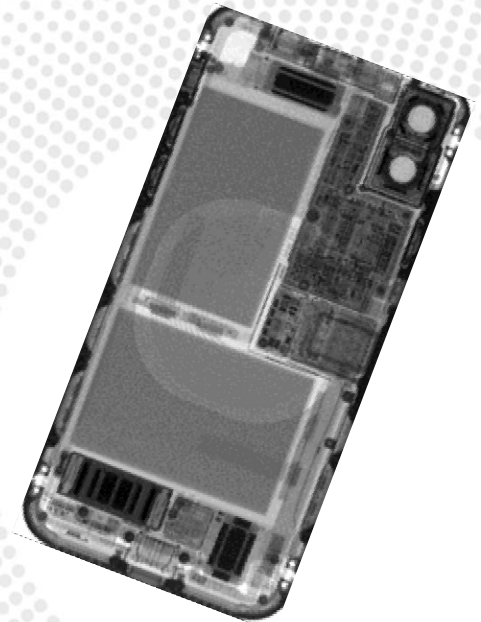
Signal to Noise ratio is improved by increasing tube current.

Factors for Image Quality: Focal Spot Size, Image Sharpness and Magnification



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- Detectors
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Types of X-ray Sources : Conventional / Milli- / Micro- / Nano-

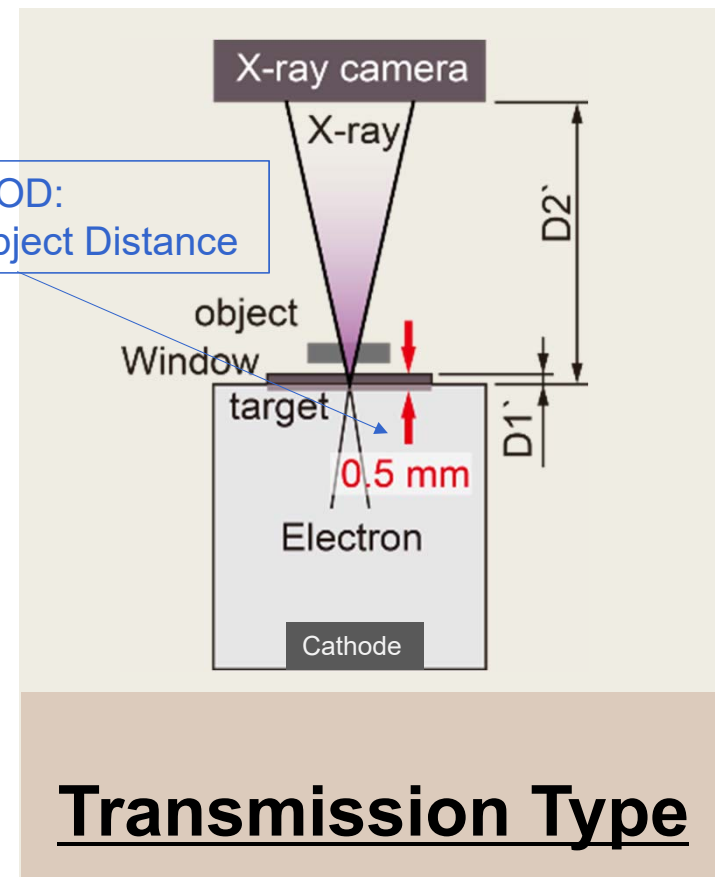
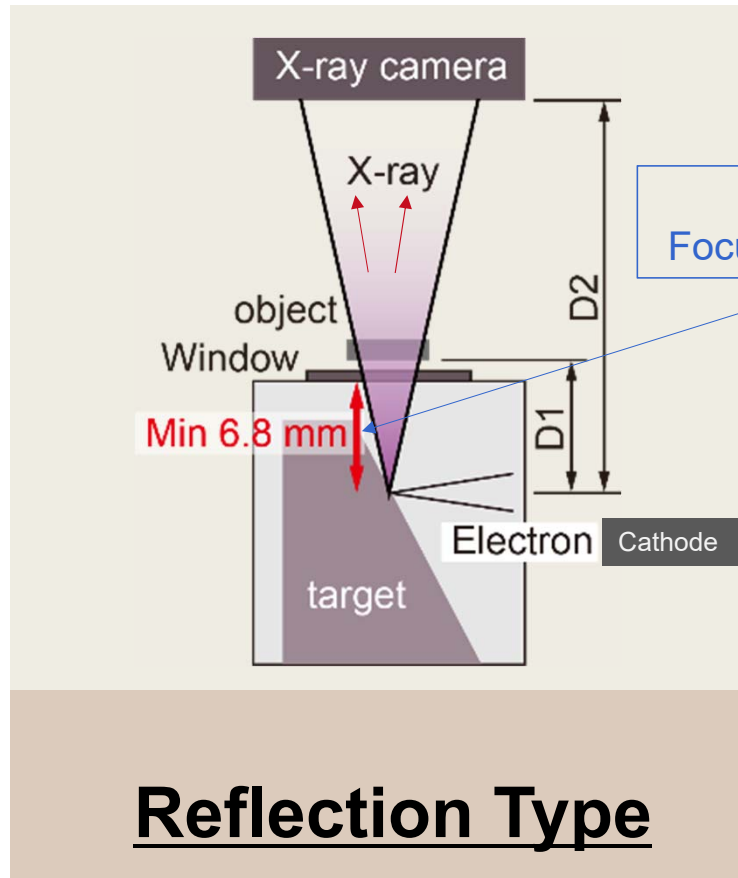
X-ray Source tubes are often characterized by the focal spot :

Type	Focal Spot (Resolution)	App	kV	Res	Mag	Config
Conventional Tube	> 1mm	Medical	600kV	Low	No	Sealed Glass or Ceramic
Milli-focus Tube	0.4 - 1 mm	Industrial / Medical	600kV	High	Not Good	Sealed Glass or Ceramic
Micro-focus Tube	2–300 μ m	Industrial CT	30-300kV	Very High	High	Sealed or Open
Nano-focus Tube	0.25-2 μ m	High end Industrial / Scientific	30-300kV	Extremely High	High	Open

