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College on Medical Physics. Digital Imaging Science and Technology to Enhance Healthcare in the Developing Countries

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Evaluating X-RAY Tube and Generator Performance: Demo for Practical Quality Control

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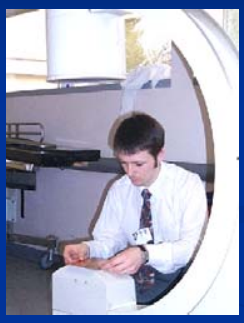
EVALUATING X-RAY TUBE AND GENERATOR PERFORMANCE : DEMO for PRACTICAL QUALITY CONTROL (QC)



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OBJECTIVES

- Principles of Quality Control (QC)
- QC equipment
- Filtration assessment
- Consistency assessment
- Accuracy and linearity assessment
- Assessment of kVp ripple and waveform
- X-ray tube radiation leakage
- Focal spot measurement
- AEC assessment
- Dental equipment QC
- Mammographic equipment QC
- Other QC tests
- Automatic protocol with EXCEL

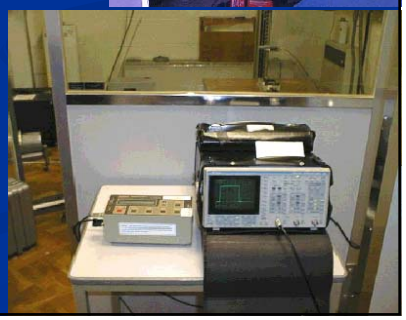
QC in Diagnostic Radiology

- PURPOSE : To ensure continuing production of diagnostic images with optimum quality, using minimum necessary dose to the patient.
- FREQUENCY: QC should include checks and test measurements on all parts of the imaging system at intervals not exceeding one year.
- UK practice for most common DR equipment:

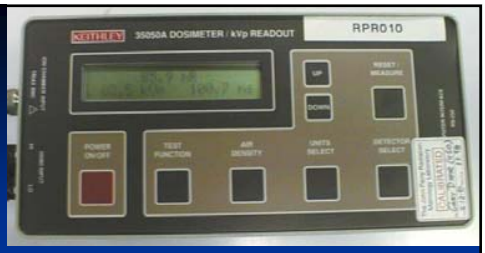
  - Radiographic (X-ray tubes) - once per year

Main steps for a QC survey in Diagnostic Radiology

- General X-ray tube & generator assessment
- Image quality assessment
- Specific parameters assessment
- Quality Control protocols



QC equipment for Radiography



- Dosimeter (ion.ch.)
- kVp detector (non-invasive) CALIBRATED !
- Oscilloscope (with memory)
- (Timer, mA meters)
- Aluminium plates (4x1mm+2x0.5mm)
- Collimator/beam alignment tool (cassette)
- Focal spot test tool (film in envelope)
- (Densitometer, Sensitometer)

QC of the X-ray tube/generator

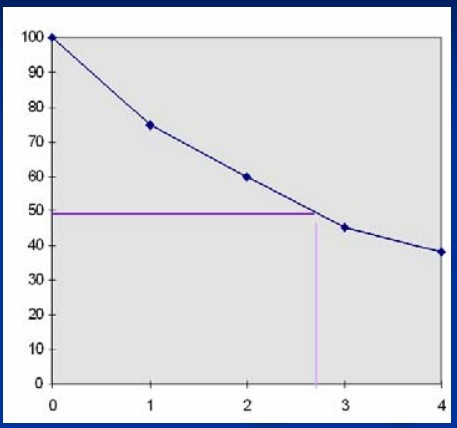
- The X-ray field must be collimated to the smallest reasonable size.
- All measurements must be performed at the middle of the X-ray field.
- g

X-ray tube and generator main tests

- X-ray beam filtration
- Dose output consistency, kV/mA influence
- kVp consistency, accuracy, ripple
- Timer consistency, accuracy
- X-ray beam/light beam alignment
- Radiation leakage of tube housing
- Focal spot size assessment
- Automatic Exposure System performance

X-ray beam filtration (HVL)

