Plymouth Hospitals NHS
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Dual Energy Imaging and the use of MOSFETs in estimating organ doses in CT

The basics and practicalities.....

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Introduction

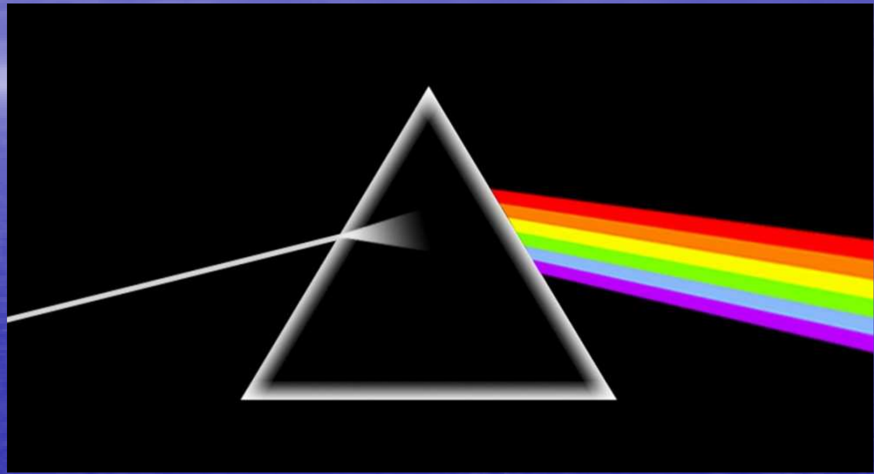
- Brief intro to Dual Energy imaging (GE)
- "The bigger picture" (Justification of DE?)
- Practical use of MOSFETS (are they good enough for CT??)
- ImPACT dose estimates (cardiac)
- Atom phantom organ doses (cardiac)
- Discussion

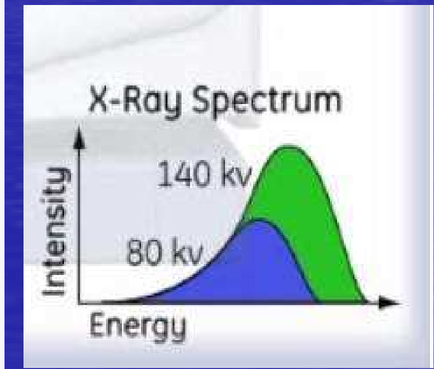
What is Dual Energy Imaging? Gemstone Spectral Imaging (GE)

- In GSI, Monochromatic images are normalised to that of one of the base materials (usually water)
- Base pairs for the majority of GSI are normally Water and Iodine
- User may (e.g. for research) import attenuation data for other base pair materials (e.g Calcium) for comparison.

The Future: Full Spectral CT

- The x-ray beam is polychromatic - range of energies at any kV
- Advanced detectors can separate the component energies
- Gemstone spectral Imaging™ (GE 750HD)
  - Fast kVp switching (0.5 milliseconds) between 80 and 140 kV
  - Can separate data from 101 different energies
  - Improved tissue discrimination