Microfocus X-ray Tube = MFX

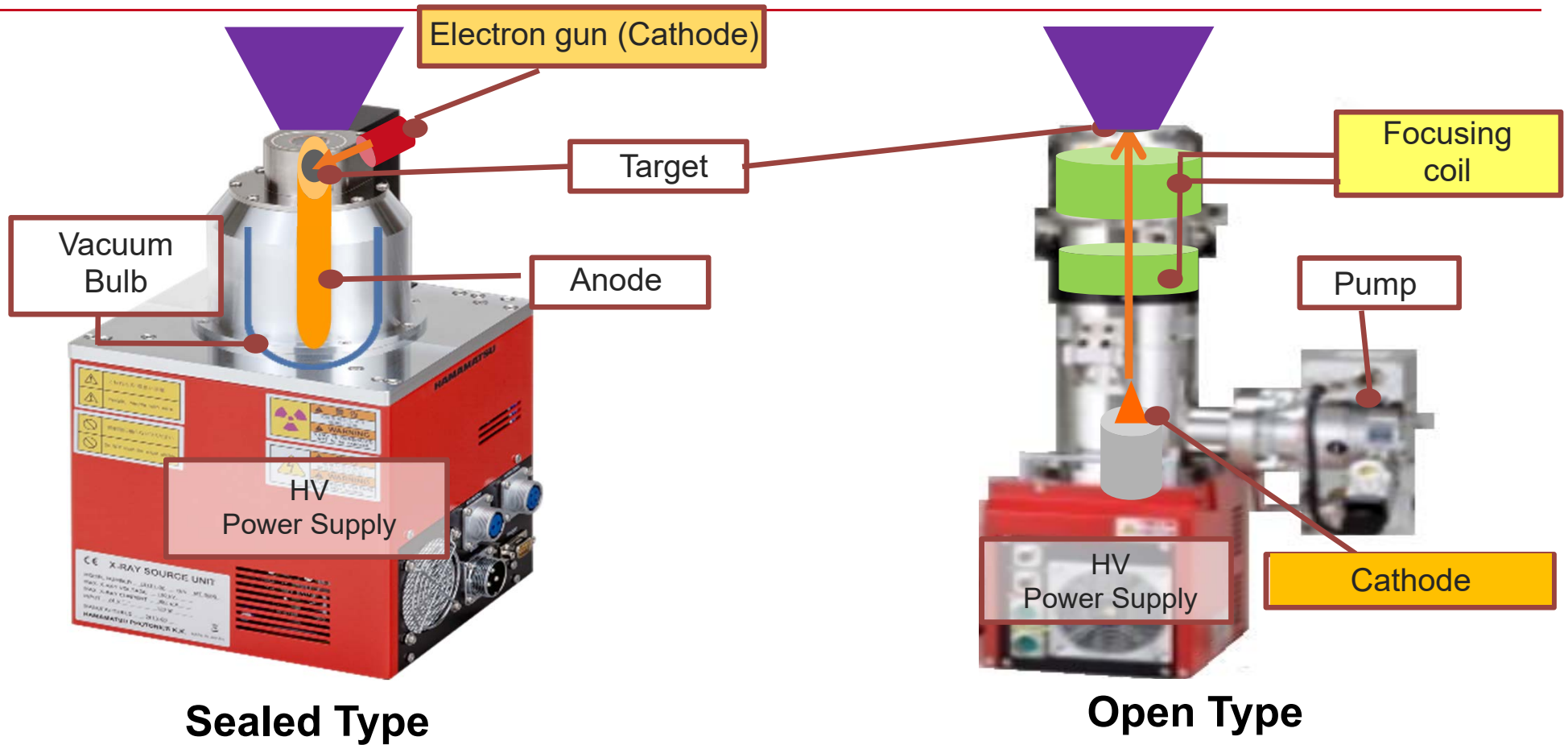
Reflection Type and Transmission Type

Small FOD = high magnification



FOD:
Focus to Object Distance

Sealed and Open-type MFX (Reflection or Transmission)



Sealed and Open-type MFX (Reflection or Transmission)



Integrated Power Supply
No HV Cables
reduces maintenance
easy system integration



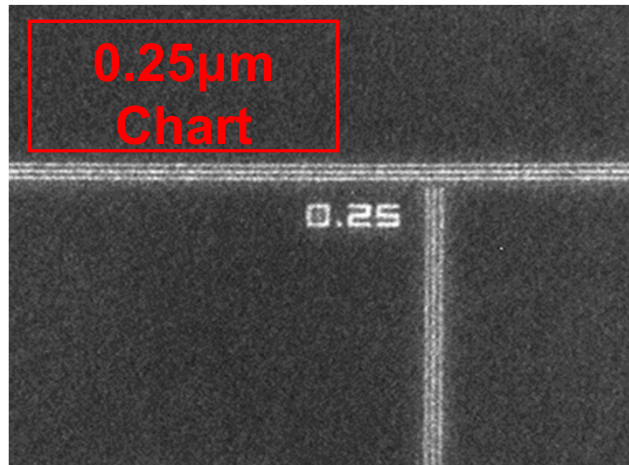
SEALED TUBE:

- Typically oil cooled
- Rugged and Compact for 24/7 in-line and off-line inspection.
- Easy to use and integrate.
- Low maintenance.

OPEN TUBE:

- Target and Cathodes can be changed
- Typically water cooled
- Highest resolution and power achievable.
- Regular maintenance required.

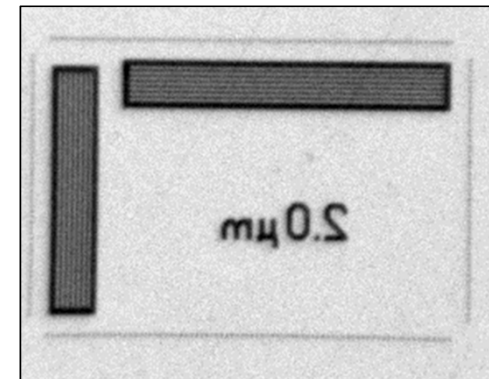
Advantage - High Resolution -



***Open-Type
(Transmission)
Nano Imaging***

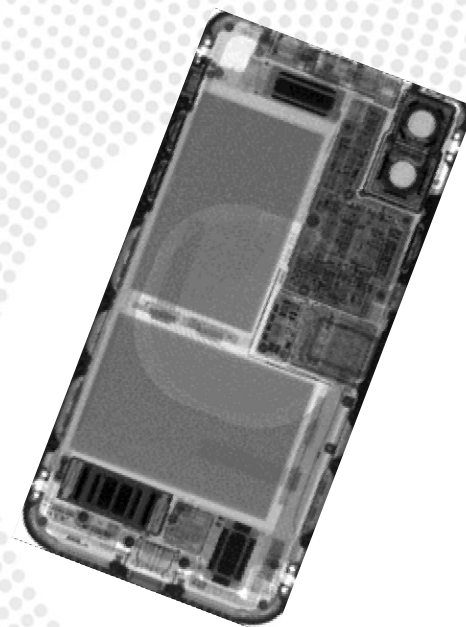
To achieve: **Stable and quiet environment is required.**