- Total X-ray filtration (incl. housing & LBD) is assessed by HVL measurement (Alum.) at known kV (80kVp)
- Special tables/graphs *Filtration = F(HVL)*



F + Al attn.	Set kV	Set mA	Set Time	Set mAs	Meas kV	Meas T	Meas exp	Air kerma	% trans
B+0mm Al	80	200	100	20			110	0.96	**100.0**
B+1mm Al	80	200	100	20			83.5	0.73	**74.6**
B+2mm Al	80	200	100	20			67.1	0.58	**59.9**
B+3mm Al	80	200	100	20			50.9	0.44	**45.4**

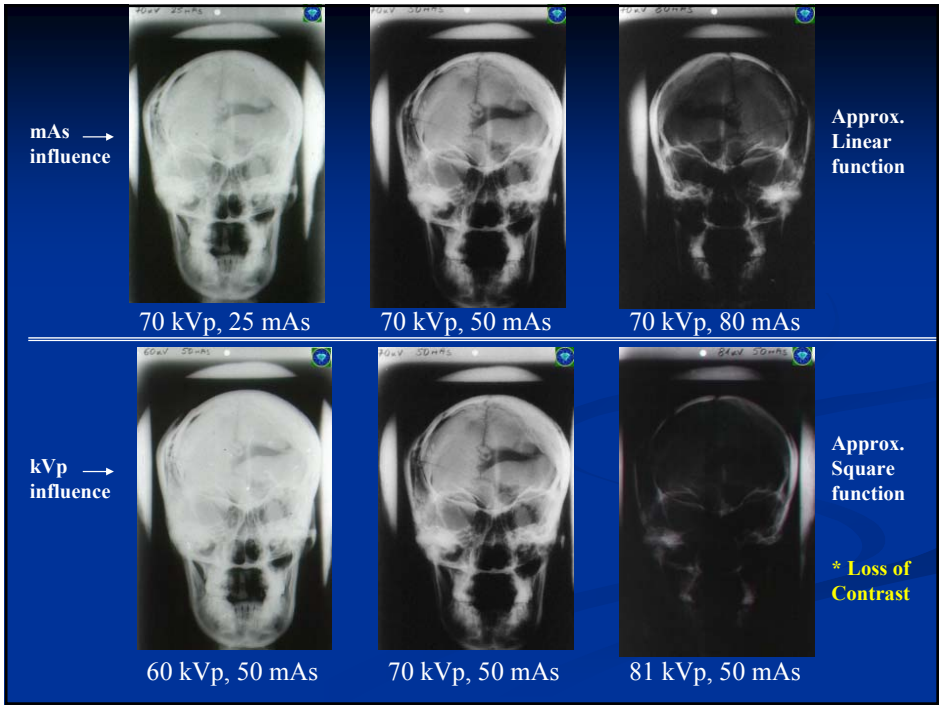
Total X-ray filtration must not be less than:

- **0.5 mm** of Al (or 0.03 mm Mo) for mammography
- **1.5 mm** of Al for equipment using voltage up to 70 kVp (most often Dental Radiology)
- **2.0 mm** of Al for equipment producing above 70kVp and up to 100 kVp
- **2.5 mm** of Al for equipment producing voltages above 100 kVp (most of the Diagnostic Radiology X-ray equipment)
- *LBD filtration Al plates MUST be fixed!*

Dose Output/kVp/Time Consistency

- Min 4 exposures with identical parameters 100*(st.dev)/(average) for all measurements
- Separate calculations for Dose, kVp, Time
- In the case below : Dose consist.=3.2%; kVp consist.=0.6%; Time consist.=0%

Focus	Set kV (kV)	Set mA (mA)	Set Time (ms)	Set mAs (mAs)	Meas kV (kV)	Meas T (ms)	Meas exp (mR)	Air kerma (mGy)
B	80	200	100	20	82	105	104	0.90
B	80	200	100	20	83	105	106	0.92
B	80	200	100	20	83	105	106	0.92
B	80	200	100	20	83	105	105	0.91



kVp accuracy and Spec.Dose = F(kV)

