Development of a new photon diffraction imaging system for nuclear diagnostic medicine

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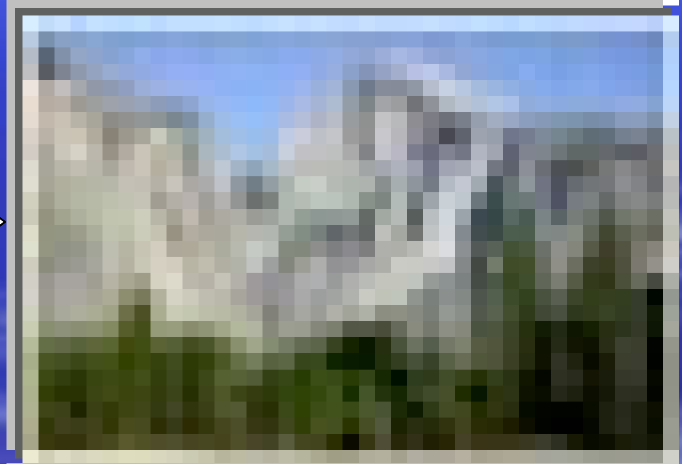
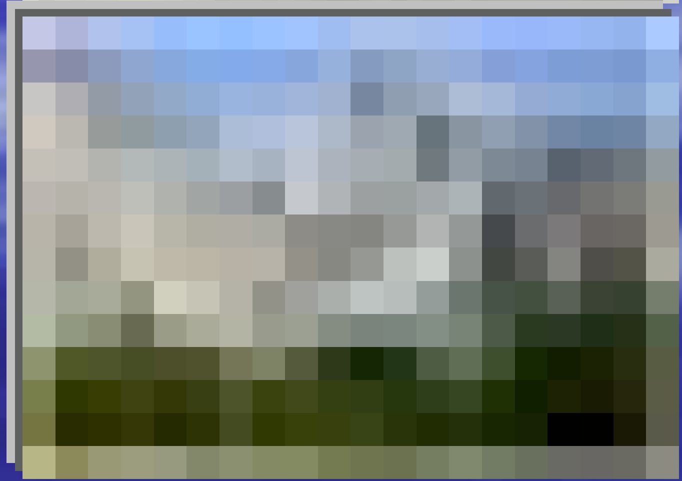
MAIN IMAGING MODALITIES

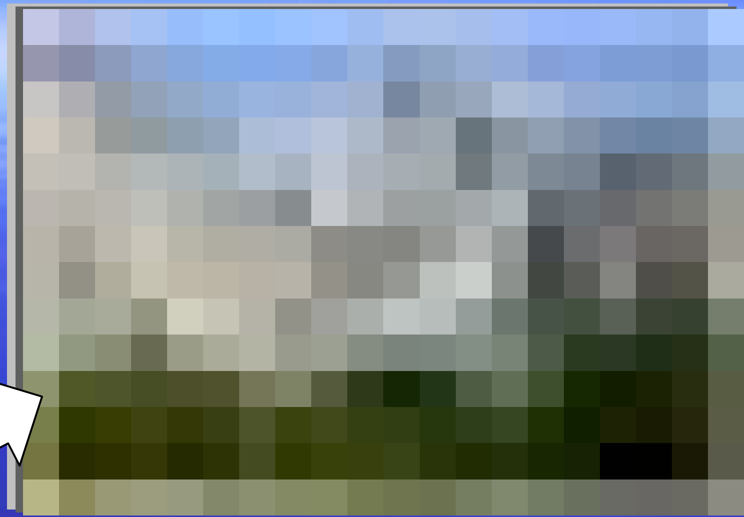
Anatomy	Physiology	Metabolic	Molecular
CT			
MRI	MRI		
	fMRI		
Ultrasound	Ultrasound		
	Nuclear Imaging - PET, SPECT, γ-Camera	Nuclear Imaging - PET, SPECT, γ-Camera	Nuclear Imaging - PET, SPECT, γ-Camera

Imaging System	Spatial Resolution
CT	≤ 1 mm
MRI	≤ 1 mm
PET	~4 – 5 mm
SPECT	~8 – 20 mm <~ 12 mm>
Gamma Camera	~4 – 10 mm <~ 8 mm>

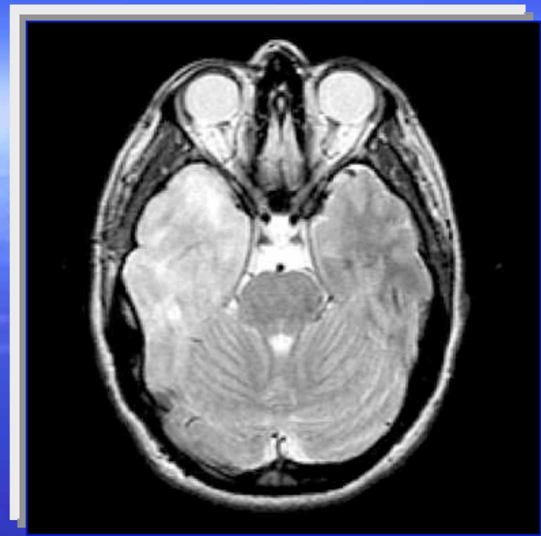




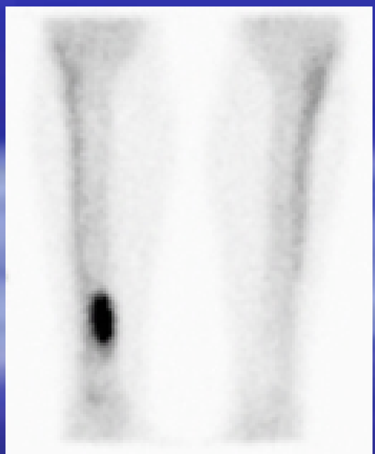
Imaging System	Spatial Resolution
SPECT	~8 – 20 mm <~ 12 mm>
Gamma Camera	~4 – 10 mm <~ 8 mm>
Proposed Imaging System	≤ 2 mm