***Sealed-Type
(Transmission)
Micro high resolution***

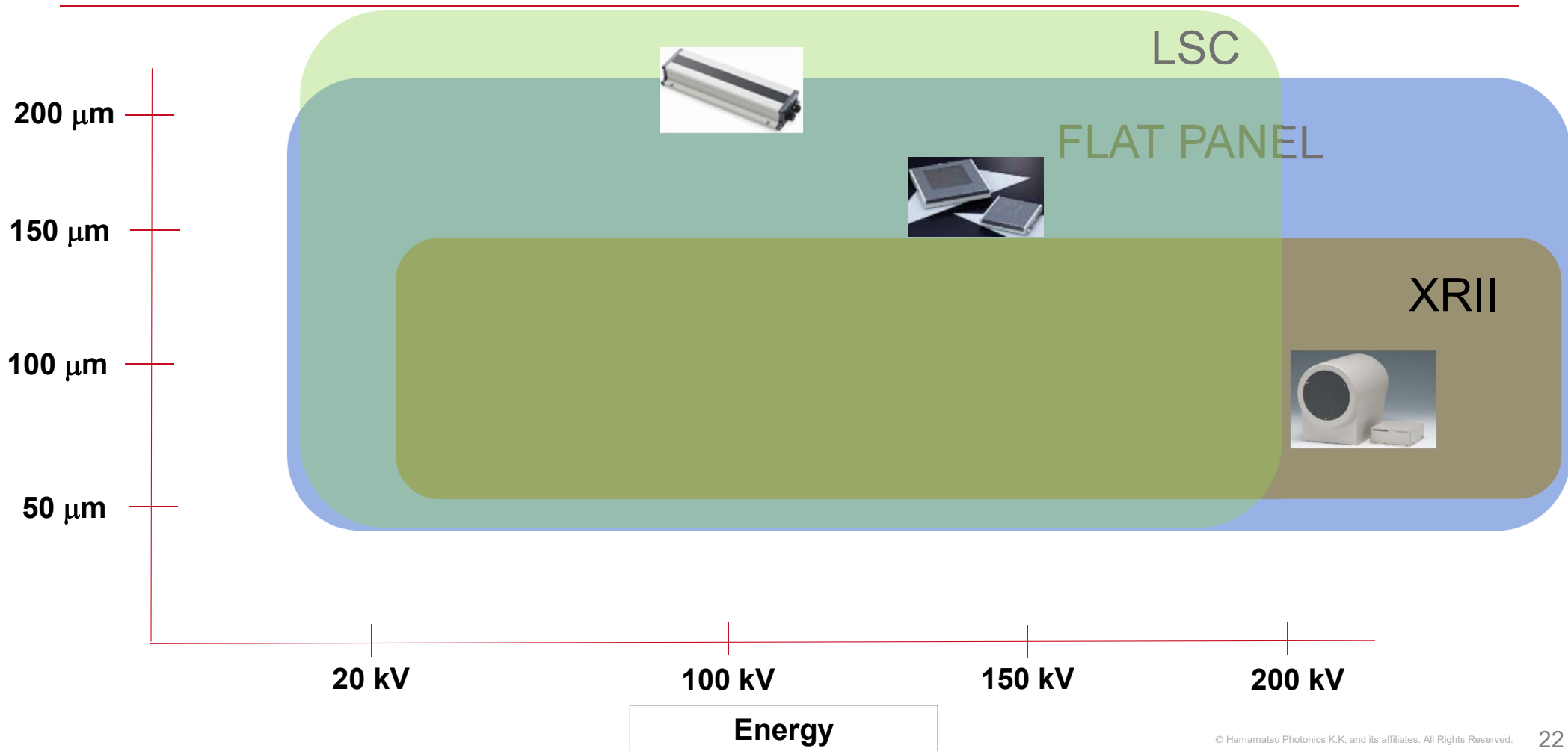


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- **Detectors**
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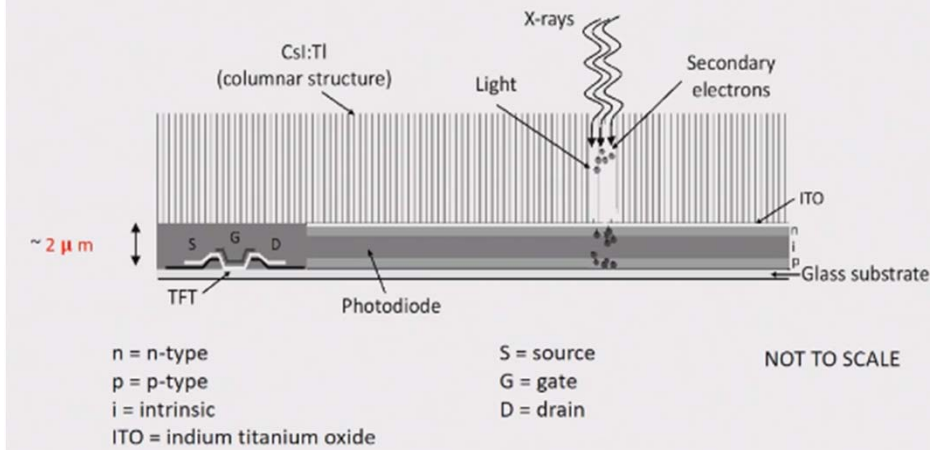


NDT Application: Energy Range

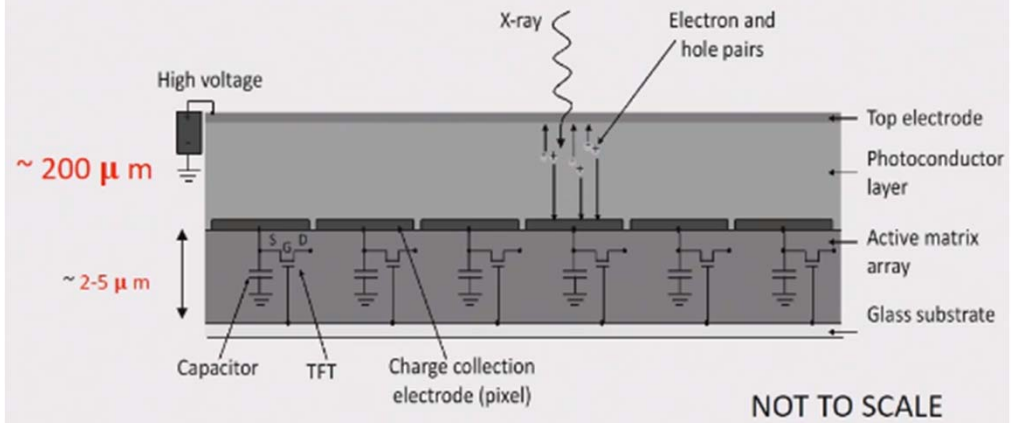


Detectors: Direct vs. Indirect

INDIRECT X-RAY DETECTION



DIRECT X-RAY DETECTION



Overview of Detectors : for NDT Applications



	Flat Panel	Line Scan Camera	Xray Image Intensifier
Energy Range	Good	Good	300kV
Resolution	50μm	48μm	Good
Size (active area)	Up to 43x43cm	Good	Good
Speed	Better	Best	Good
Low Dose Performance	Good	Better	Best
Ease of Use/ Interface	Good	Good	Good
Application: Food Inspection		✓	
Industrial CT	✓	✓	✓
Electronics Inspection	✓	✓	✓

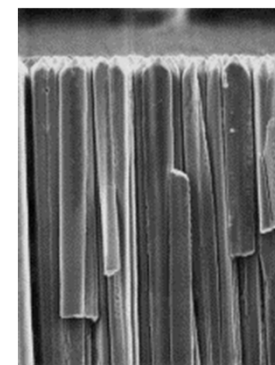
Flat-Panel Sensors (FPS)

Intro to Scintillator and Deposition Types

Scintillator Material (Converts x-ray to light photon)