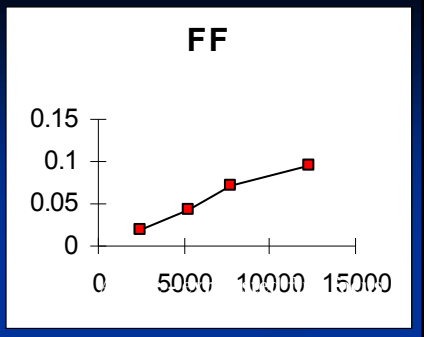
Linearity

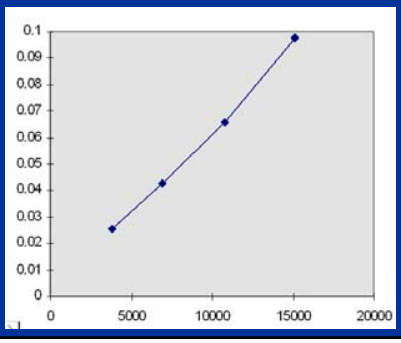
- Min 4 measurements with varia kVp
  100*(mean error)/(real value)
- In the case below kVp accur. = 3.4%
- Specific Dose : Dose/mAs (mGy/mAs) @ ...kV
- Linearity - graph: X-kV^2 Y-(mGy/mAs)

							FDD(cm)=	100
Focus	Set kV (kV)	Set mA (mA)	Set Time (ms)	Set mAs (mAs)	Meas kV (kV)	Meas T (ms)	Meas exp (mR)	Air kerma (mGy)
B	60	200	100	20	62	101	59	0.51
B	80	200	100	20	83	105	98.5	0.86
B	100	200	100	20	104	103	151	1.31
B	120	200	100	20	123	103	224	1.95

Linearity Graph

- Linear approximation
- Perform for each focal spot size!
- In the case (20mAs):



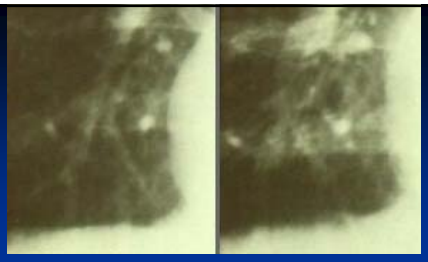


mGy(20mAs)	Meas. kV	kV^2	mGy/mAs
0.51	62	3844	0.026
0.86	83	6889	0.043
1.31	104	10816	0.066
1.95	123	15129	0.097

Output & kV variation with mA; Timer accuracy

- Dose output and kVp vary with the mA 100*st.dev/average for mGy/mAs or kVp
- In the case below : O'put var. with mA = 9.5% and kVp var with mA = 4.2%
- Timer accuracy = -1.6%

Set kV (kV)	Set mA (mA)	Set Time (ms)	Set mAs (mAs)	Meas kV (kV)	Meas T (ms)	Meas exp (mR)	Air kerma (mGy)	Spec.Output mGy/mAs
80	25	100	2.5	83	107	18.4	0.16	0.064
80	300	100	30	84.7	105	198	1.72	0.057
80	500	100	50	90	103	305	2.65	0.053
80	200	20	4	83	19	20.5	0.18	0.045
80	200	400	80	83	390	440	3.82	0.048
80	200	800	160	83	780	814	7.07	0.044