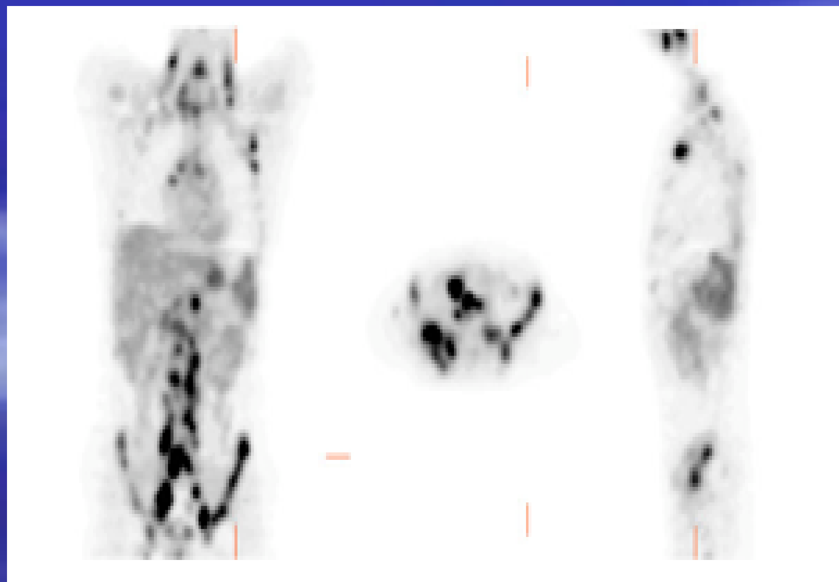
CT Image



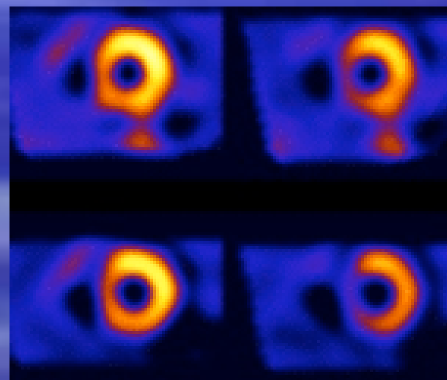
Fused CT / MRI Image



Bone scan



PET scan



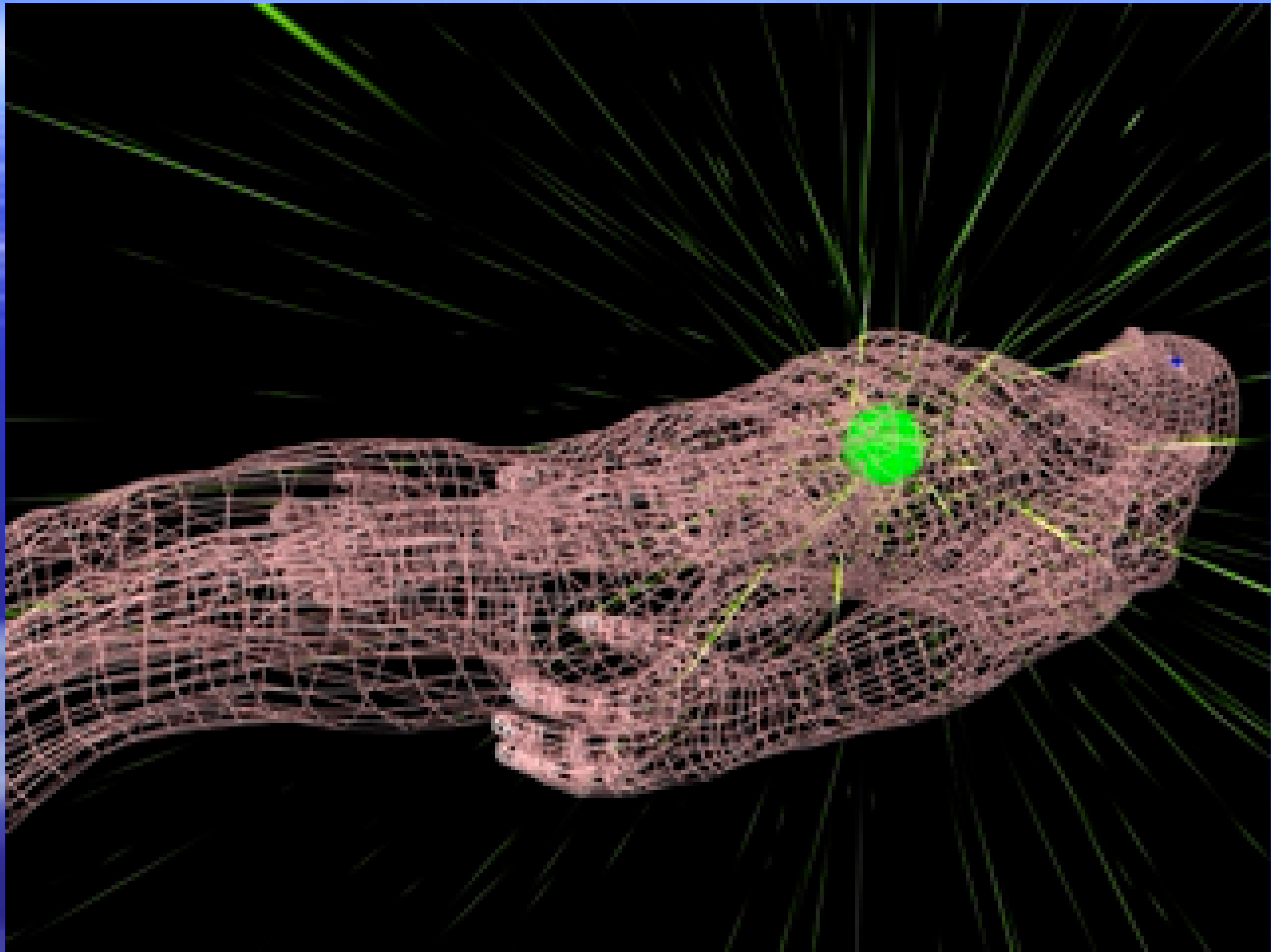
Myocardial function.

Typical Radiopharmaceuticals used in Nuclear Medicine for Imaging

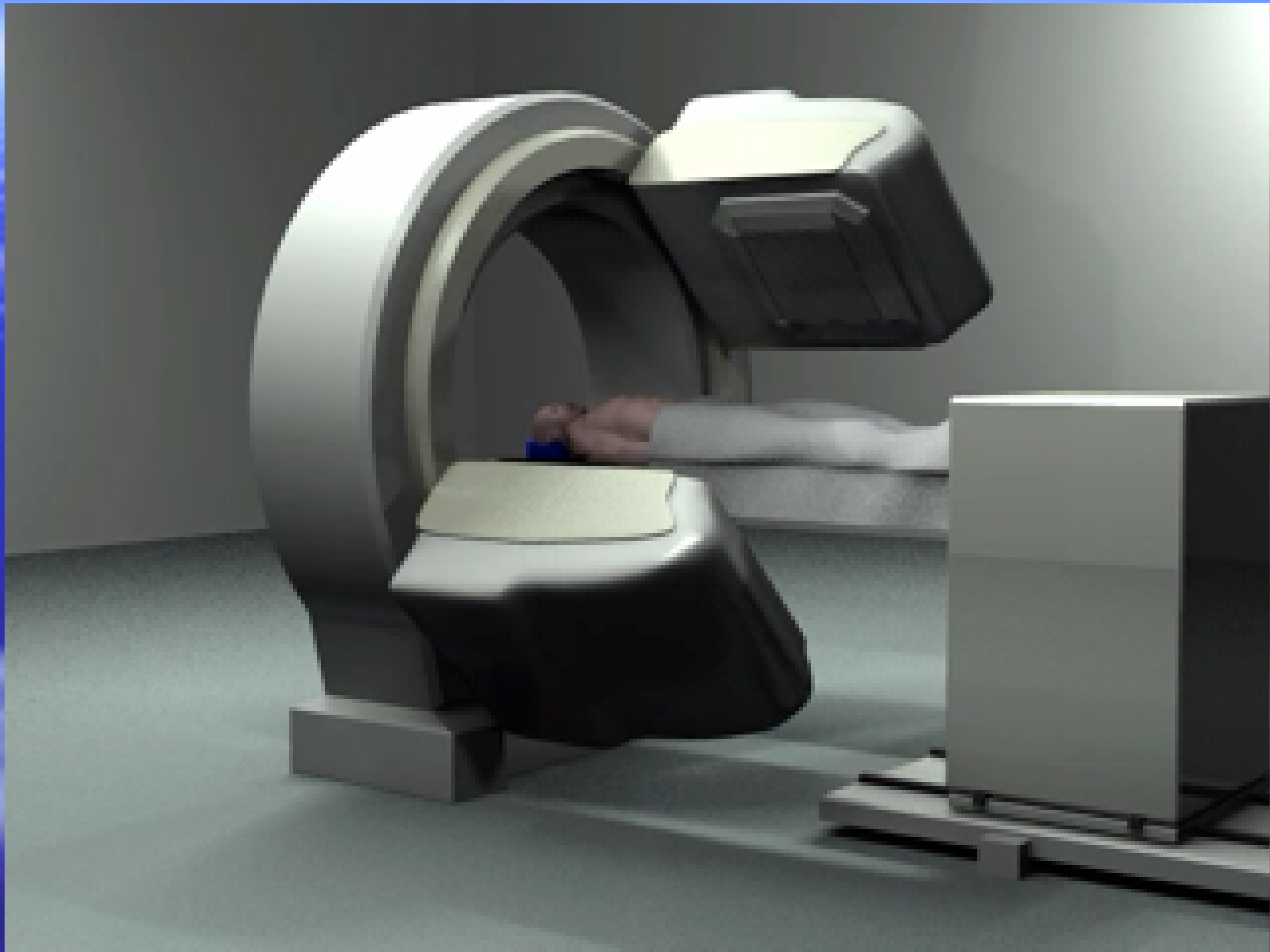
Nuclide	$T_{1/2}$	Energy (keV)	Purpose
Cr-51	28 d	320	Red cell volume
Ga-67	79.2 h	94, 184, 296, 159	Tumor location & inflammation
I-123	8.08 d	364.5	Imaging of thyroid
In-111	67 h	173, 247, 393	Labeling white blood cells
Tc-99m	6.02 h	140.5	Multi-purpose imaging
Tl-201	73 h	135, 167	Myocardial imaging
Xe-133	5.3 d	81	Ventilation imaging
F-18	1.92 h	PET	Tumor imaging