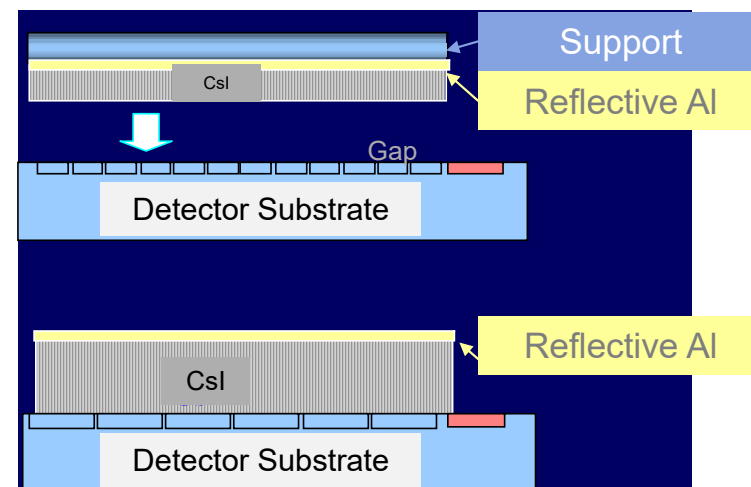
CsI Scintillator

- Needle Structure for High Resolution
- Deposition applicable

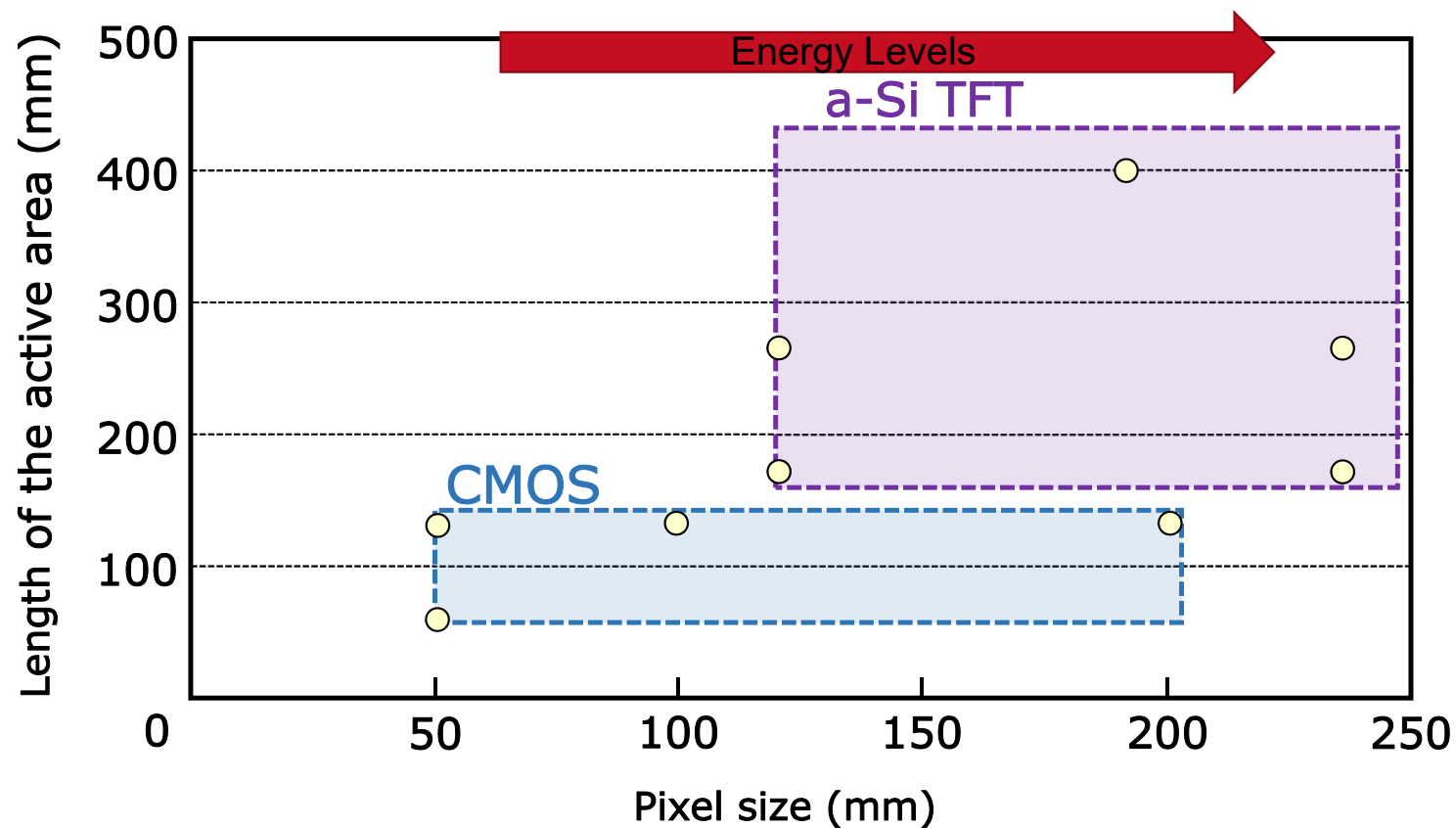


Scintillator Deposition or Coupling Methods:

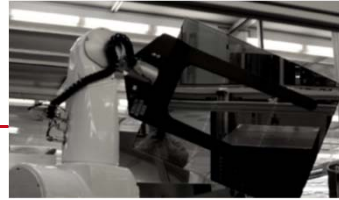
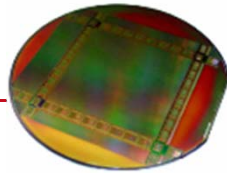
- 1) “Flipped” Scintillator Plate Type:
cost effective
- 2) “Direct Deposition” Type:
eliminate light scattering on the contact surface and maintain better resolution



Compare CMOS and a-Si Flat-Panel



CMOS vs. a-Si



Currently Only CMOS offered for NDT

Attribute	CMOS	A-Si	
Radiation Hardness		✓	TFT on Glass Substrate vs. Silicon Wafer
Cost	✓	✓	
Detector Size	30x30cm	✓ 43x43cm	
Pixel Size	✓ 50μm	100μm	Higher Charge Mobility in Crystalline vs. Amorphous
Noise	✓		
Speed	✓		
Dynamic Range	✓		
Low Dose / High Dose	✓ /	/ ✓	

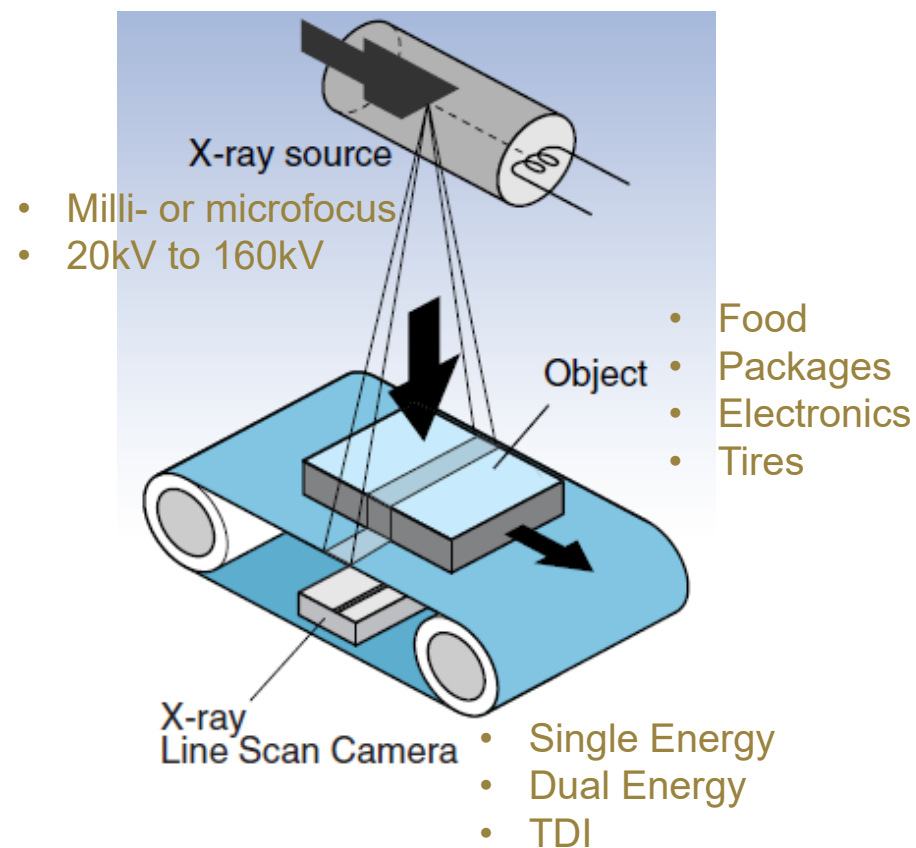
Line Scan Cameras (LSC)

Basic configuration of X-ray inspection system


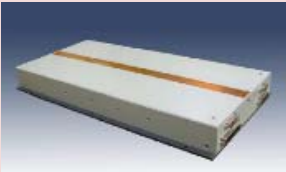

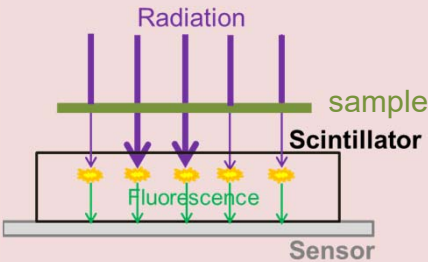
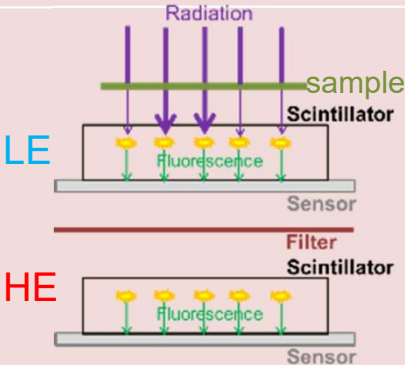
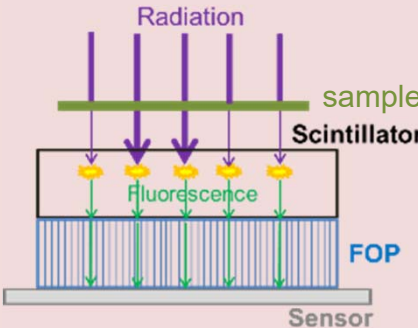


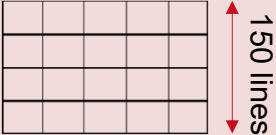
Confidential

General system consist of...