<< kVp accuracy
influence on contrast

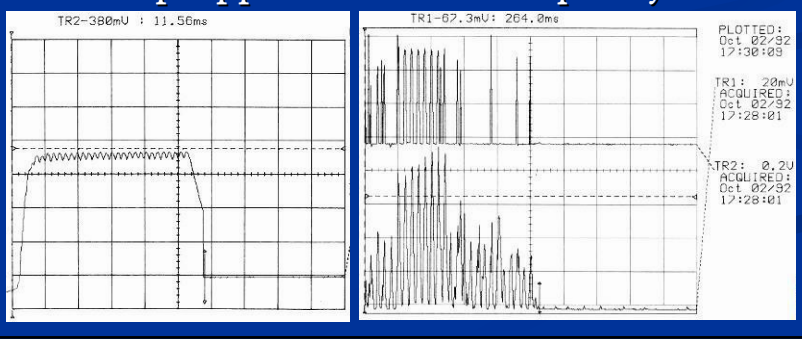
kVp ripple influence on resolution

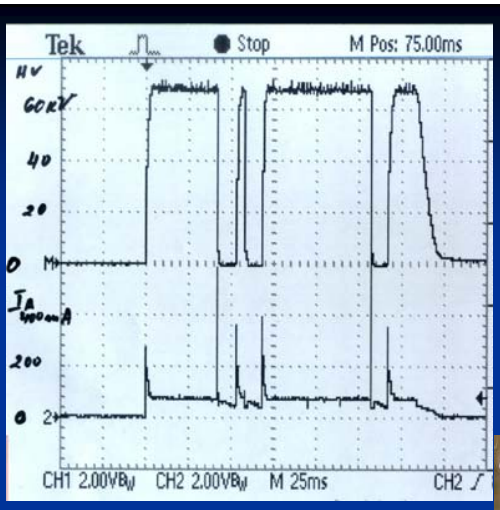
low ripple

high ripple

Dose output & kVp waveforms kVp ripple

- Waveforms -powerful method for analysis of X-ray tube and generator performance
- Abnormal (high) ripple blurs the image (often indicates exhausted tube; arcing)
- kVp ripple of medium frequency

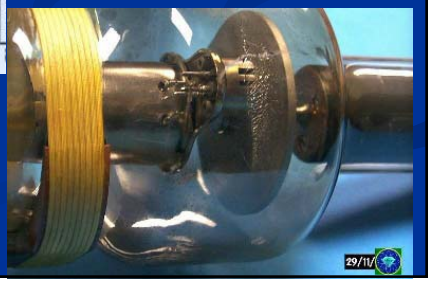




Arcing

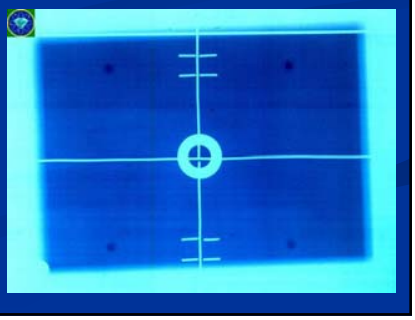
- Often with new tubes, or after long time in store

- Very dangerous for the generator



LBD Alignment

- Light beam diaphragm/X-rays alignment (less than 1 cm displacement), perpendicularity



X-ray tube housing leakage

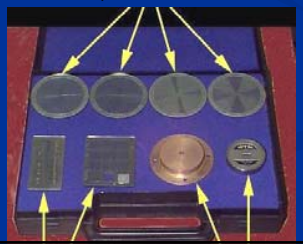
- X-ray tube housing radiation leakage - tested with closed collimator, tube housing surrounded with cassettes and heavy (~100 kV) exposure (keep the films!)

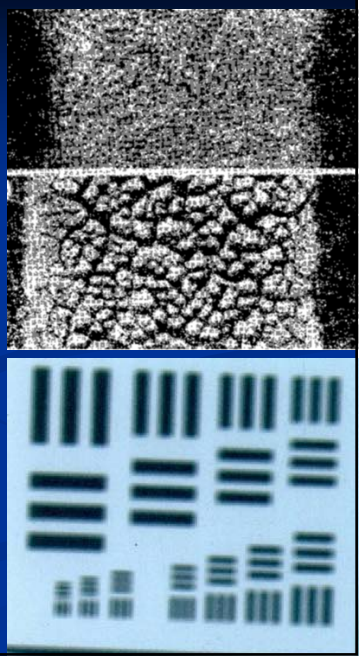
Cathode

Anode

Focal spot size assessment

- The focal spot size increases with the age of the X-ray tube.
- Radiograph of a special tool placed at exact focal distance.
- Use film in envelope (not X-ray cassette !)
- (Pinhole)