Formation of the Monochromatic image

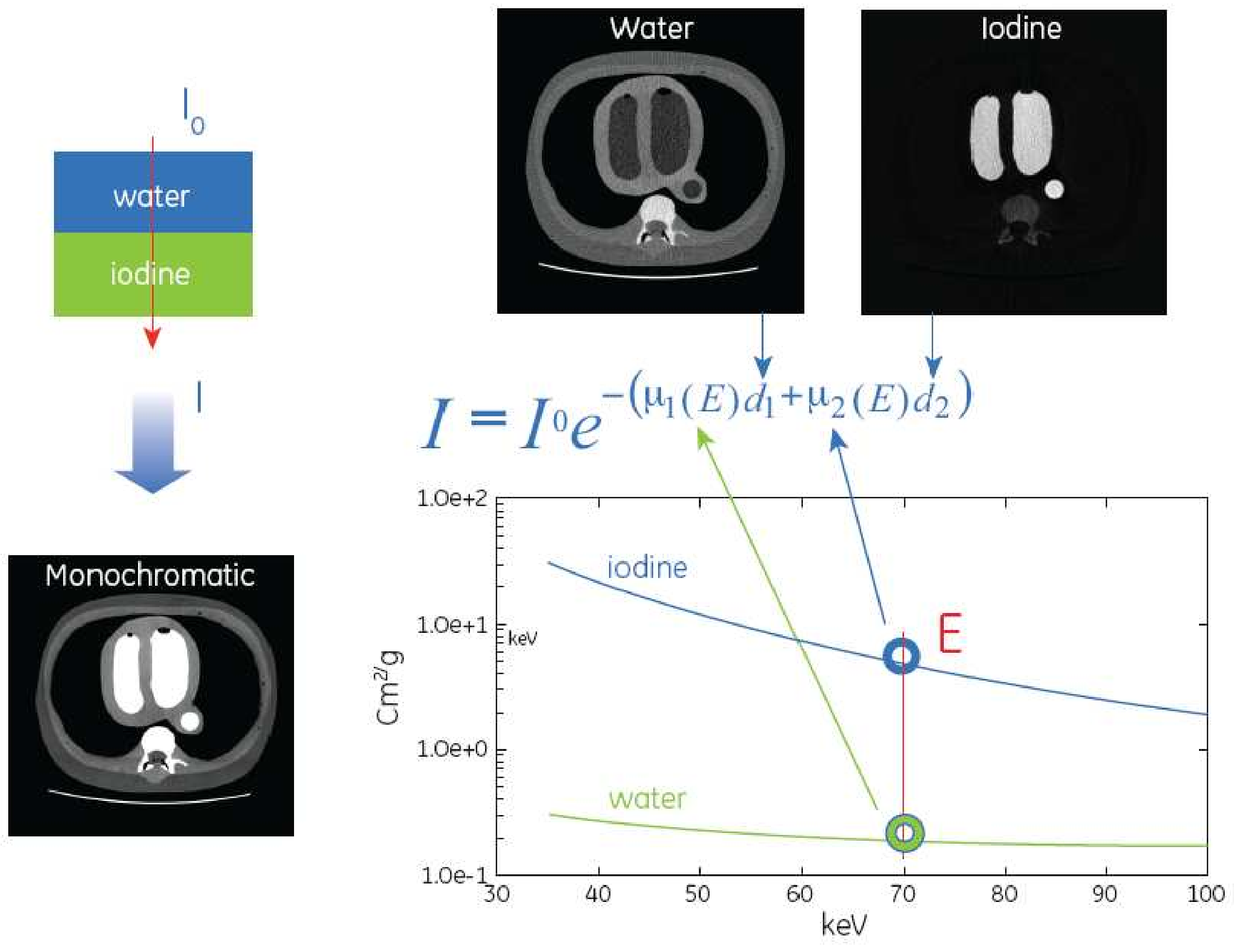


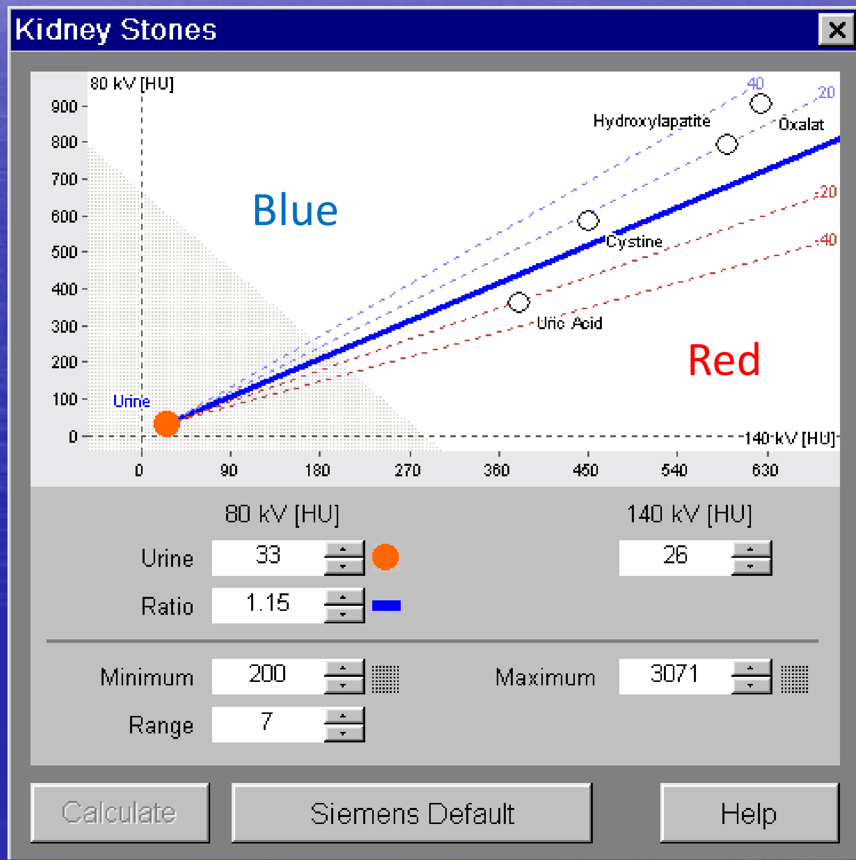
Figure 6: Calculation of monochromatic images

A potential use....

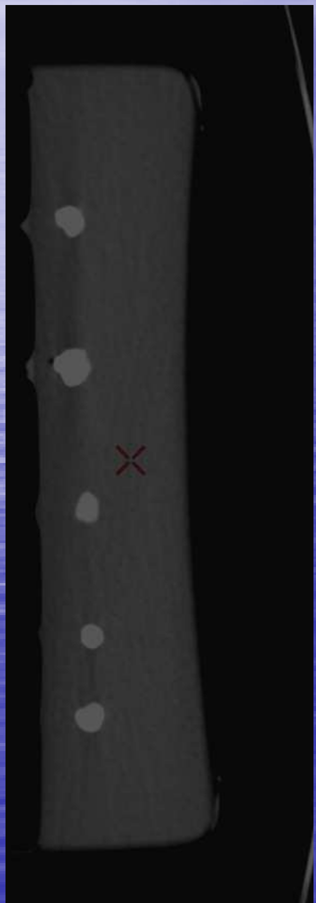
Sophonisba Receiving the Poisoned Chalice: Simon Vouet c. 1623

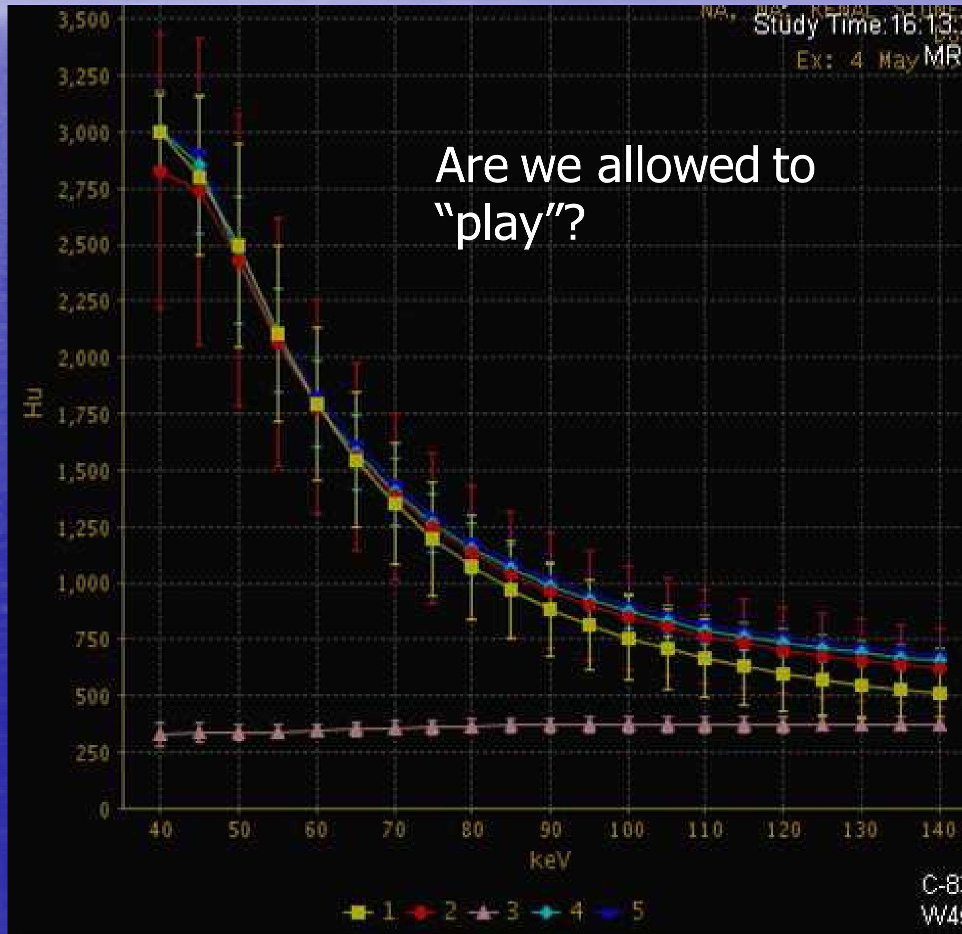
DECT in Clinical Practice: Uric acid stone characterisation

- Siemens – Somatom Definition
  - Limited DE acquisition through stone (following CT KUB)
  - 80 and 140 kVp single breath- hold acquisition
  - Automated calculation of attenuation differences for each voxel
  - Ratio (slope of reference line) represents threshold between uric acid and other stones
  - Result displayed in colour: uric acid red, non uric acid blue