- X-ray camera (LSC)
- Milli- or micro- X-ray source
- Conveyers
- Shielding box
- PC
- Software



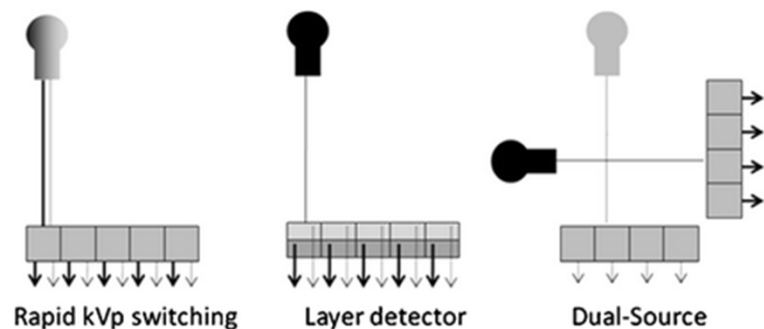
Line Scan Camera Types

	LSC SINGLE Energy	LSC DUAL Energy	LSC TDI
			
Side view			
Top view (pixels)			

More on Dual-Energy and TDI

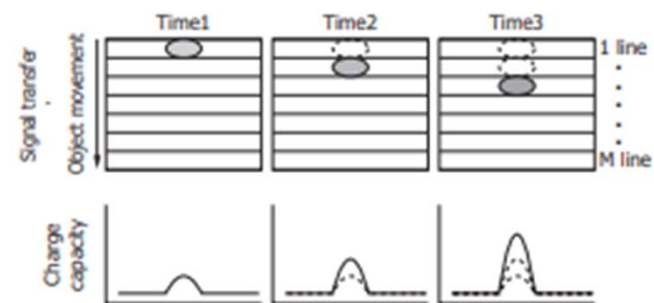
Confidential

Dual-Energy



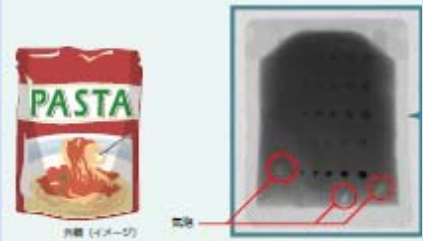


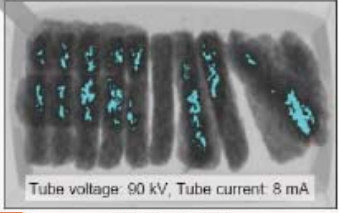
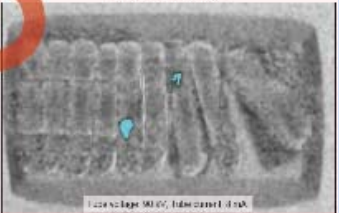
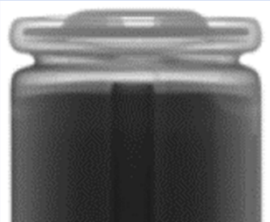
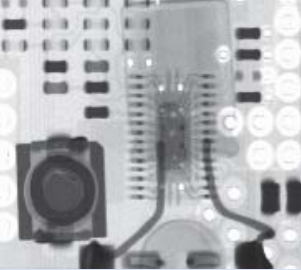
TDI (Time Delay Integration)

Schematic diagram showing integrated exposure by TDI mode



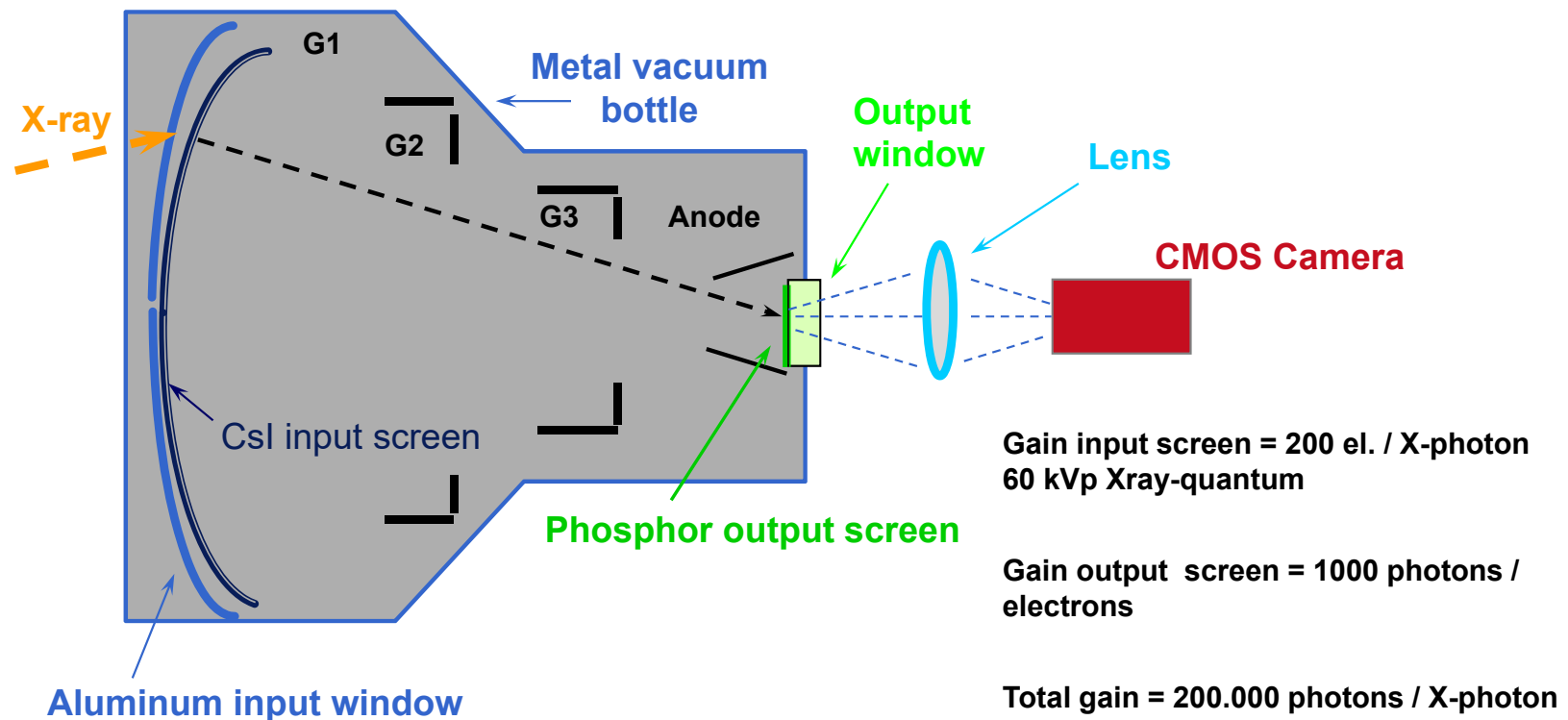
- Improved sensitivity by $x \#$ lines
- SNR improved by $\sqrt{\# \text{ lines}}$