Focus size influence:

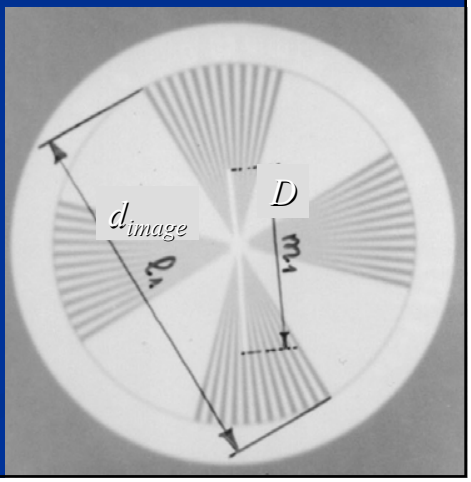
Broad focus

Fine focus

- **Star test phantom**

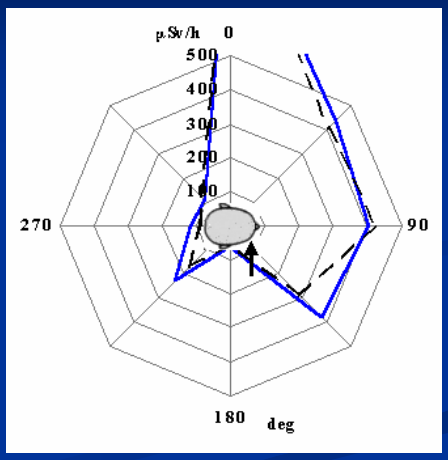
$$f = \frac{2\pi\theta^0}{360^0}\ \frac{D}{M-1}$$

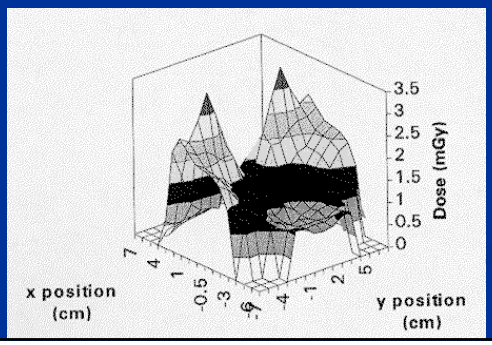
$$M = d_{image} / d_{star}$$



QC of special X-ray equipment

- Dental X-ray equip. scatter rad.chart = >
- Orthopan tomography
- Mammography X-ray equipment
- Classical tomography
- Capacitor discharge X-ray equipment





Basic QC tests in Dental/OPG X-ray Equipment

- Kilovoltage
- Timer
- Dose (end of cone)
- Dose distribution
- Dose/kV waveform
- Filtration (HVL)
- Field (end of cone)
- OPG Slits/Alignement
- Scatter radiation
- Movement/Mechanics

Dental X-ray Equipment

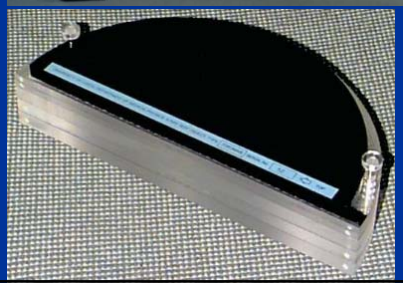
HVL – min 1.5mm Al (<70 kVp)

Intra-oral radiography : min 50 kV

Min FSD 20cm @ 60kV (10cm <60)

Collimation – max 60mm circular or 40x50 rectangular (recommended)

				Stated kV	Stated mA	FDD (cm)
				70	10	50
Set Time (ms)	Meas Time (ms)	Meas kV (kV)	Meas exp (mR)	Air Kerma (mGy)	(%)Timer inaccuracy	Output (mGy/s)
153	222.9	66	17.69	0.155	45.69	0.70
255	300	65.7	25	0.219	17.65	0.73
306	340.7	66	29.91	0.262	11.34	0.77
408	420.5	66	41.1	0.360	3.06	0.86
595	541.3	66	60.16	0.527	-9.03	0.97
408	381.6	66	40.53	0.355	-6.47	0.93
408	401.4	66.3	42.58	0.373	-1.62	0.93
408	382	66.3	40.64	0.356	-6.37	0.93