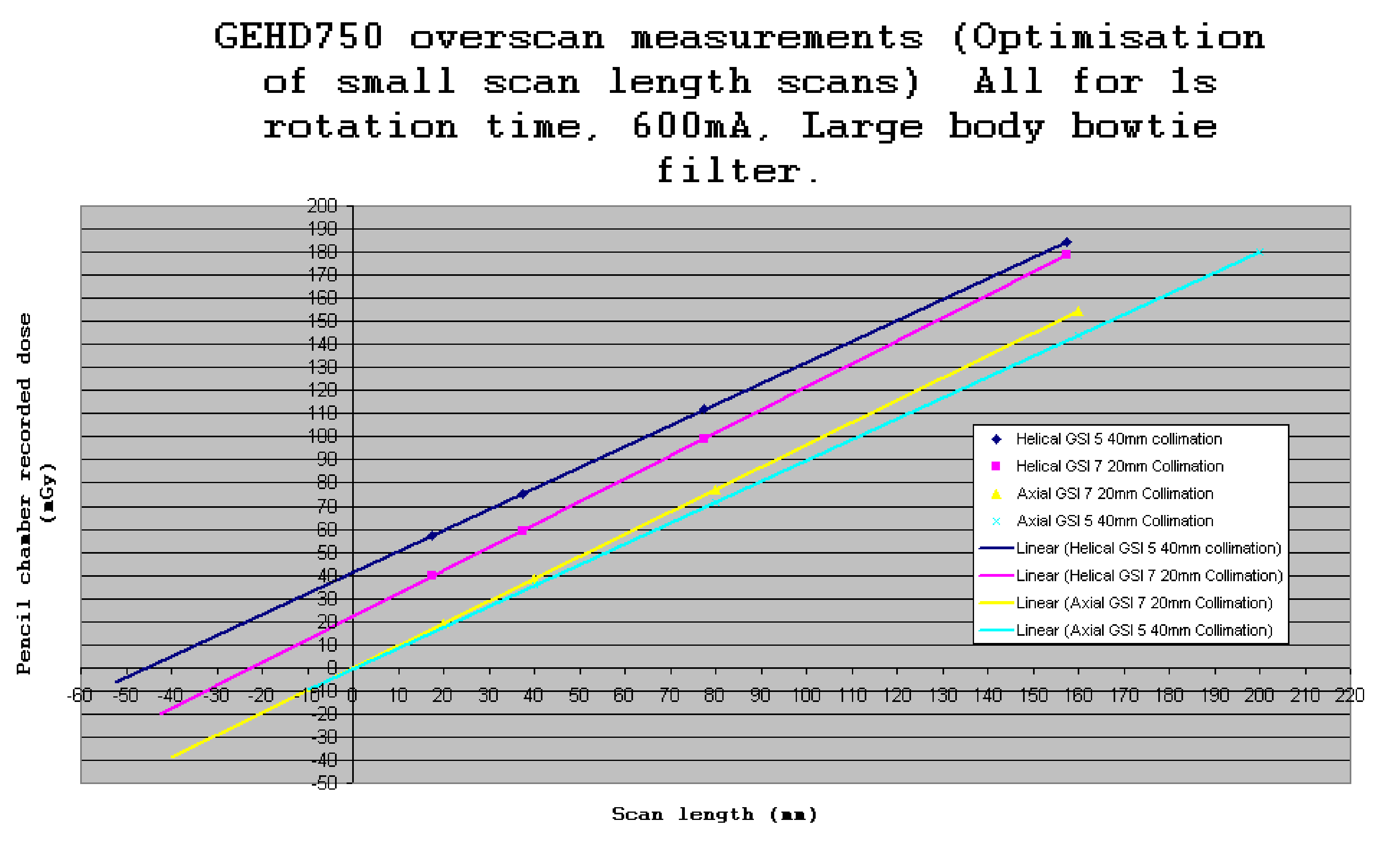


GE…GSI (Showing renal stones in phantom)

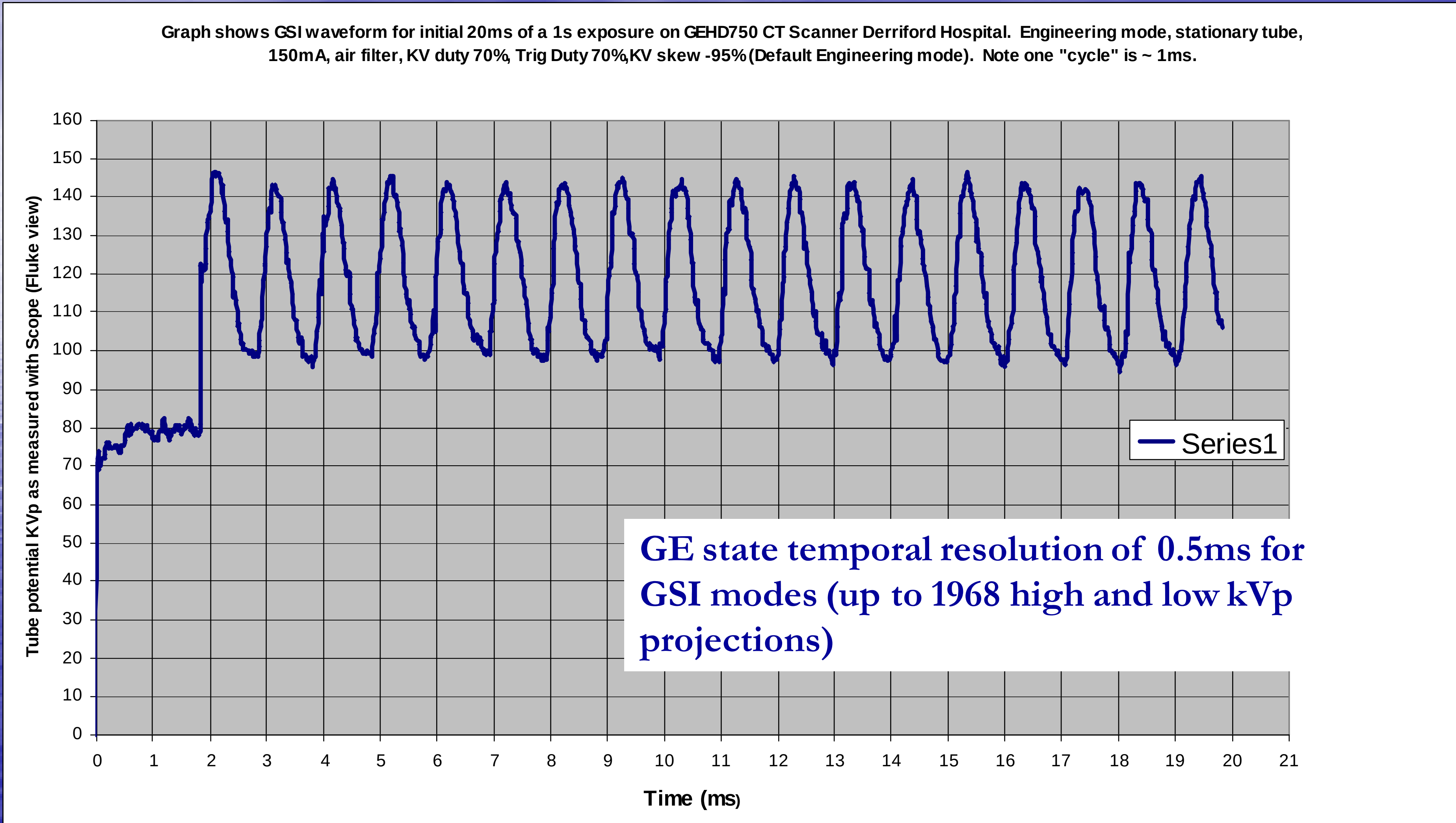




Don’t forget the basics!