LSC - Applications

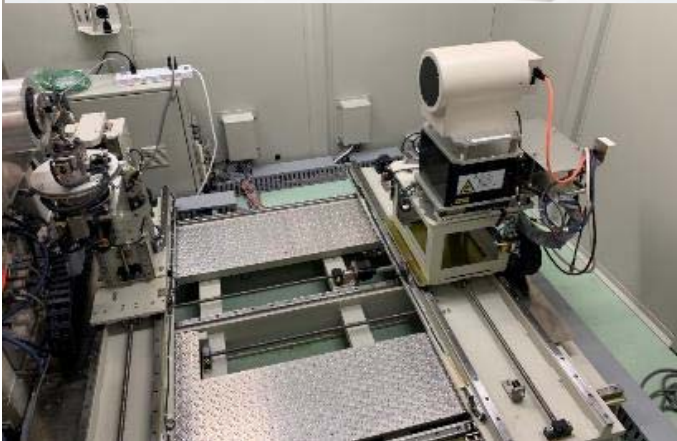
	LSC SINGLE Energy	LSC DUAL Energy	LSC TDI
Applications	<p>Food inspection</p>  <p>Food in glass jar</p> 	<p>Food inspection</p>  <p>rubber</p> <p>glass</p> <p>Single energy</p>  <p>Tube voltage: 90 kV, Tube current: 8 mA</p> <p>New dual energy</p>  <p>Can detect thin rubber pieces and thin glass pieces</p>	<p>LiB inspection</p>  <p>PCB inspection</p> 

X-ray Image Intensifier (XRII)

Operations in an X-ray image chain



X-ray Image Intensifier + CMOS Camera



Features:

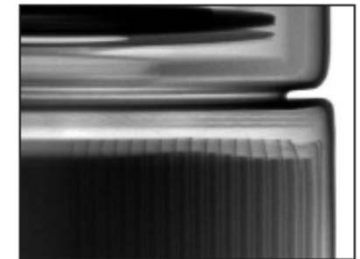
- Very Good Energy Levels
20 ~ 300kV
- CMOS Camera:
 - 2048 x 1544
 - 65 fps
 - USB 3.0

Applications:

- Electrical Comp and Boards
- Battery Inspection

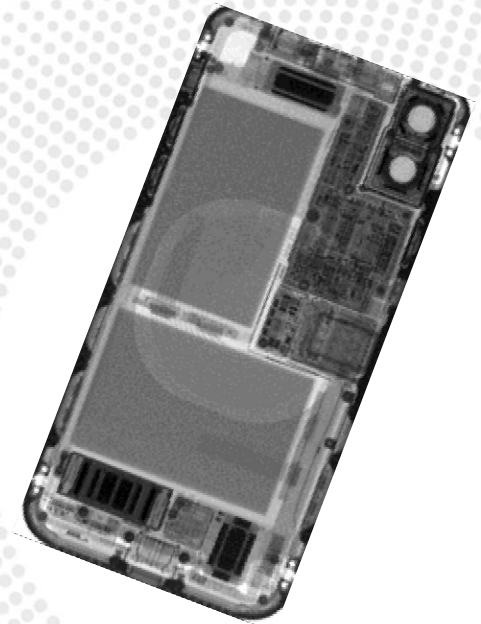
■ Lithium ion battery

X-ray tube voltage: 100 kV



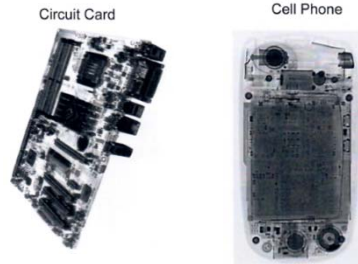
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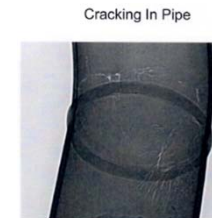


Industrial CT Application : Examples

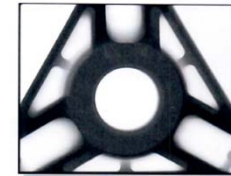
Electronics



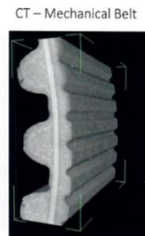
Metal Parts



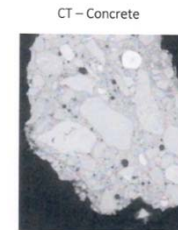
Aluminum Casting



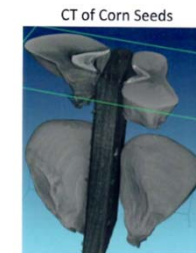
Composites



Material Sciences

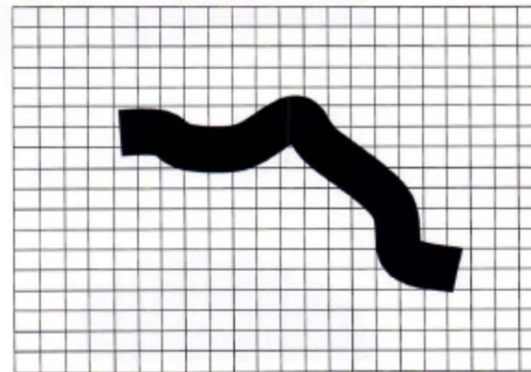
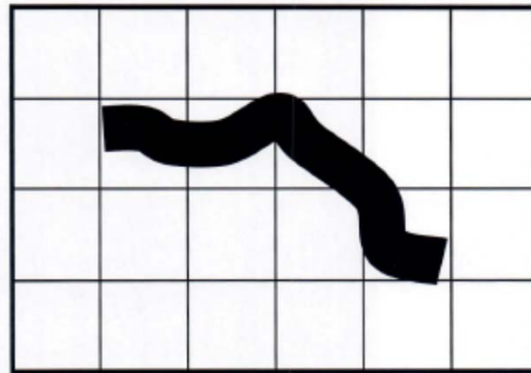


Agriculture



Industrial CT Application : Image Quality – Magnification

Magnification allows the defect to be projected onto more pixels at the detector. Therefore better detectability.



MFX will allow good magnification of a sample/part onto the FPS:

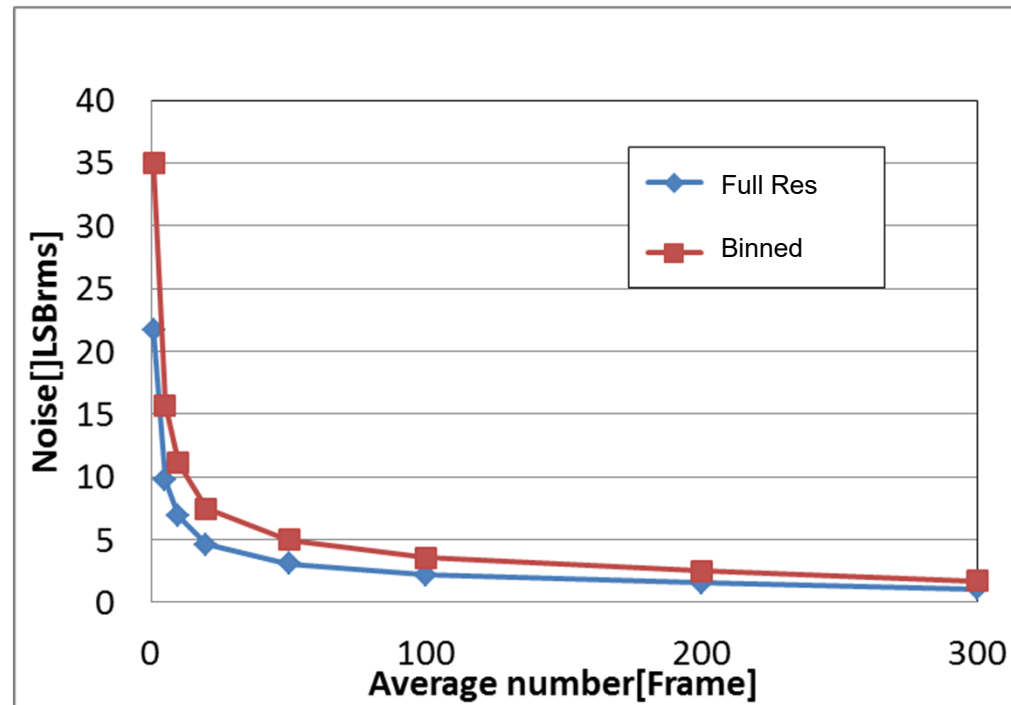
- High Magnification
- Micro focus reduces Unsharpness
- Increases # pixels representing the sample

Flaw Detectability of System is increased.