Radiopharmaceutical administered intravenously prior to undergoing a scan with a gamma camera

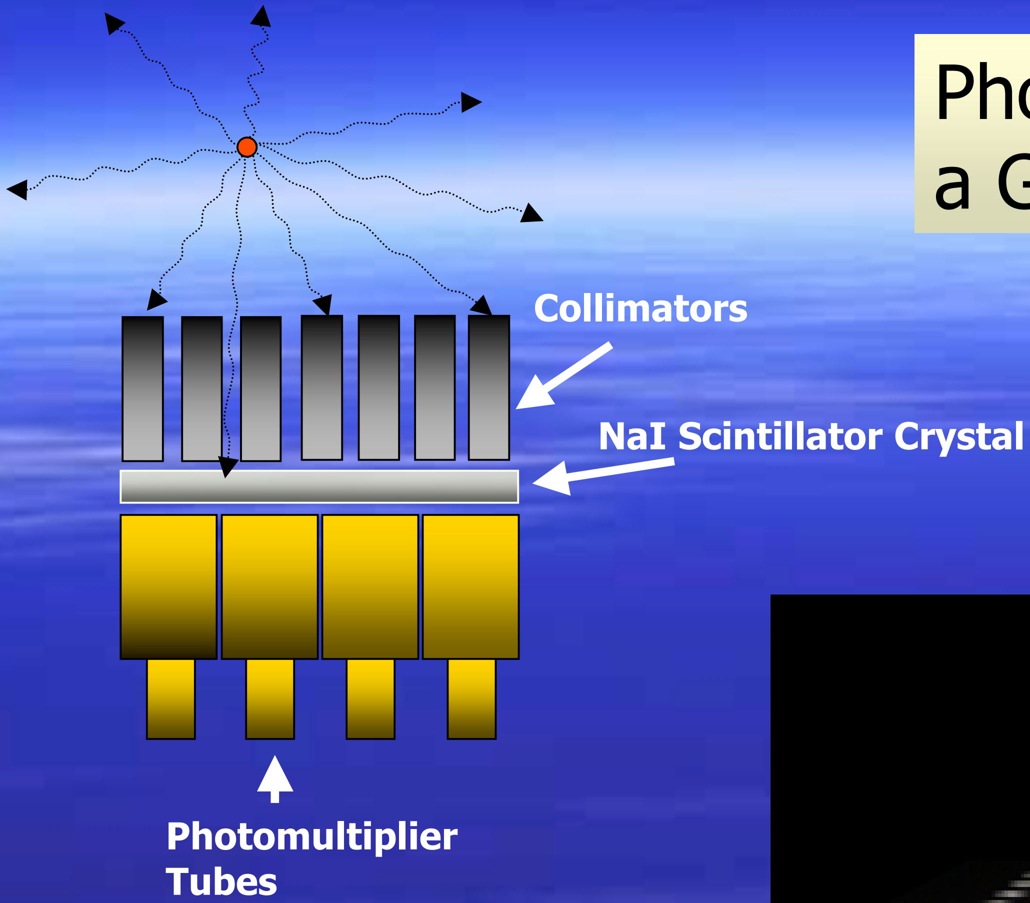
Tumor Tagged with a Radiopharmaceutical

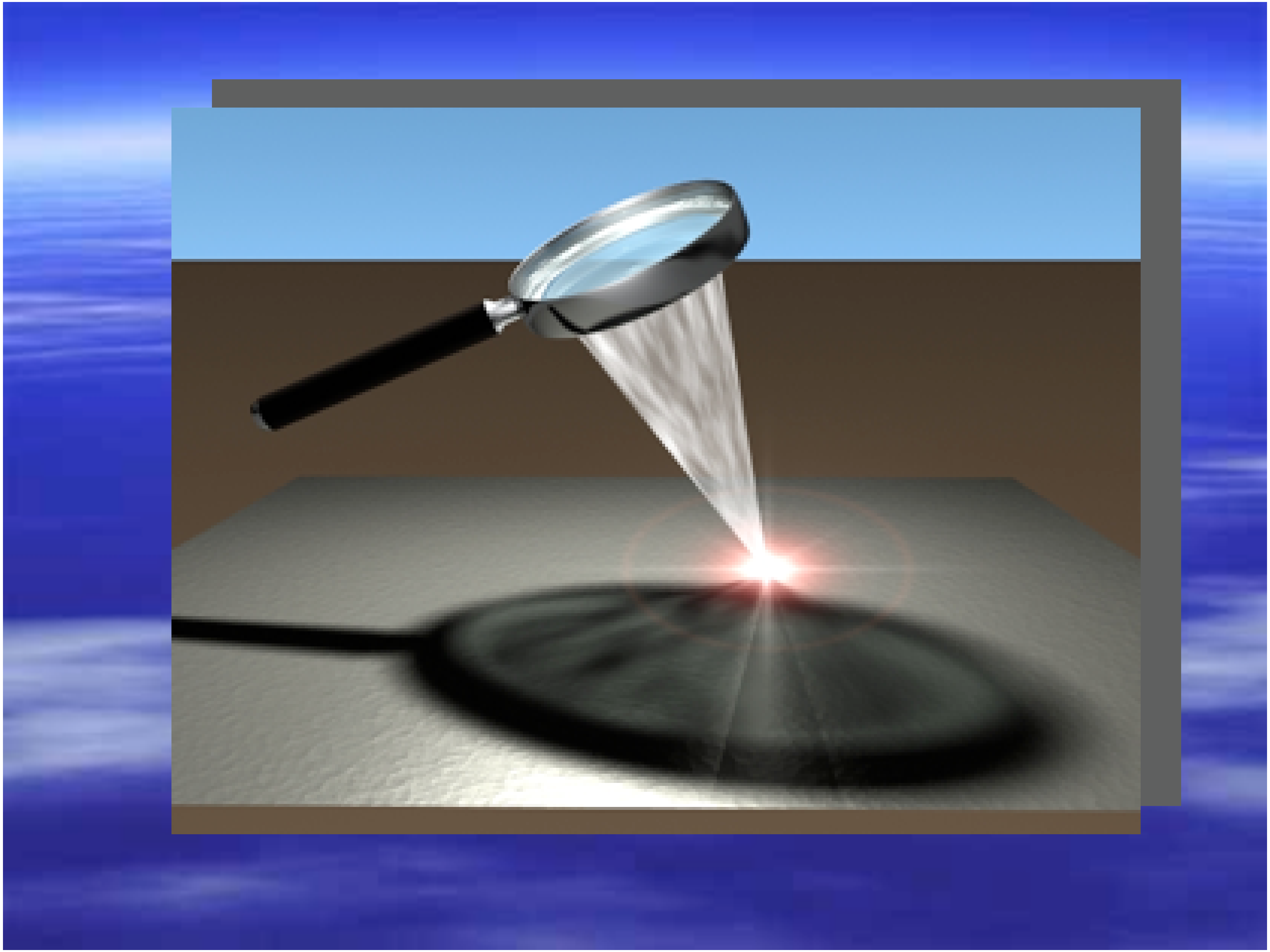


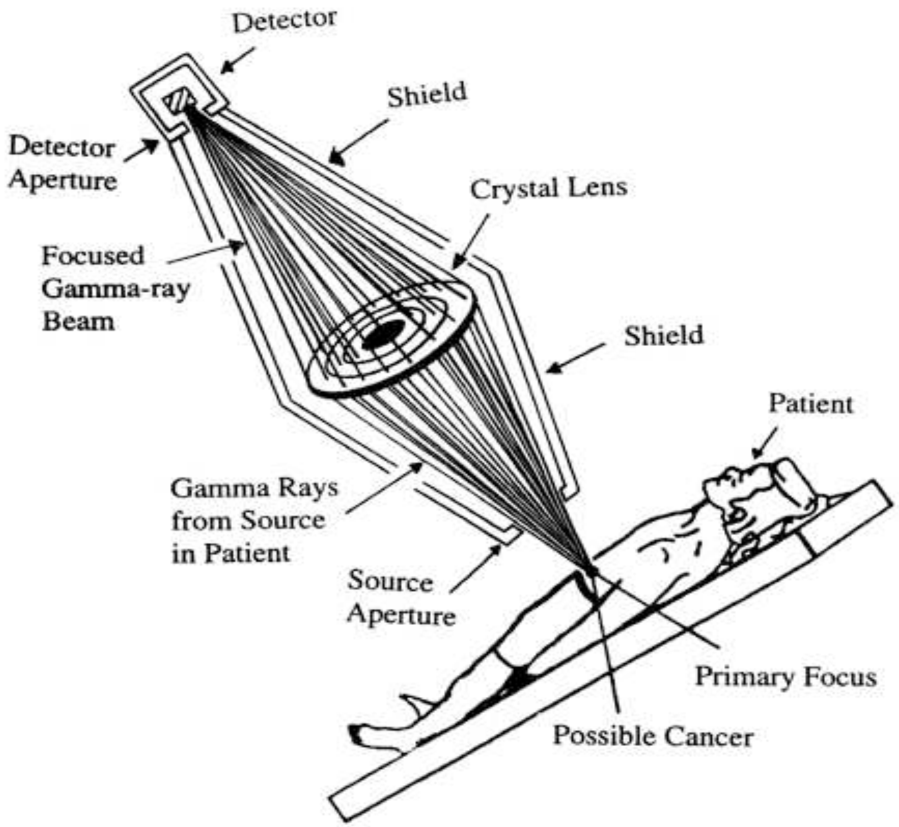
Patient undergoing a scan using a Gamma Camera