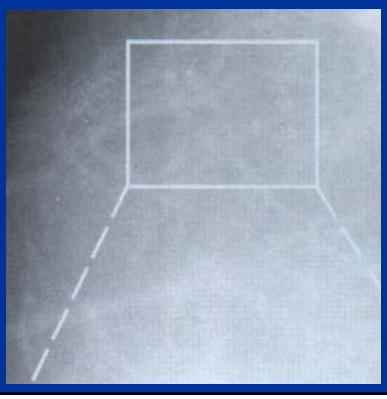


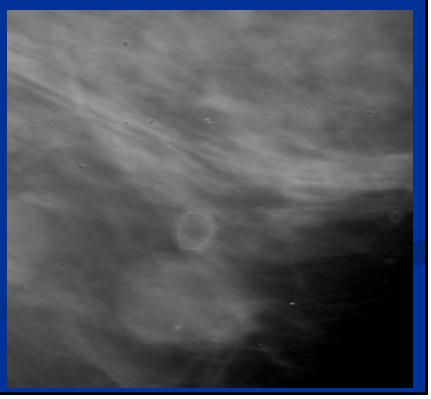
Basic QC tests in Mammography

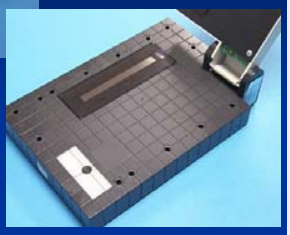
- Kilovoltage
- Exposure time
- Tube output
- Breast dose
- Alignement
- Image quality
- Sensitometry
- AEC
- Filtration
- Compression

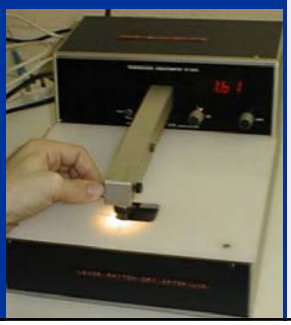
Requires test objects and special measuring equipment - kVp and Dose meter

Focus to chamber distance in cm				43				Calculated
Target / Filter	Set kV (kV)	Set mA (mA)	Set Time (ms)	Set mAs (mAs)	Meas kV (kV)	Meas T (ms)	Air kerma (mGy)	Output @1m (Gy/mAs)
			Variation of output with kilovoltage					
Mo/Mo	26	100	500	50	26.2	503	9.75	36.06
Mo/Mo	28	100	500	50	28.2	503	12.31	45.52
Mo/Mo	30	100	500	50	29.9	502	15.15	56.02
Mo/Mo	32	100	500	50	31.9	501	18.17	67.19
Mo/Rh	28	100	500	50	27.7	503	7.39	27.33
Mo/Rh	30	100	500	50	28.9	502	9.28	34.32
Mo/Rh	32	100	500	50	30.8	503	11.31	41.82

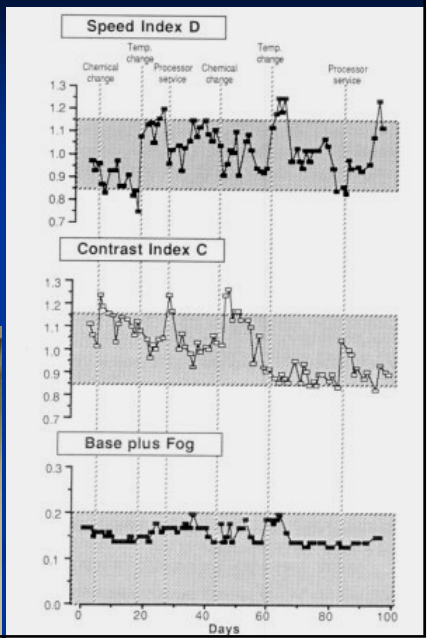








QC of X-ray film processing



Automatic QA protocols with *EXCEL*

- Raw data page
- Calculative page (hidden)
- Result page
- Image quality and graphics pages
- Statistical page
- Summary and Recommendation page
- Additional protocols for AEC and other specific X-ray systems

X-RAY GENERATOR AND TUBE MEASUREMENTS

These measurements were made with a keithley kVp divider s/n 27775, digital storage oscilloscope Gould 450 s/n 14400056, and an MDH electrometer s/n 3011with 6 cc chamber.