Industrial CT Application : Image Quality – Frame Averaging

Random Noise intensity fluctuations can be reduced.

Noise drops by 1/the square root of the number of frames averaged.

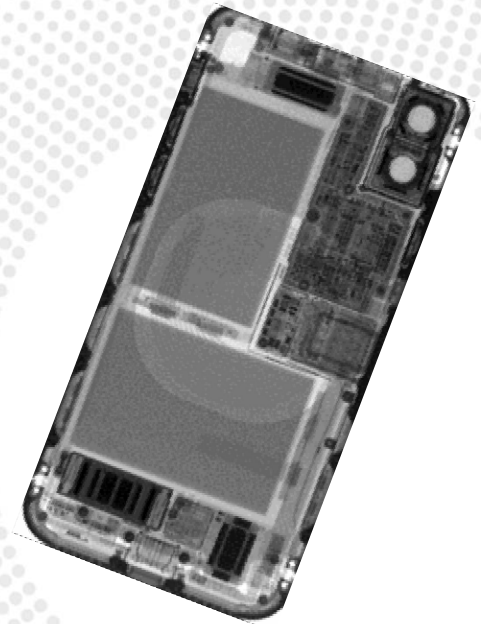


Optimizing SNR is a balance of Signal Increase and Noise Reduction.

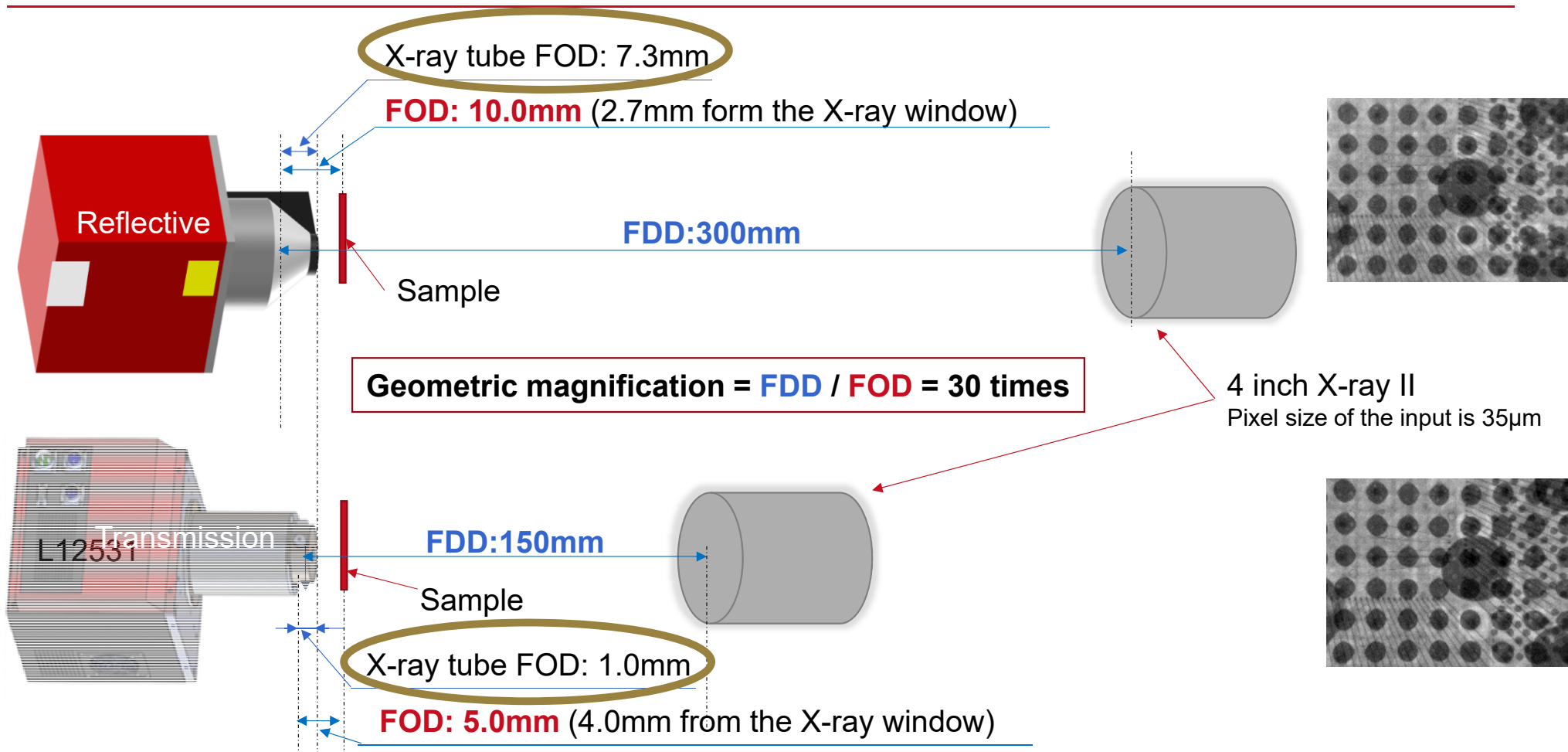
1. Confirm sample penetration, **adjusting Tube Potential kV.**
2. Add beam **FILTER** to remove unwanted low energy x-rays.
3. **Collimate** output of source tube to reduce scatter.
4. For given kV (i.e. part material density or desired penetration), drive signal as high as possible **adjust Tube Current**, and/or **reducing geometric focal** distance (Dose drops/increases by inverse square of the distance).
5. Adjust **FPS frame rate and frame averaging.**

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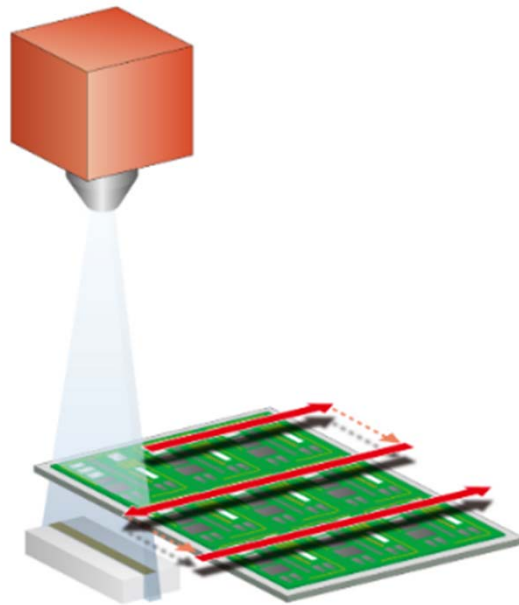


