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

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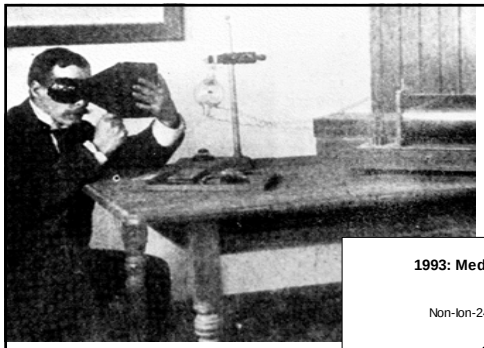
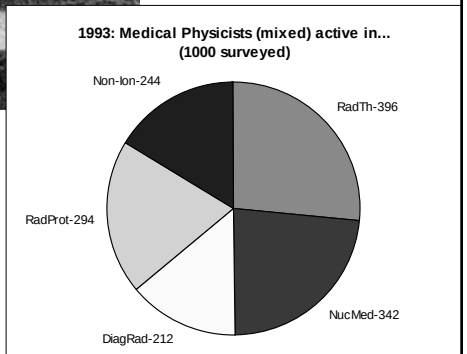
QC in Diagnostic Radiology

- 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



Approx. 1/4 of all medical physicists in the UK are working in the field of X-ray equip. Quality Control



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.
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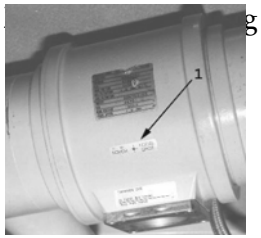
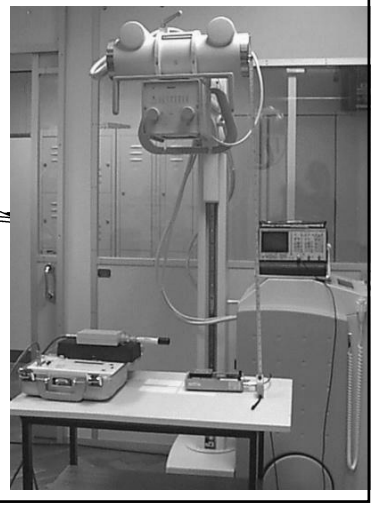


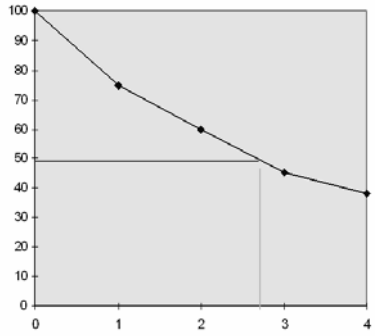


X-ray tube and generator main tests

- 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**

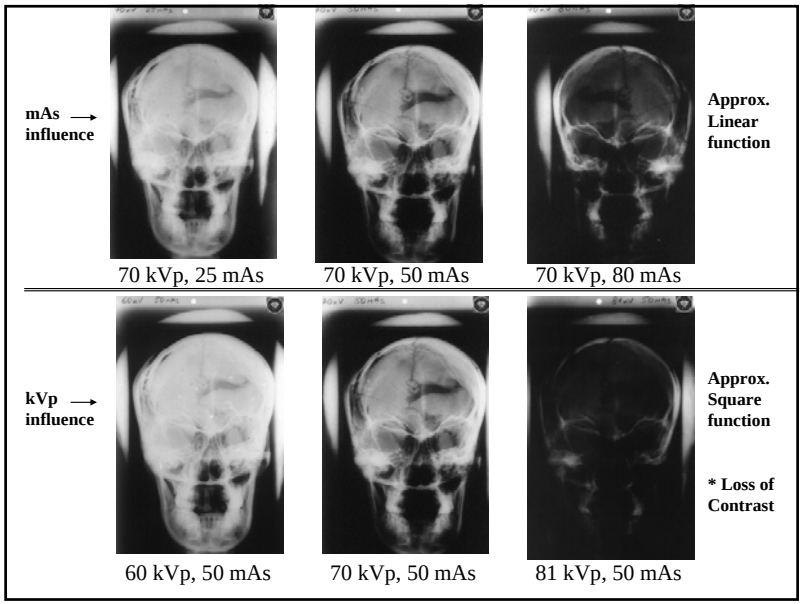
Total X-ray filtration must not be less than:

- **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

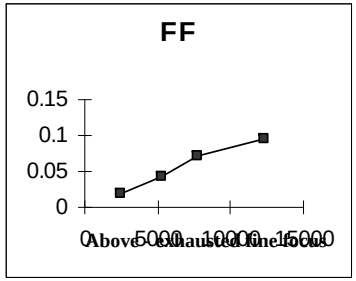
- Min 4 measurements with varia kVp
  100*(mean error)/(real value)
- In the case below kVp accur.=3.4%
- Specific Dose : Dose/mAs (mGy/mAs) @ ...kV
- Linearity - graph: X-kV^2 Y-(mGy/mAs)

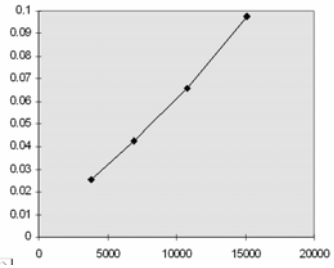
FDD(cm)= 100

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):



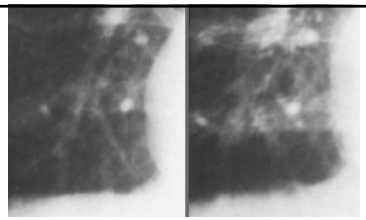


mGy(20mAs)	Meas. kV	kV^2	mGy/mAs
0.51	62	3844	0.026
0.86	83	6889	0.043
1.31	104	10816	0.066
1.95	123	15129	0.097

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%

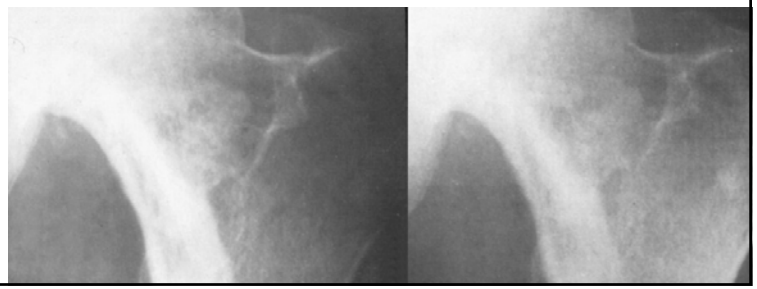
Set kV	Set mA	Set Time	Set mAs	Meas kV	Meas T	Meas exp	Air kerma	Spec.Output
(kV)	(mA)	(ms)	(mAs)	(kV)	(ms)	(mR)	(mGy)	mGy/mAs
80	25	100	2.5	83	107	18.4	0.16	0.064
80	300	100	30	84.7	105	198	1.72	0.057
80	500	100	50	90	103	305	2.65	0.053
80	200	20	4	83	19	20.5	0.18	0.045
80	200	400	80	83	390	440	3.82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