GSI –Initial measurements 1



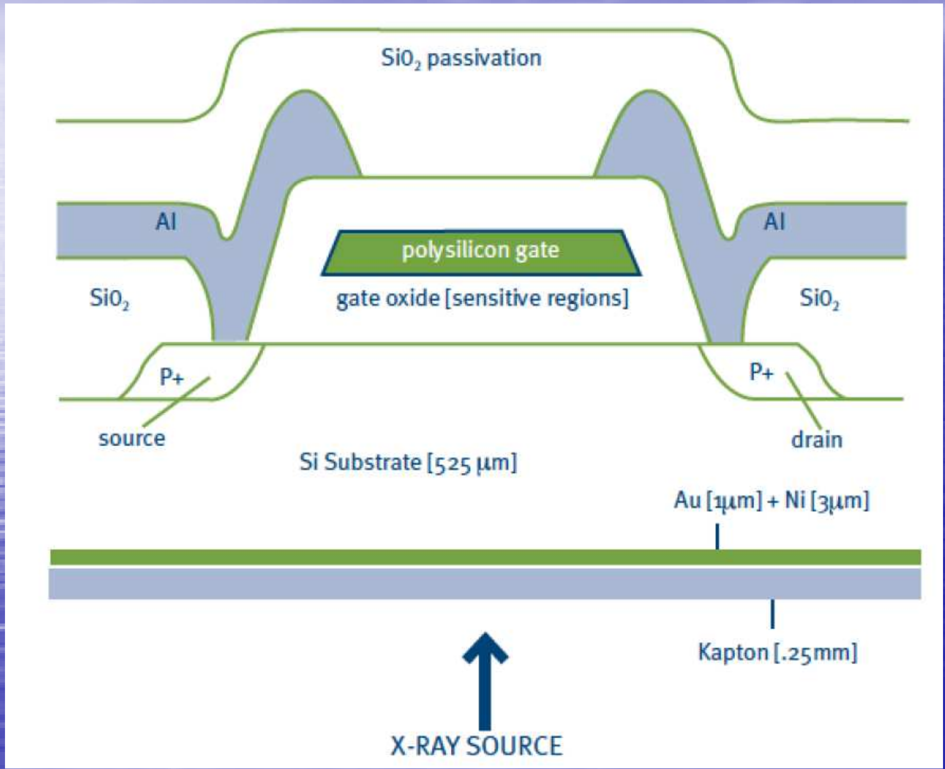
GE state temporal resolution of 0.5ms for GSI modes (up to 1968 high and low kVp projections)

MOSFETS (practicalities)

- TN-502RD dosimeter (Best medical Canada

MOSFETS

Schematic cross section of a P-channel MOSFET



When the MOSFET is irradiated, electron-hole pairs are formed in the oxide insulation layer.

Electrons migrate to gate, hole pairs migrate to oxide-silicon interface and are trapped.

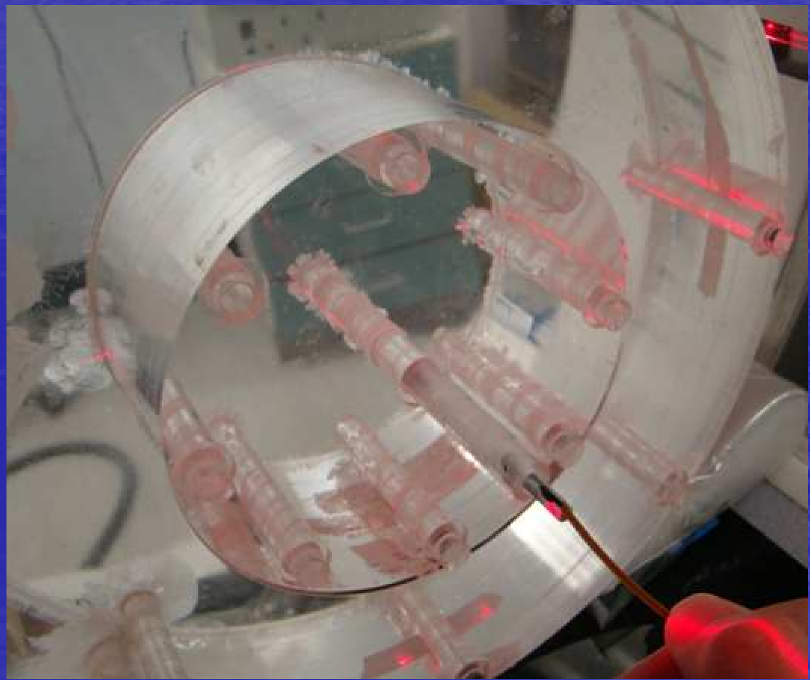
p.d across device is proportional to the trapped positive charge at oxide-silicon interface.

Soubra M. , J. Cygler, and G. Mackay, "Evaluation of a dual bias dual metal oxide-silicon semiconductor field effect transistor detector as radia- tion dosimeter," Med. Phys. 21, 567–572 (1994).

Characterising MOSFETS

- Linearity
- Angular dependence
- Energy dependence
- MOSFET Calibration with dose