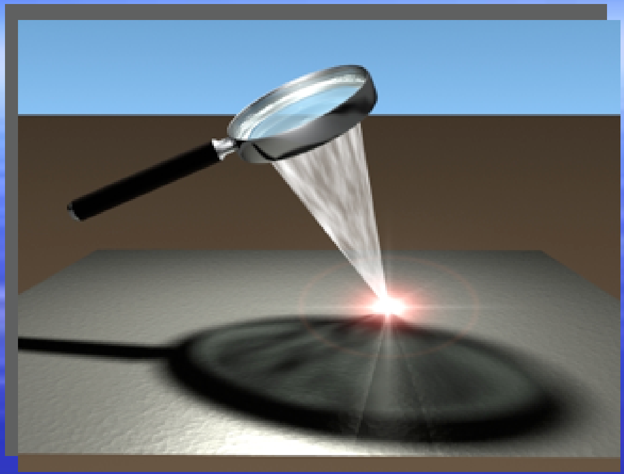
Photon Detection with a Gamma Camera

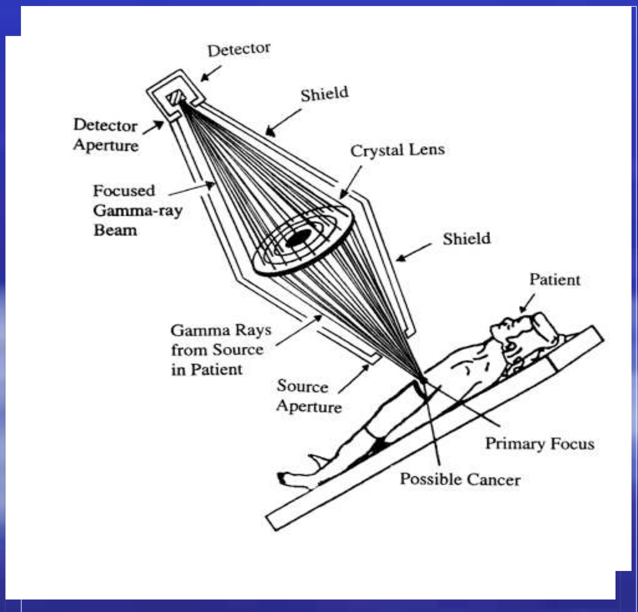


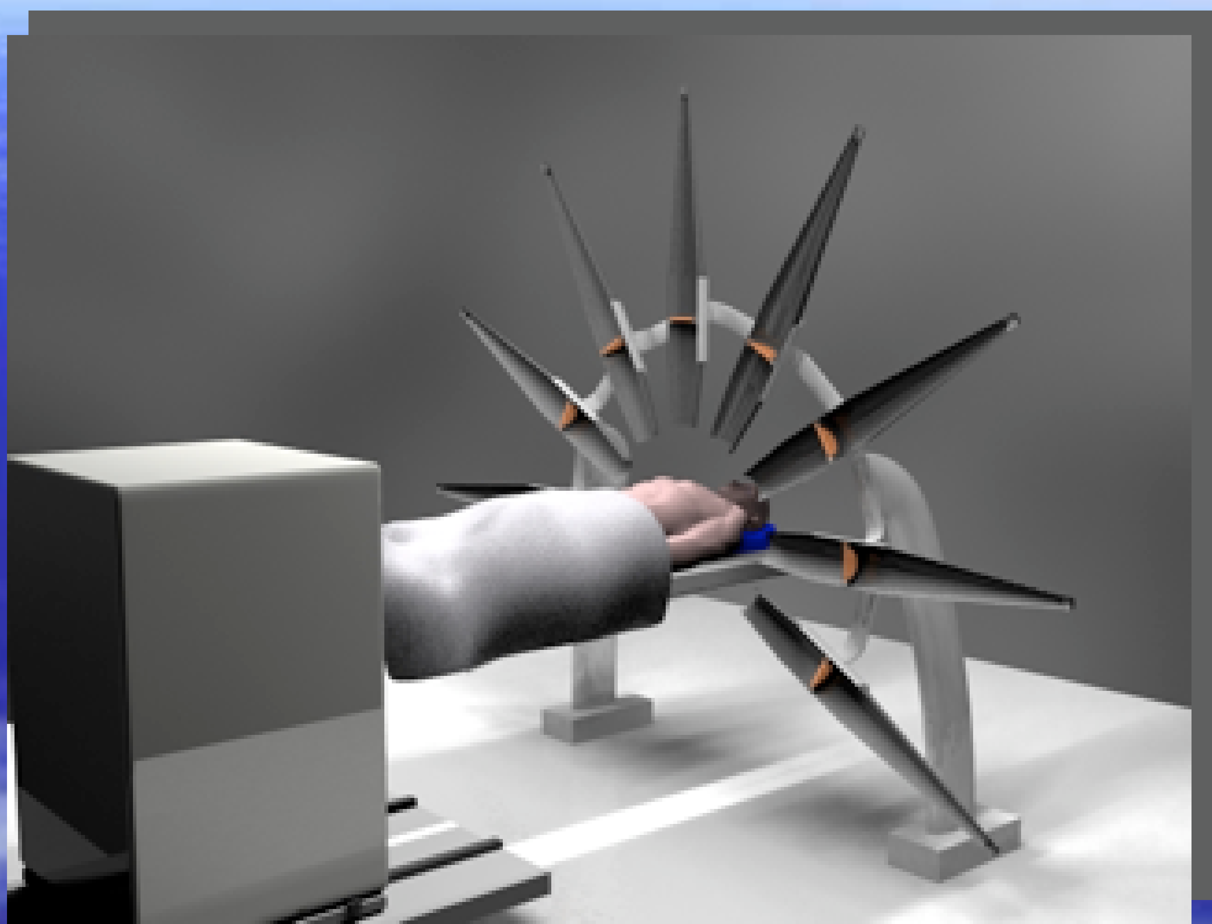




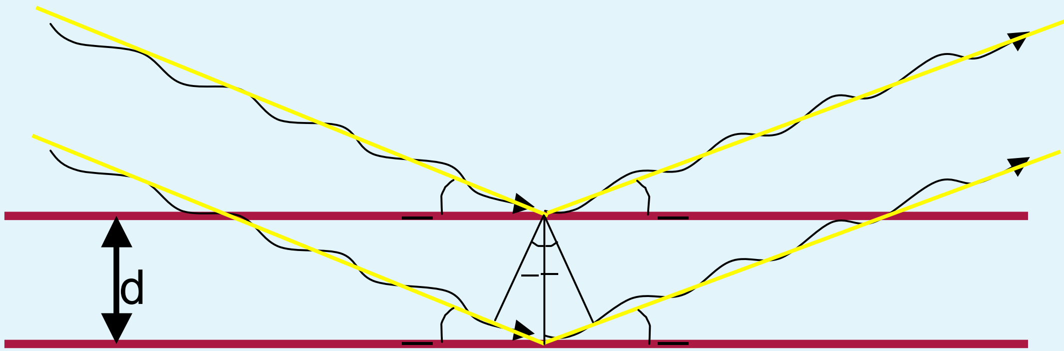
Detector
Shield
Detector
Aperture
Crystal Lens
Focused
Gamma-ray
Beam
Shield
Patient
Gamma Rays
from Source
in Patient
Source
Aperture
Primary Focus
Possible Cancer




Detector
Shield