<< kVp accuracy influence on contrast

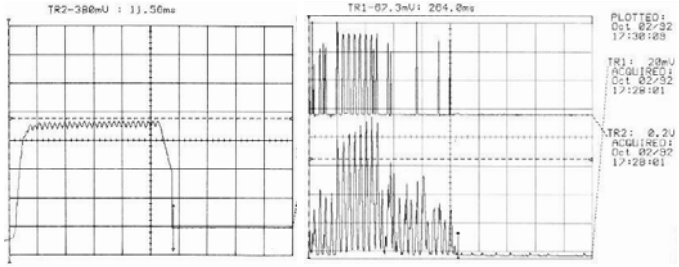
kVp ripple influence on resolution

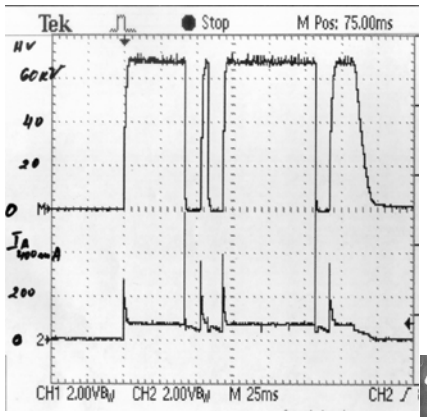
low ripple high ripple



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

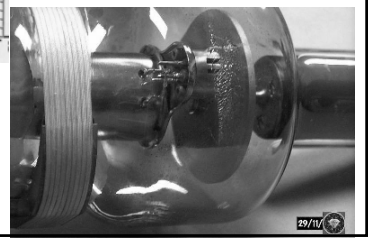




Arcing

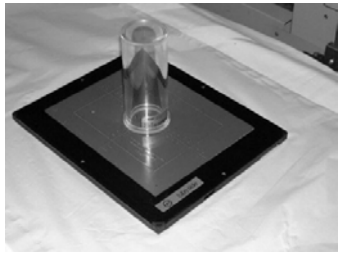
- Often with new tubes, or after long time in store

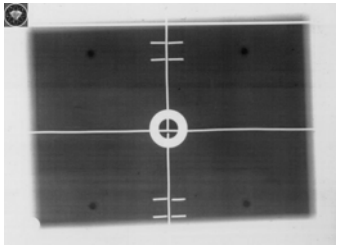
- Very dangerous for the generator



LBD Alignment

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

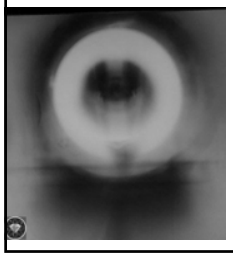


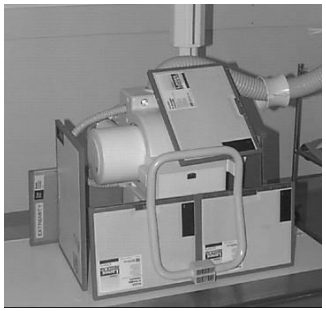


X-ray tube housing leakage

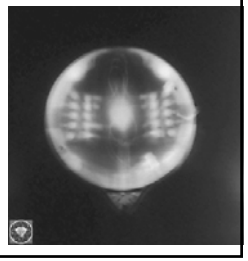
- X-ray tube housing radiation leakage - tested with closed collimator, tube housing surrounded with cassettes and heavy (~100 kV) exposure (keep the films!)

Cathode



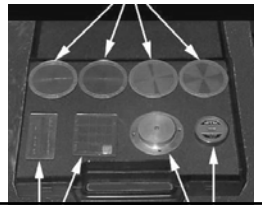


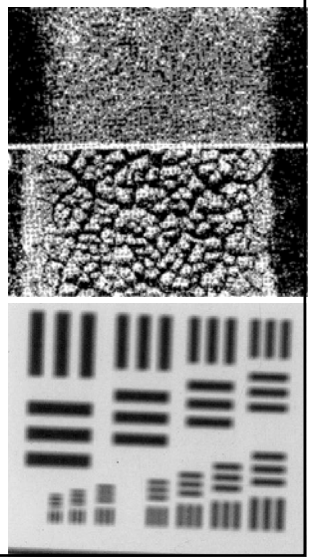
Anode



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)