							FDD(cm)=	100
Focus	Set kV	Set mA	Set Time	Set mAs	Meas kV	Meas T	Meas exp	Air kerma
	(kV)	(mA)	(ms)	(mAs)	(kV)	(ms)	(mR)	(mGy)
B	60	200	100	20	62	101	59	0.51
B	80	200	100	20	83	105	98.5	0.86
B	100	200	100	20	104	103	151	1.31
B	120	200	100	20	123	103	224	1.95
F	50	100	200	20	50	202	46	0.40
F	70	100	200	20	73	205	101	0.88
F	90	100	200	20	88	202	167	1.45
F	110	100	200	20	111	204	221	1.92
B	80	200	100	20	82	105	104	0.90
B	80	200	100	20	83	105	106	0.92
B	80	200	100	20	83	105	105	0.91
B	80	25	100	2.5	83	107	18.4	0.16
B	80	300	100	30	84.7	105	198	1.72
B	80	500	100	50	90	103	305	2.65
B	80	200	20	4	83	19	20.5	0.18
B	80	200	400	80	83	411	440	3.82
B	80	200	800	160	83	780	814	7.07
		Half Value Layer Measurements are shown below						
B+0mm Al	80	200	100	20			114	0.99
B+0mm Al	80	200	100	20			110	0.96
B+1mm Al	80	200	100	20			83.5	0.73
B+2mm Al	80	200	100	20			67.1	0.58
B+3mm Al	80	200	100	20			50.9	0.44
B+4mm Al	80	200	100	20				#VALUE!

FDD(cm)=	100							
Meas exp	Air kerma		Meas'	mGy/mAs	mGy/mAs	For lin'	%age kV	%age T
(mR)	(mGy)	Meas kV	kV^2	mGy/mAs	per kV^2	grad'	Accuracy	Accuracy
59	0.51	62	3844	0.025636	6.67E-06	5.64E-06	3.333333	
98.5	0.86	83	6889	0.042798	6.21E-06	5.81E-06	3.75	
151	1.31	104	10816	0.06561	6.07E-06	7.35E-06	4	
224	1.95	123	15129	0.097328	6.43E-06		2.5	
46	0.40	50	2500	0.019987	7.99E-06		0	
101	0.88	73	5329	0.043885	8.24E-06	8.45E-06	4.285714	
167	1.45	88	7744	0.072562	9.37E-06	1.19E-05	-2.22222	
221	1.92	111	12321	0.096025	7.79E-06	5.13E-06	0.909091	
104	0.90	82	6724	0.045188	6.72E-06			
106	0.92	83	6889	0.046057	6.69E-06			
105	0.91	83	6889	0.045623	6.62E-06			
18.4	0.16	83	6889	0.063958	9.28E-06			7
198	1.72	84.7	7174.09	0.057354	7.99E-06			5
305	2.65	90	8100	0.053009	6.54E-06			3
20.5	0.18	83	6889	0.044536	6.46E-06			-5
440	3.82	83	6889	0.047795	6.94E-06			2.75
814	7.07	83	6889	0.04421	6.42E-06			-2.5
114	0.99	IVL mm of A	% trans					#VALUE!
110	0.96	1	100					
83.5	0.73	2	74.5535714					
67.1	0.58	3	59.9107143					
50.9	0.44	4	45.4464286					
	#VALUE!	5	#VALUE!					