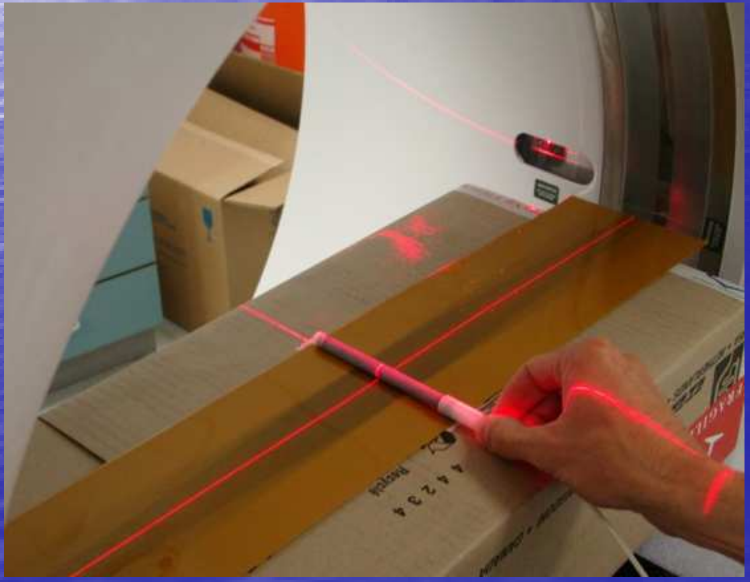
Chamber/MOSFET set-up

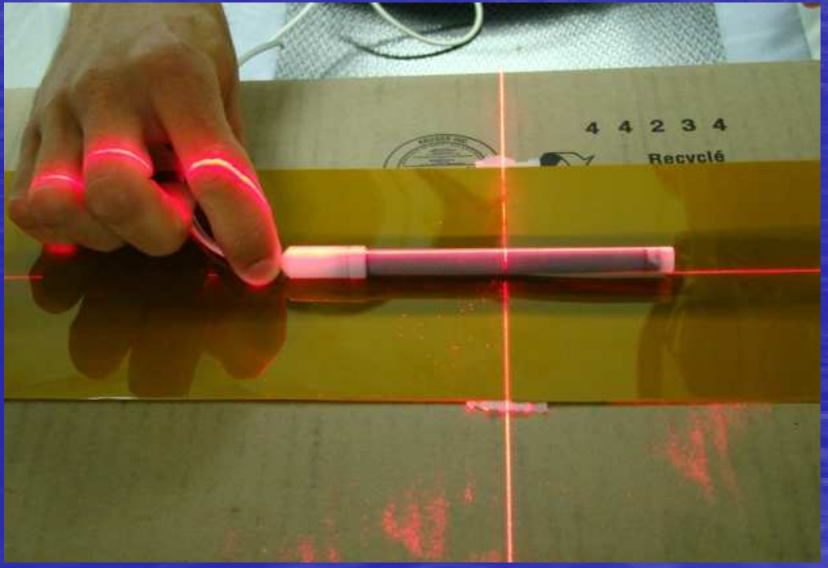


Ion chamber dosimetry

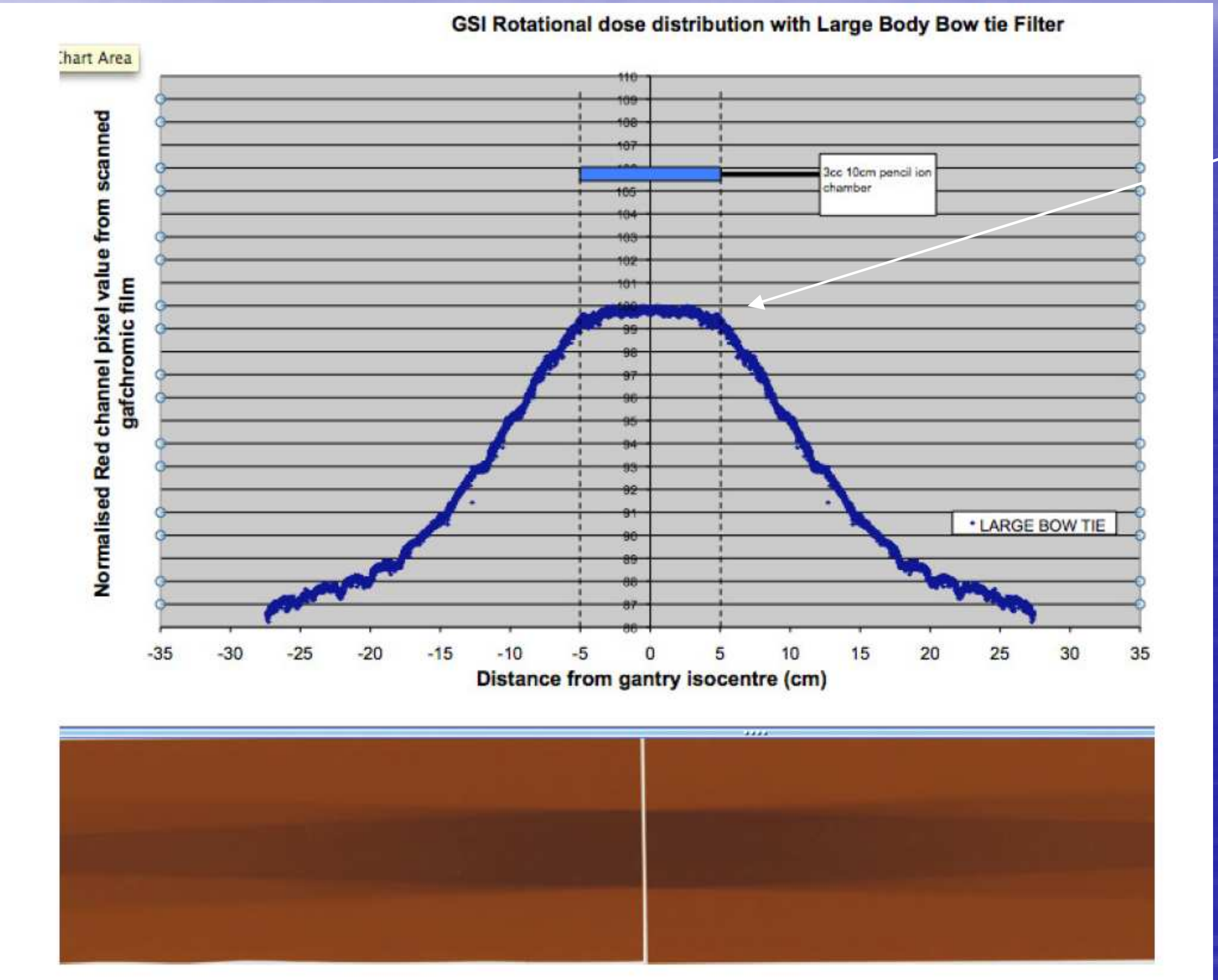
Other Authors used standard X-ray units with additional filtration to calibrate MOSFETS.

We wanted to use CT scanner… but problems to overcome





Can we use the 3cc pencil chamber for calibrating MOSFETS?



Slight loss ~1% over last 2cm of each tail.