Electronic Inspection Application : Sample Dose and Magnification

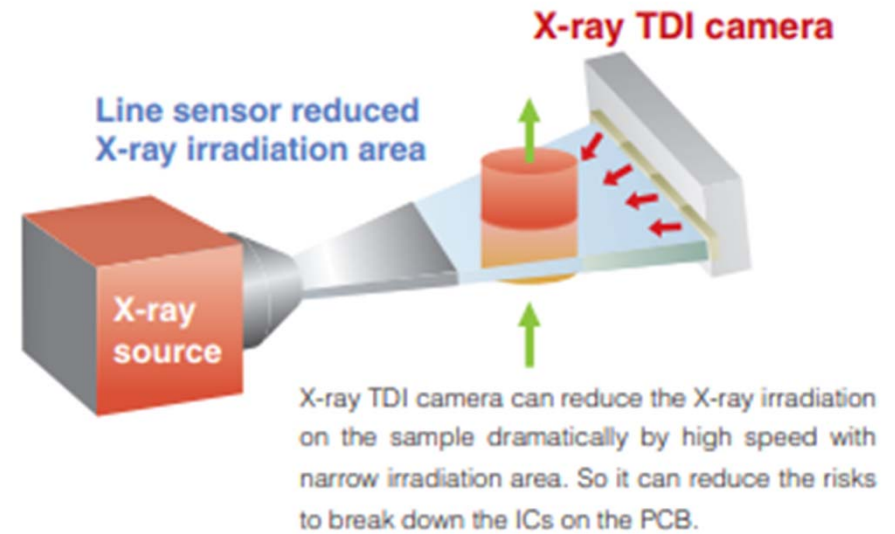


Electronic Inspection Application : Sample Dose and Detector

Bidirectional Scanning

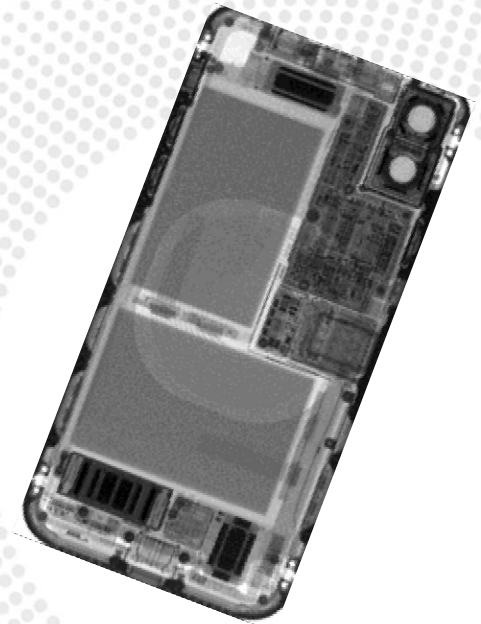


Focused fan beam onto small detector area



Agenda

- Intro to X-rays
- Source Tubes
- Detectors
- Applications :
 - Industrial CT
 - Electronics Inspection
 - Food Inspection

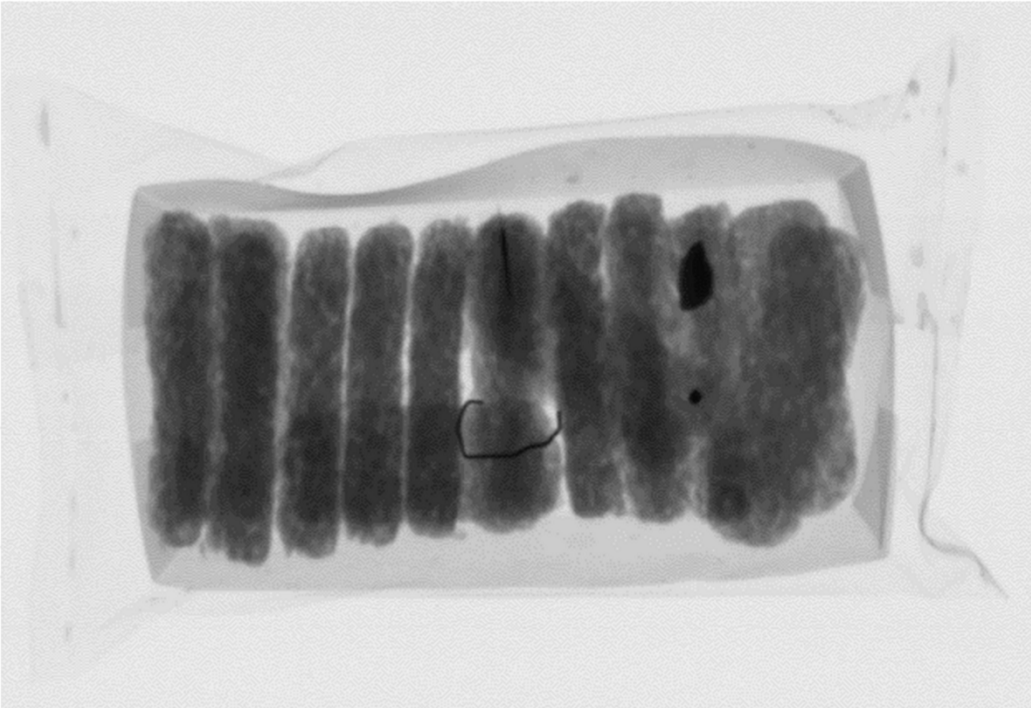


Food Inspection Applications

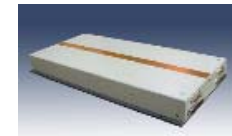
Hash brown potatoes



X-ray LSC



Food Inspection Applications - Detectability

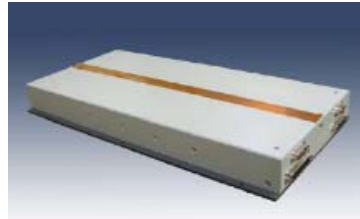


Looking For:	Inside of:	Need:	LSC	Dual-Energy	TDI
Quality and Safety Check	General	High Speed	BEST	Good	Good
Organic Materials (Glass, Bone, Mineral Stone) or High Density Plastic/Rubber	<u>Homogeneous</u> (Yogurt, Butter)	Dynamic Range	BEST	Good	Good
Organic Materials (Glass, Bone, Mineral Stone, Low Density Plastic/Rubber)	<u>Heterogeneous</u> (Bag Hard Candy, Mixed Nuts)	Material Differentiation	Good	BEST	Better
Contaminants	Complex Packaging	Resolution and Material Differentiation	Good	BEST	BEST
Small Voids	Sealed Package	High Resolution	Better	Good	BEST

Food Inspection Application - **Where**



Single Energy LSC



Dual Energy LSC



TDI LSC



In from Field

Bulk Food Process

Processing Lines

Packaged / Sealing

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Spectral distribution from end window X-ray tubes

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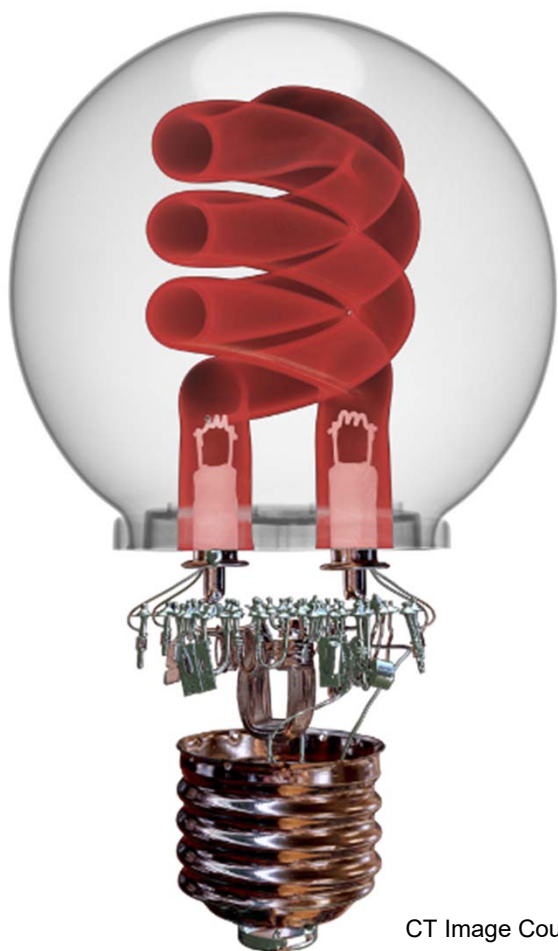
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2	Emerging Applications - LiDAR & Flow Cytometry	2	2-Jun-20	4-Jun-20
3	Understanding Spectrometer	2	9-Jun-20	11-Jun-20
1 Weeks Break				
4	Specialty Products – Introduction to Light Sources & X-Ray	2	23-Jun-20	25-Jun-20
5	Introduction to Image Sensors	2	30-Jun-20	02-Jul-20
1 Weeks Break				
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7	Image Sensor Circuits and Scientific Camera	2	21-Jul-20	23-Jul-20
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