Parameters		Expected		Measured		Assessmen
Radiography Mode						
Beam/LBD Alignement	displacement (cm)	<1		<1		Accept
Bucky centering	displacement (cm)	<1		<1		
Focus size (mm)	Broad Focus-(BF)	1		1X1		Accept
	Fine Focus-(FF)	0.6		0.6x0.6		Accept
O'put consistency(BF)	(%) inconsist.	<5		3.2		Normal
O'put var'n with mA(BF)	(%) variation	<10		9.49		Normal
O'put var'n with kV (BF)	Linearity (%)			4.2		Normal
Specific O'put-80kV(BF	(uGy/mAs) @ 1m			42.74		Normal
Lin.Grad.with kV^2(BF)	(mGy/mAs/kV^2)			6.27E-06	15	
O'put var'n with kV (FF)	Linearity (%)			8.4		Normal
Specific O'put-80kV(FF	(uGy/mAs) @ 1m			57.47		Normal
Lin.Grad.with kV^2(FF)	(mGy/mAs/kV^2)			8.48E-06	40	
kVp consistency (BF)	(%) inconsist.	<5		0.6		Good
kVp accuracy (BF)	(%) inaccuracy	-10<A<10		3.4		Good
kVp accuracy (FF)	(%) inaccuracy	-10<A<10		0.7		Good
	St.dev.			2.31		
kVp var'n with mA (BF)	(%) variation	<10		4.25		Good
Ripple at ~ 100 kV(BF)	+/- kVp ampl.			5		Accept
Timer consistency (BF	(%) inconsist.	<5		0.00		Good
Timer accuracy (BF)	(%) inaccuracy	-10<A<10		-1.58		Good
	St.dev			3.96		
First Half Value Layer	(mm of Al eq')			2.7		Accept
Inferred Total Filtration	(mm of Al eq')	>2.5		2.6		Accept
Labelling						Accept
Stated filtration	(mm of Al eq')	2.5				
Stated Total Filtration	(mm of Al eq')					
Calcul. max. leakage	(mGy/h)@1m	<1				Accept

Department of Medical Engineering and Physics

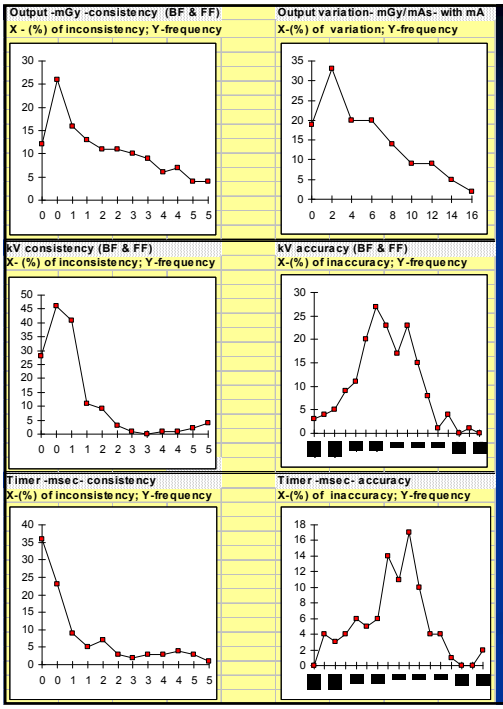
Radiological Protection and Quality Assurance Report

Hospital/Clinic:	Brook Hospital	**Unit type :**	Overcouch
Department :	X-ray	**Generator/Manuf.:**	Philips
		Type:	DR3T/500
Room/Unit:	3b	**X-Tube / Type:**	SRO 25 50
		Ser.No.	675449
Date of QA survey:	22/3/93	**Reference no.:**	BXOB3B.033

SUMMARY AND RECOMMENDATIONS

The X-ray generator and tube perform well .
However, the X-ray beam is about 1cm displaced from the light beam of LBD in longitudinal direction. We would advise you the bring this to the attention of the service engineer on his next routine visit.

Report compiled by:
Dr. S.D.Tabakov



Statistics of QC parameters from 100 different X-ray sets "Normal values"

EMERALD

The Consortium of European Medical Radiation Learning Development

www.emerald2.net

The QC protocols and all images in the lecture are from the EMERALD vol.1 Training materials - Workbook and Image Database, based on the experience in King's College Hospital, London