Linearity

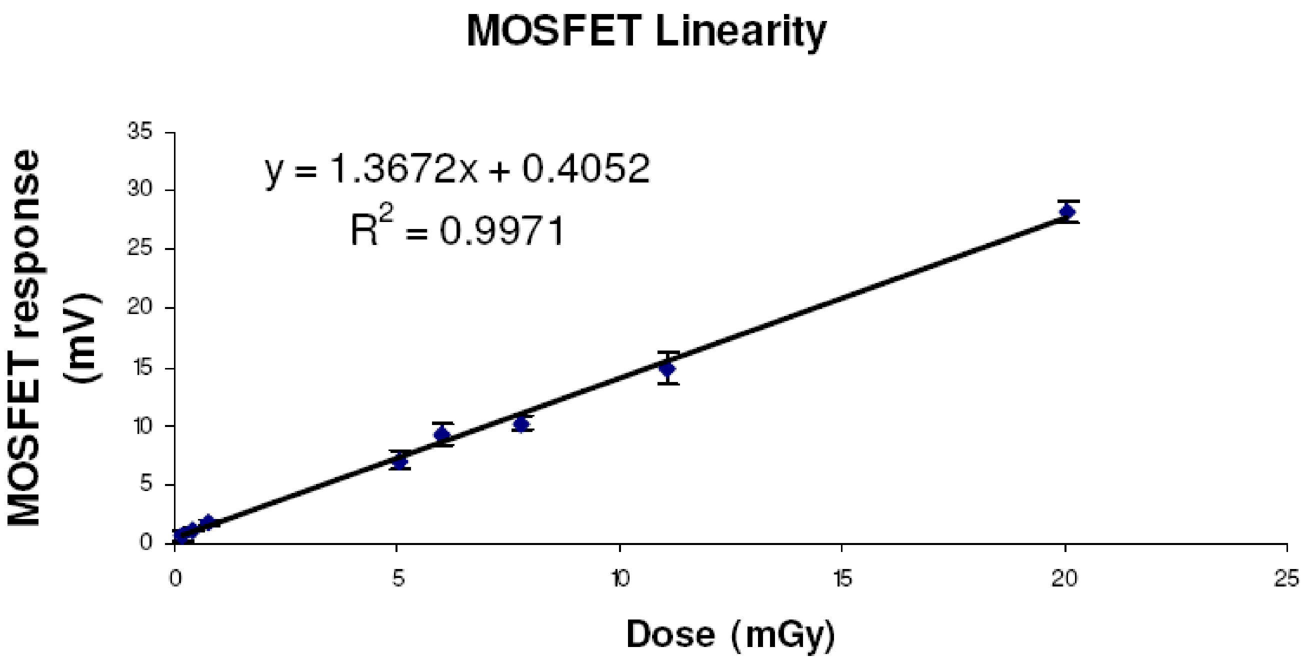
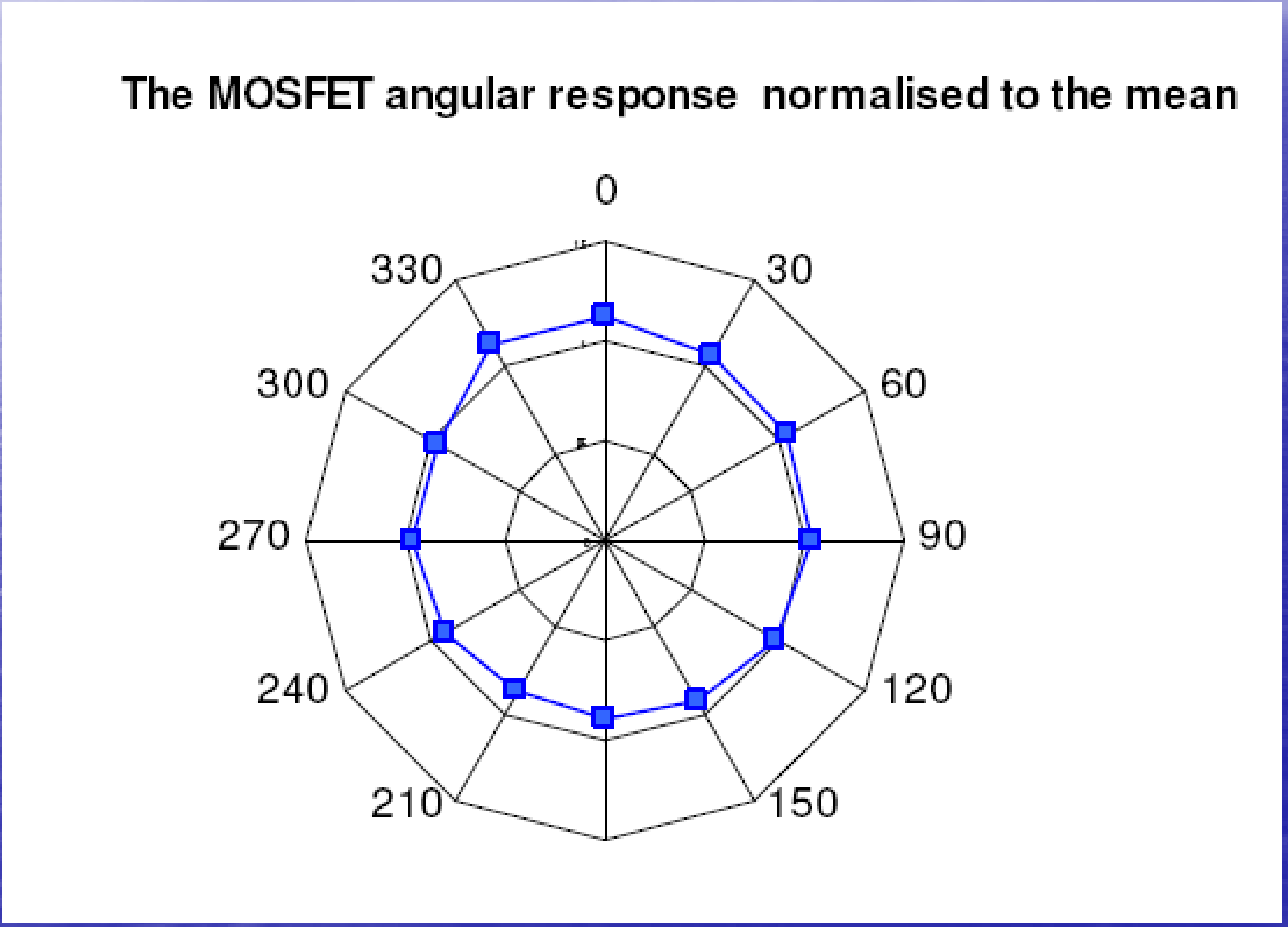
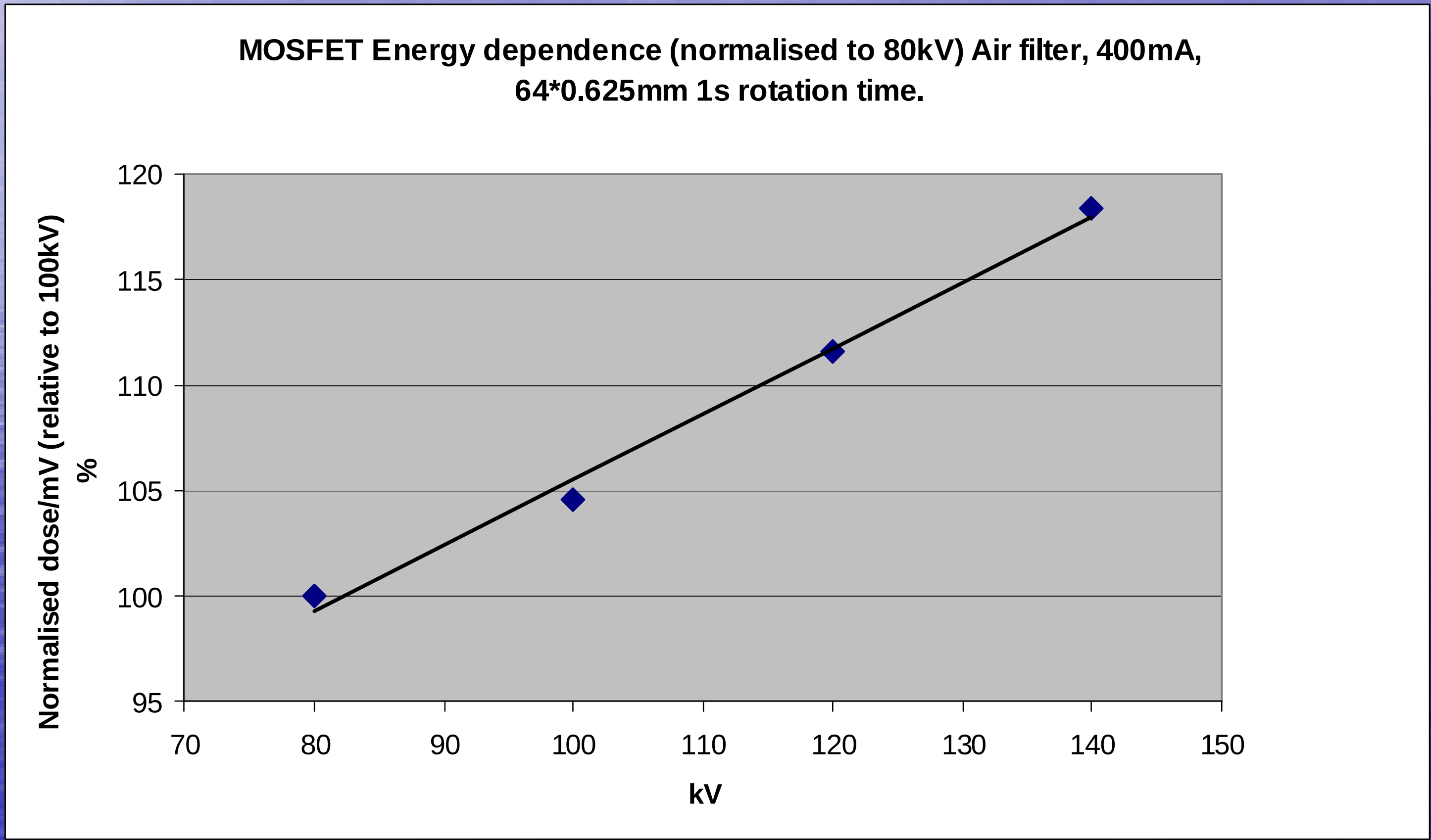