Detector Aperture
Crystal Lens
Focused Gamma-ray Beam
Shield
Patient
Gamma Rays from Source in Patient
Source Aperture
Primary Focus
Possible Cancer

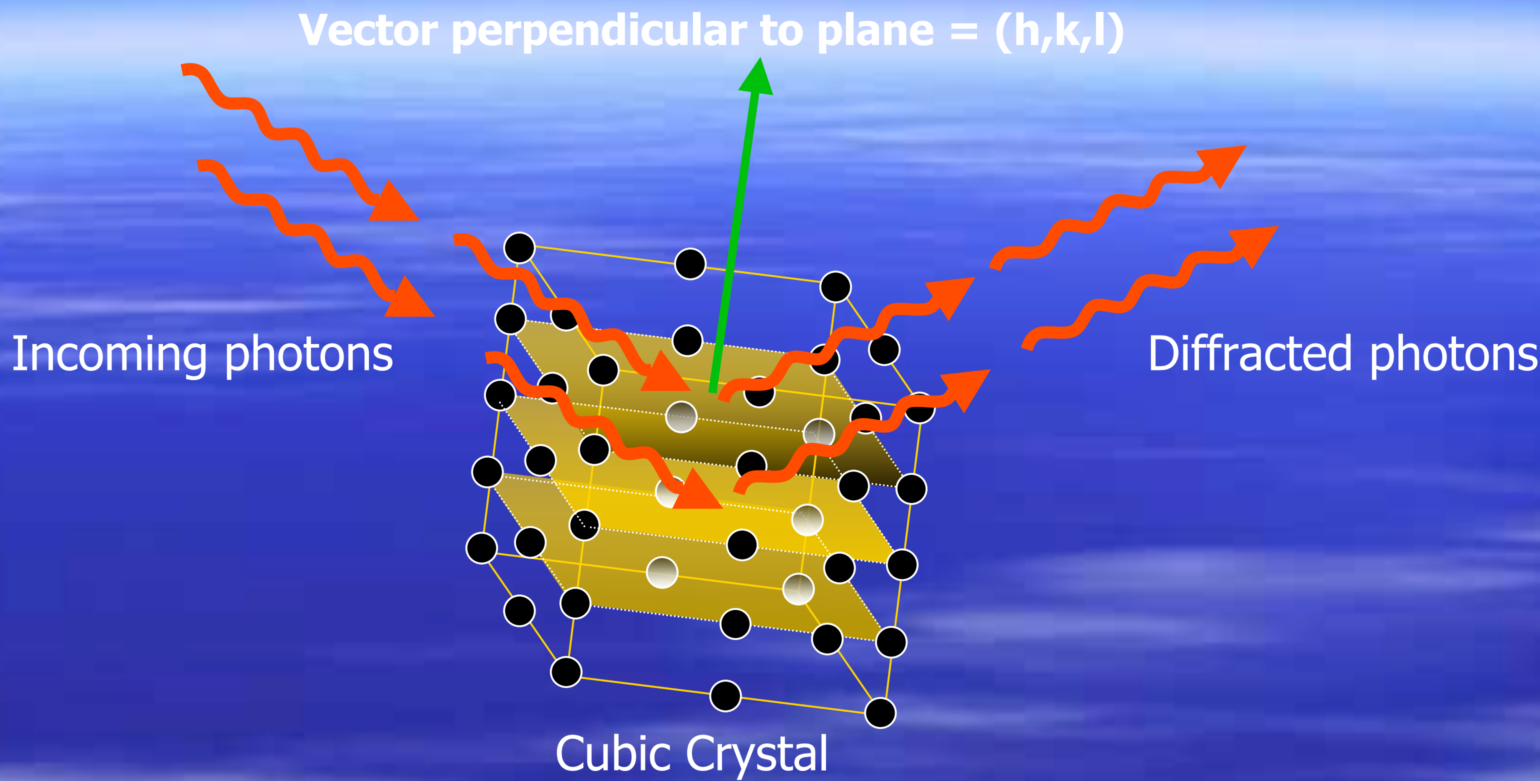


Schematic Description of Bragg's Law



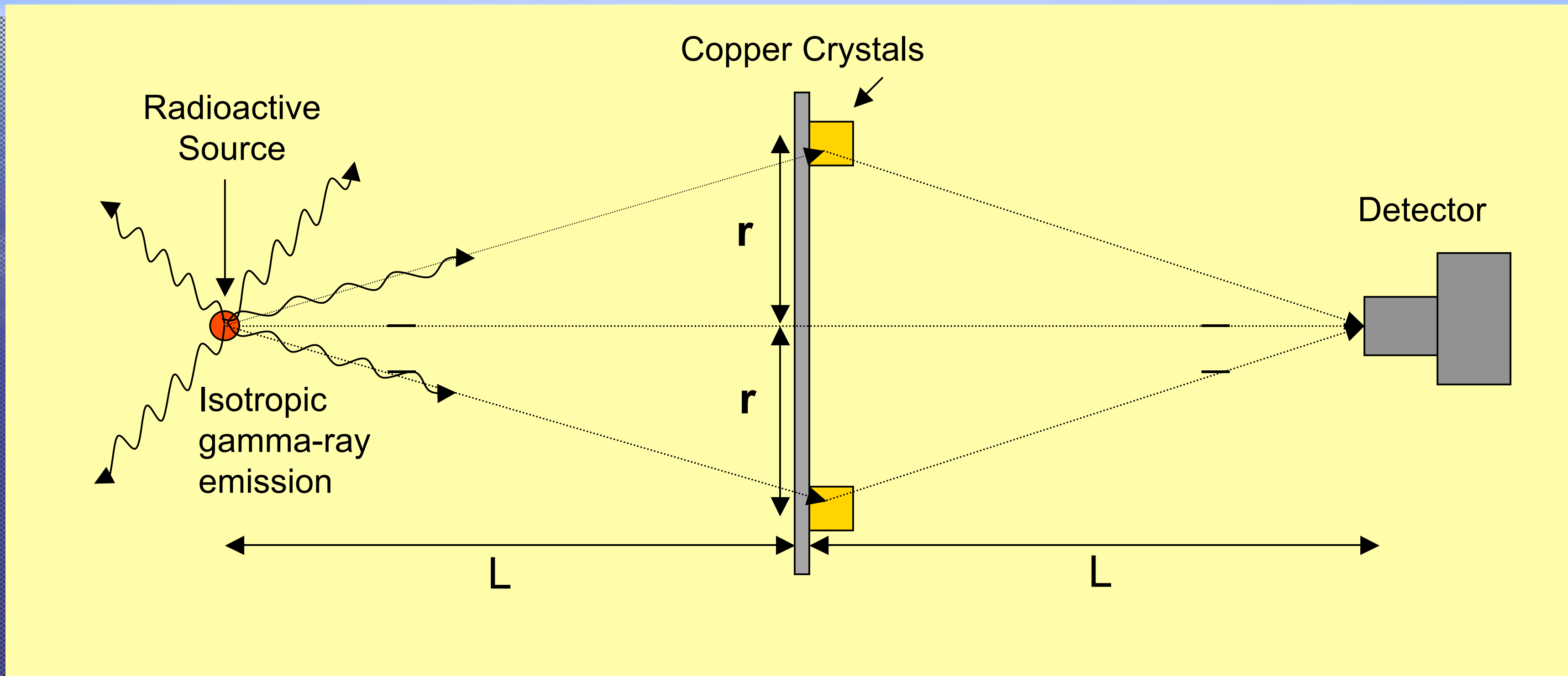
2dSin_ = n_

d = separation distance between consecutive planes
n = integer > 0



d = (lattice constant) / sqrt ($h^2 + k^2 + l^2$)