Fig 19: Threshold voltage versus dose: The threshold voltage increases linearly with the applied dose for GSI exposure setting.

Angular dependence
(centre of 32cm CTDI phantom)



Energy dependence



Calibration

MOSFETs No.	Calibration Factor (cGy/ mV)	Relative Standard Error (%)
254-1	0.062	4.216
254-2	0.058	6.631
254-3	0.057	2.489
254-4	0.061	7.247
254-5	0.063	0.840
253-1	0.056	14.584
253-2	0.045	13.982
253-3	0.052	19.924
253-4	0.066	20.197
253-5	0.040	10.403

Table 11: MOSFET Calibration factors

Chosen protocol

Protocol	GSI 15	**Current**	640 mA
Imaging mode	Axial mode	**Slice collimation**	16ix 2.5 (40 mm)
Scan length	160 mm	**Focal Spot**	Large
Tube status	Rotating	**Bow-tie filter**	Large
Tube rotation time	0.6 sec	**$CTDI_{vol}$**	21.5 mGy
Peak voltage	80~140 kVp	**DLP**	344 mGy-cm

Table 2: Imaging parameters for GSI 15 protocol

NB: optimisation of scan protocols relatively inflexible (can't adjust KV or mA). User can chose pitch or exposure time.

MOSFET positioning

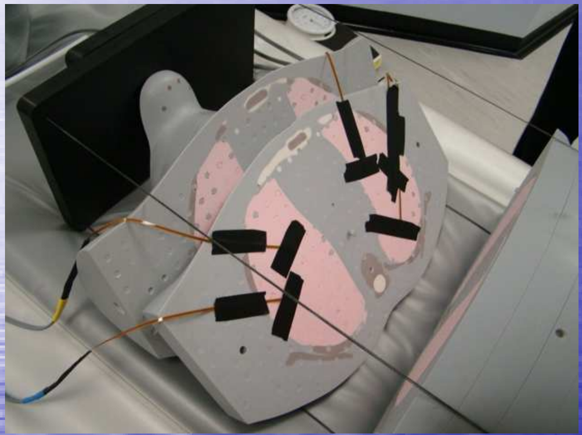
Lung (33 points)	Stomach (13 points)	Esophagus	Breasts (8 points)
12 (±6, 0)	21 (0, 0); 21 (-7, 0); 21 (-7, 5)	15 (0, -2)	Displayed in Fig 11
13 (±7, 0)	22 (-6, 6); 22 (0, 0); 22 (-6, 0); 22 (0, 6)	17 (0, -2)	
14 (±9, 0); 14 (±6, 3); 14 (±6, -4)	23 (-6, 6); 23 (0, 6); 23 (-6, 0)		
15 (±9, 0); 15 (±7, 4); 15 (±8, -5)	24 (±3, 6)		
16 (±9, 0); 16 (±10, -5); 16 (7, 4)	25 (3, 6)		
17 (9, 0); 17 (7, 5); 17 (±6, -4)			
18 (9, 0); 18 (±5, -4)			
9 (9, 0); 19 (±6, -3)			
20 (±6,- 4)			

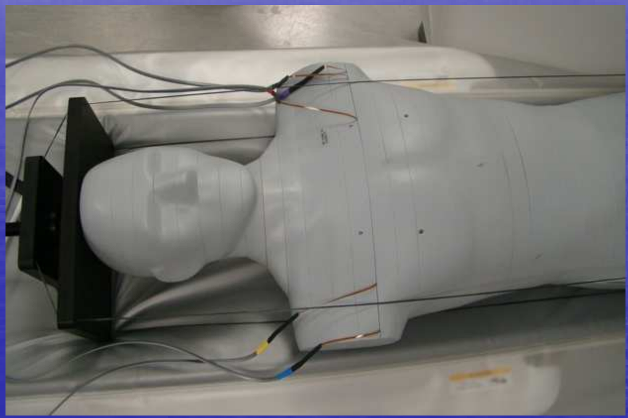
Table 8: Organs points measurements locations

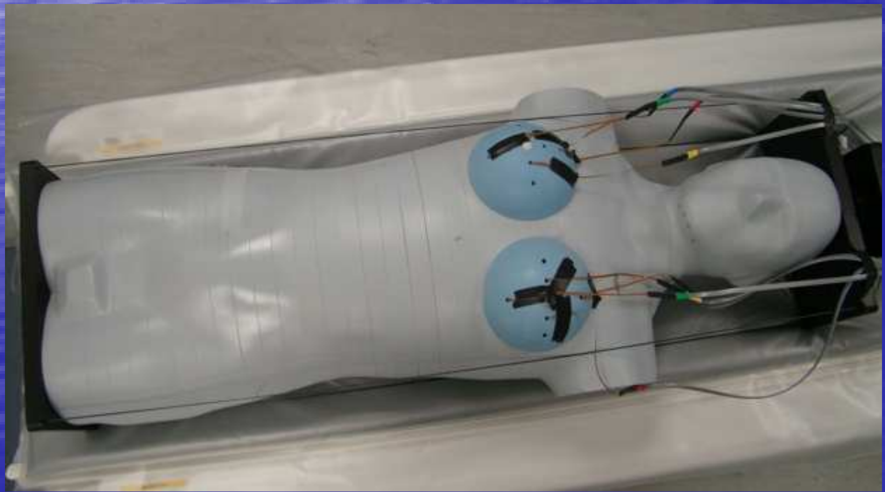
Could not attain organ loading coordinates for ATOM phantom… Used loading pattern for a RANDO phantom by Scalzetti et al.

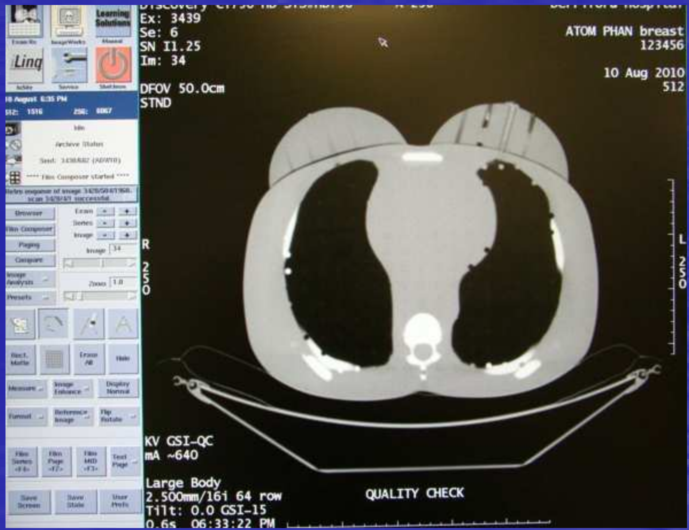
Scalzetti, Ernest M.; Huda, Walter; Bhatt, Shashank; Ogden, Kent M. A Method To Obtain Mean Organ Doses in
A Rando Phantom. Volume 95 (2). 241-244.(2008)

MOSFET positioning (patience!)



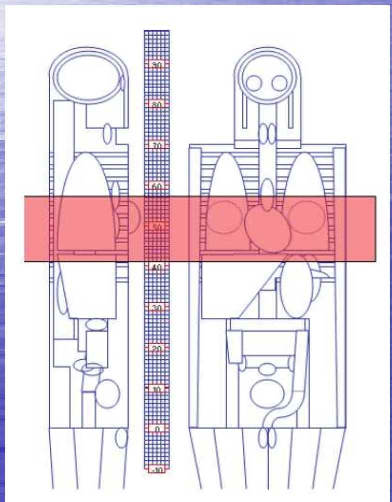


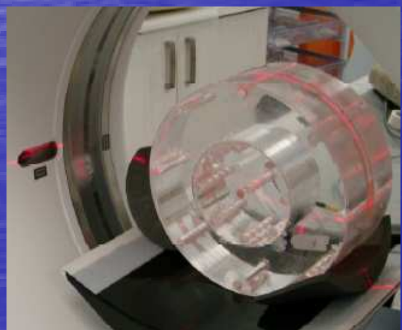




ImPACT dosimetry

GSI 15	**Current**	640 mA
Axial mode	**Slice collimation**	16ix 2.5 (40 mm)
160 mm	**Focal Spot**	Large
Rotating	**Bow-tie filter**	Large
0.6 sec	**$CTDI_{vol}$**	21.5 mGy
80~140 kVp	**DLP**	344 mGy-cm





ImPACT CT Patient Dosimetry Calculator
Version 1.0 28/08/2009

Scanner Model:		
Manufacturer:	GE	
Scanner:	GEHD750 GSI 15	
kV:	140	
Scan Region:	Body	
Data Set	MCSET22	Update Data Set
Current Data	MCSET22	
Scan range		
Start Position	42 cm	Get From Phantom Diagram
End Position	58 cm	
Organ weighting scheme	ICRP 103	

Acquisition Parameters:			
Tube current		640	mA
Rotation time		0.6	s
Spiral pitch		1	
mAs / Rotation		384	mAs
Effective mAs		384	mAs
Collimation			mm
Rel. CTDI	Look up	1.00	(assumed)
CTDI (air)	Look up	15.5	mGy/100mAs
CTDI (soft tissue)		16.6	mGy/100mAs
$_nCTDI_w$	Look up	5.5	mGy/100mAs

$CTDI_w$	21.1	mGy
$CTDI_{vol}$	21.1	mGy
DLP	337	mGy.cm

Organ	w_T	H_T (mGy)	$w_T.H_T$
Gonads	0.08	0.022	0.0018
Bone Marrow	0.12	4.3	0.52
Colon	0.12	0.14	0.017
Lung	0.12	22	2.6
Stomach	0.12	3.2	0.39
Bladder	0.04	0.01	0.0004
Breast	0.12	23	2.8
Liver	0.04	5.5	0.22
Oesophagus (Thymus)	0.04	21	0.86
Thyroid	0.04	0.59	0.024
Skin	0.01	3.4	0.034
Bone Surface	0.01	9.2	0.092
Brain	0.01	0.021	0.00021
Salivary Glands (Brain)	0.01	0.021	0.00021
Remainder	0.12	5.5	0.66
Not Applicable	0	0	0
Total Effective Dose (mSv)			**8.2**

Remainder Organs	H_T (mGy)
Adrenals	6.5
Small Intestine	0.16
Kidney	1.1
Pancreas	4.2
Spleen	3.7
Thymus	21
Uterus / Prostate (Bladder)	0.022
Muscle	3.2
Gall Bladder	1.3
Heart	26
ET region (Thyroid)	0.59
Lymph nodes (Muscle)	3.2
Oral mucosa (Brain)	0.021

Other organs of interest	H_T (mGy)
Eye lenses	0.047
Testes	0.0011
Ovaries	0.043
Uterus	0.034
Prostate	0.01

Scan Description / Comments	
	GSI 15 Cardiac example 160mm coverage

CTDI (Body, mGy/100mAs)			ImPACT Factor				Scanner Match	
Air	Centre	Perip	Head	Body			Head	Body
15.5	3.1	6.7	0.39	0.89	3	12	4	22

MOSFET vs ImPACT

Organs	Measured (cGy)	Calculated (cGy)	Percentage difference (%)
LUNG	1.54	2.00	-22.88
BREAST	1.53	2.20	-30.62
STOMACH	0.29	0.34	-15.63
Oesophagus	1.47	1.80	-18.44

Table 13: Comparison of average organ doses between Im-PACT and point measurement using MOSFET

Discrepancy ??

- MOSFETs appear to under-read organ doses by 15-30% (30% breast) for GSI....

Possible causes...

1. Difference in Phantom (ATOM vs RANDO vs CRISTY)
2. MOSFET Loading pattern
3. MOSFET calibration
4. MOSFET X-talk for rapid kV switching?
5. Energy dependence?
6. High uncertainty for low dose (diagnostic examinations).

LAR for "Cardiac GSI"

ED~8mSv,

Age (Y)	Male		Female		
	Stomach	Lung	Stomach	Lung	Breast
30	1	16	1	37	39
50	1	16	1	35	11
80	0	5	0	12	1

Table 14: Estimates of LAR for Cancer after performing DECT examination (GSI 15) on the heart.

~1/2500

Just for fun… ED measured for a proposed GSI renal exam for kidney stone classification. Single 40mm Axial slice centred over the kidneys ~1.5mSv.

Conclusions 1

- Dual Energy and Spectral imaging are emerging technology. We have new toys, but what can they tell us?
- They have promised to significantly improve classification of ROI's. The question is, who provides the "key"!
- "Monochromatic images, allow the operator to optimise the image for "radiographic contrast" without the need for repeat exposure.
- To introduce properly into the UK market we need to Justify on an exam by exam basis.
- How can a radiologist justify a new technique if the benefits are unproven?
- Rapid switching of kV in patient dosimetry presents significant challenges to Diagnostic Physicists.
- MOSFETS have high Energy dependence
- Calibration is tricky on a CT scanner
- Uncertainty in measurement appears high at diagnostic energies.
- Further work is required.

A final thought…

We must at least attempt to keep up with emerging developments in CT !