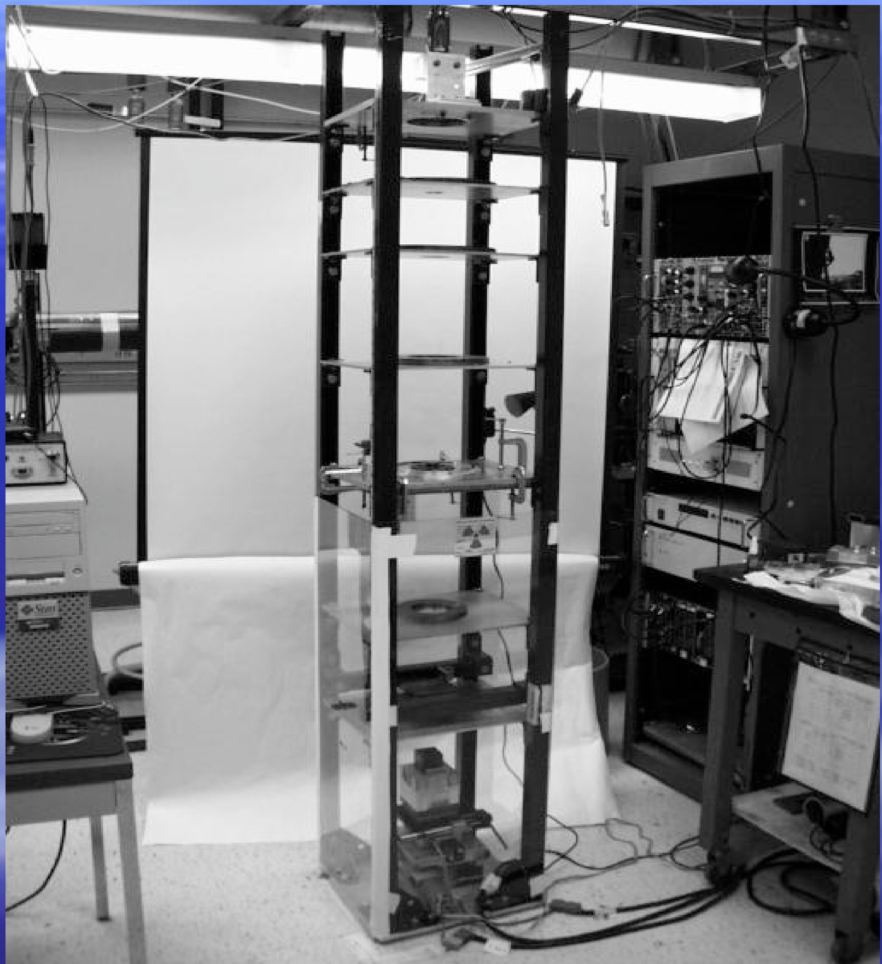
_ = (Planck's constant) x (speed of light) / (Photon energy)

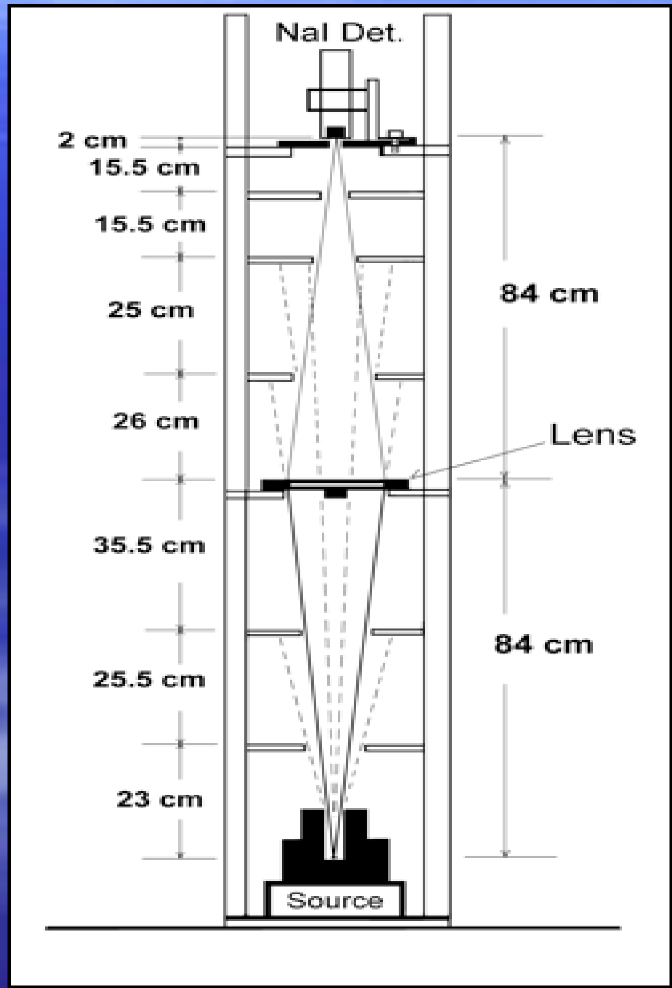


$$è_B = \mathrm{Sin}^{-1}\left(\frac{hc\sqrt{h^2+k^2+l^2}}{2aE_{ã}}\right) \cong è = \mathrm{Tan}^{-1}\left(\frac{r}{L}\right)$$

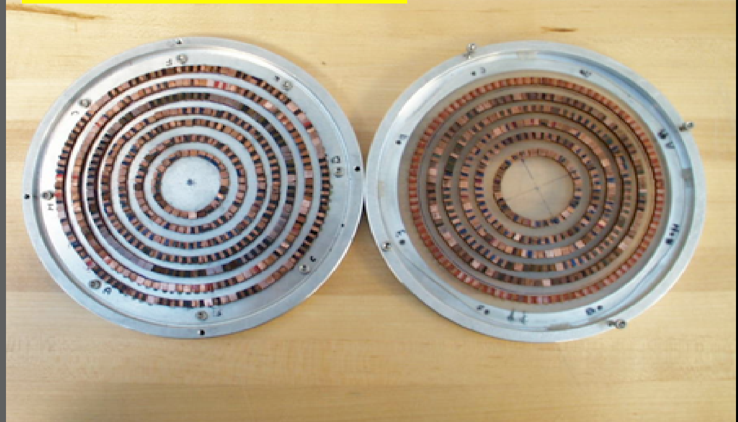
Copper Crystals

Medical Lens Assembly Setup



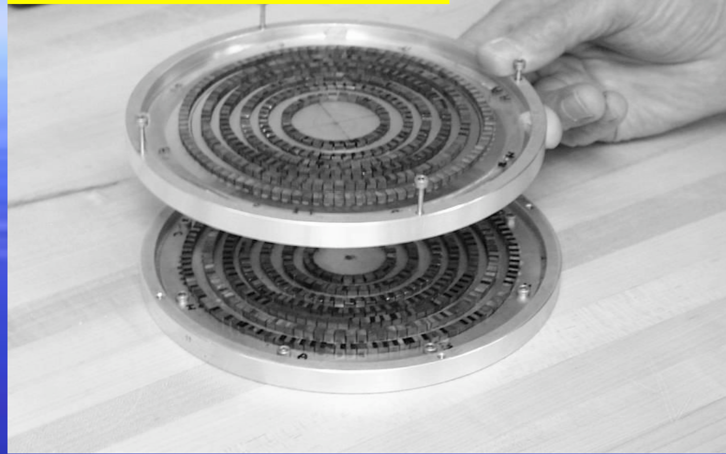


Lens Substrates

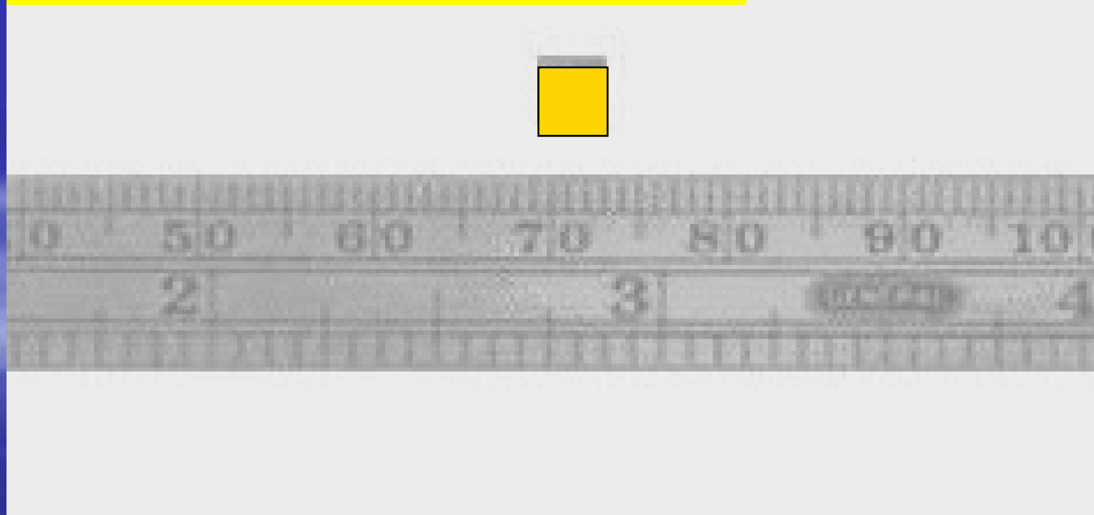


7 rings 6 rings

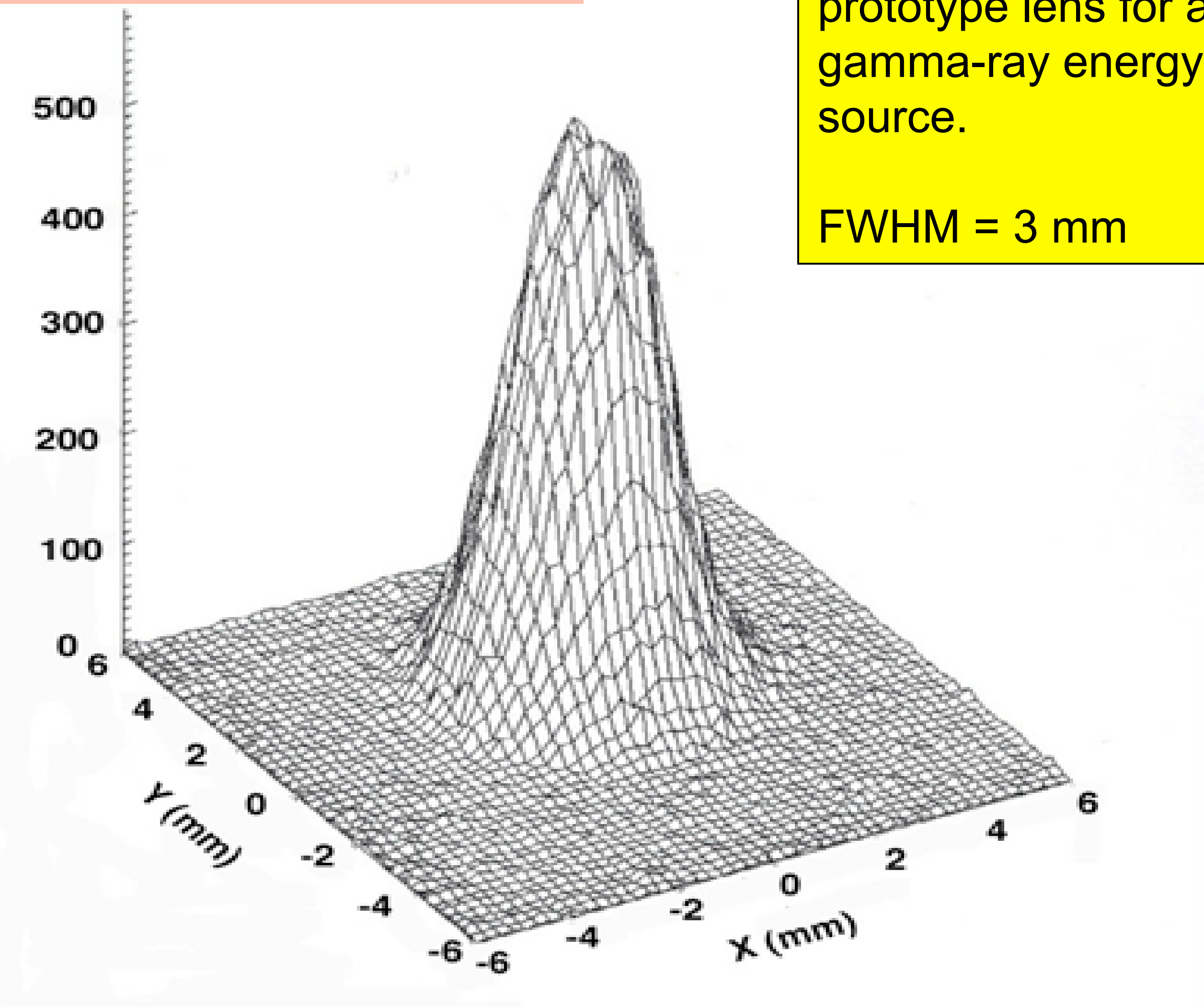
Lens Configuration



Copper Crystal Cube 4x4x4 mm^3

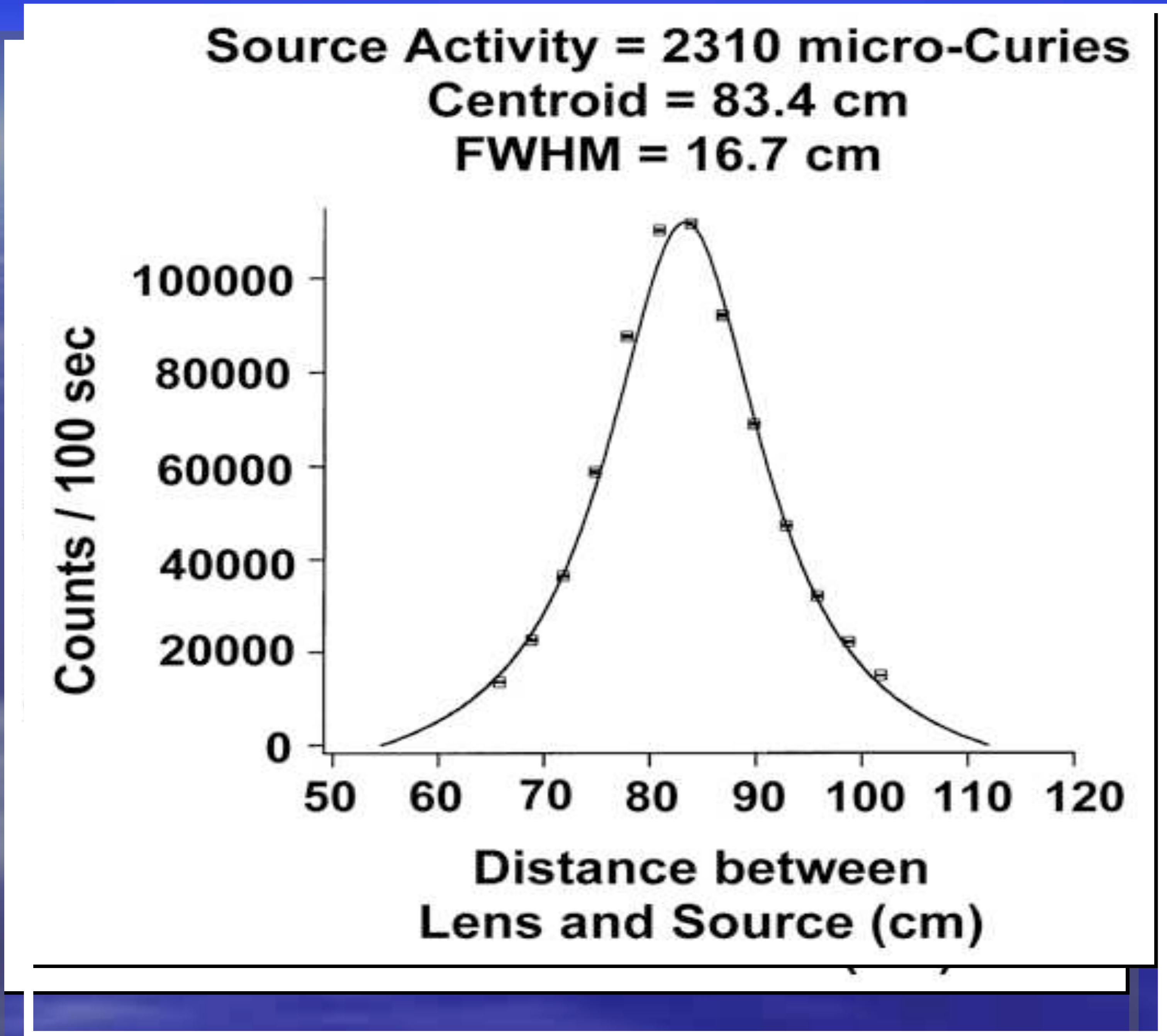


Phantom Measurement

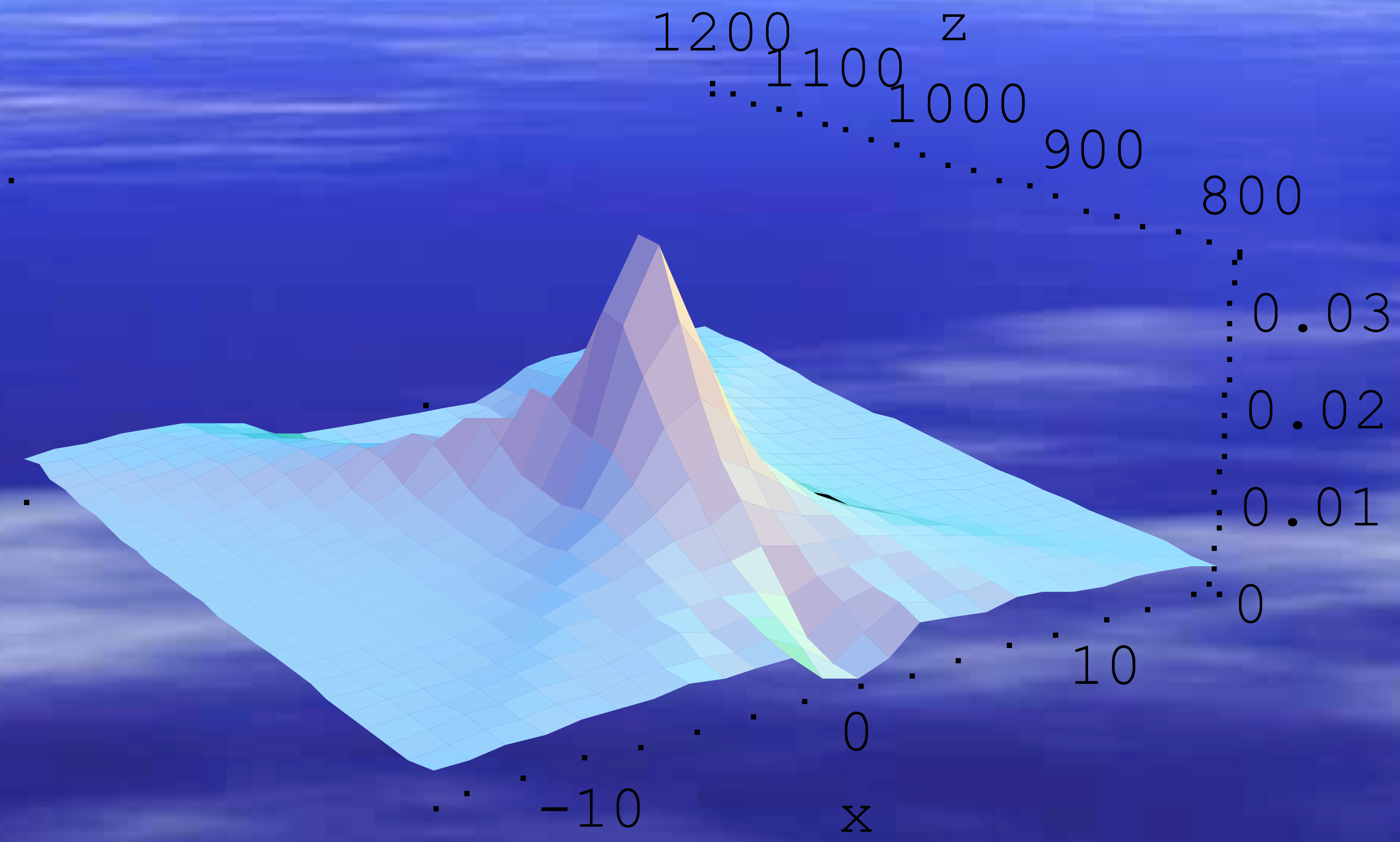


Diffraction response of the prototype lens for a 122 keV gamma-ray energy from a Co-57 source.

FWHM = 3 mm


Source Activity = 2310 micro-Curies
Centroid = 83.4 cm
FWHM = 16.7 cm
Counts / 100 sec
100000
80000
60000
40000
20000
0
50
60
70
80
90
100
110
120
Distance between
Lens and Source (cm)

Calculated Diffraction Efficiency for a Single Lens



Expected Overall Efficiency

For 1-Lens:

_$_{1}$ = (Diff. Eff.) x (155 cm^2 / 4 pi (100 cm)^2)

=>_$_{1}$ = 3.7 x 10^{-5}

For a 9-Lens Array:

_ = (3.7 x 10^{-5}) x 9 = 3.3 x 10^{-4}

Gamma Camera:

_ = ~3.0 x 10^{-4} (*)

* E. L. Palmer, J. A. Scott and H. W. Strauss, “Practical Nuclear Medicine”, W. B. Saunders Company, Philadelphia (1992)

Expected Features

- Gamma-ray energies ranging from 100 – 200 keV can be imaged with the new system, by simply adjusting the source-to-lens and lens-to-detector distances.
- Because of the properties of photon diffraction, only one gamma-ray energy can be imaged at a time which can significantly reduce the background contribution from scatter gamma rays.
- No additional radioactivity would be needed on a patient who has already undergone a scan since the new system should be sensitive enough to detect the remaining radioactivity.

Work to be done for this Stage of Development

- Monte Carlo simulations to assess the performance of the medical diffraction lens array system at different stages of development.
- Monte Carlo simulations for determining the overall efficiency of the system under different clinical scenarios and comparison with existing imaging modalities.
- Grant proposal to the NIH.

Conclusions

- Work towards the realization of a new imaging system based on photon diffraction continues.
- Preliminary phantom measurements using Tc-99m and Co-57 sources have yielded encouraging results regarding improved spatial resolution and sensitivity of a lens system.

Special Thanks

To Edward J. Orlowski for all his help with the animation portion of this presentation.