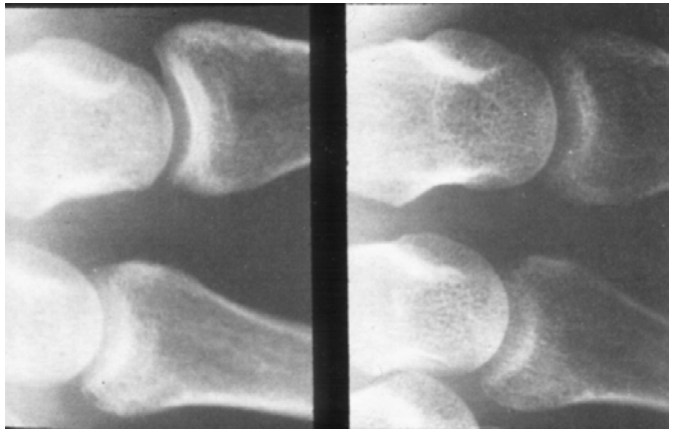




Focus size influence:

Broad focus

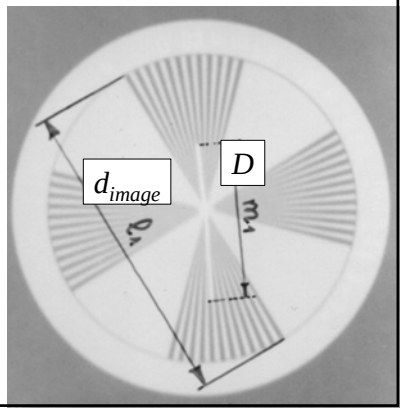
Fine focus



- Star test phantom

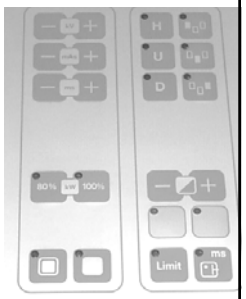
$$f = \frac{2\pi\theta^0}{360^0}\ \frac{D}{M-1}$$

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

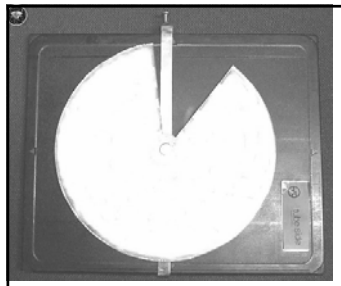


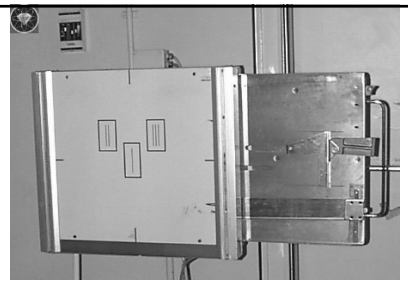
Automatic Exposure Control

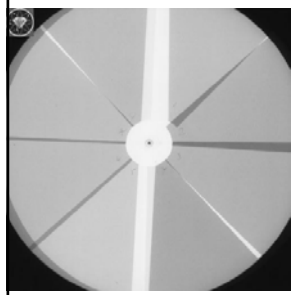
- Tested with various attenuators for all AEC fields
- Measured: cassette entrance dose and film optical density (for best results these are very similar)
- AEC guard timer : Cut-off time (max. dose)

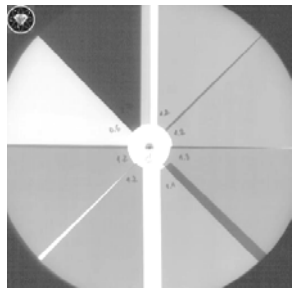


*AEC - field &dose set	Attenuator (mm Cu)	Set kV (kV)	Read ms (ms)	mAs (mAs)	Optic.Dens (D)	Meas exp (mR)
L	1.6	80	7	7	1.55	0.96
R	1.6	80	6	7	1.45	0.88
C	1.6	80	5	6	1.3	0.76
All	1.6	80	6	6	1.5	0.88
L	3.2	80	52	52	1.8	1.12
R	3.2	80	47	47	1.75	1.02
C	3.2	80	40	40	1.7	0.88
All	3.2	80	45	45	1.75	0.98









Good AEC performance

Poor AEC performance

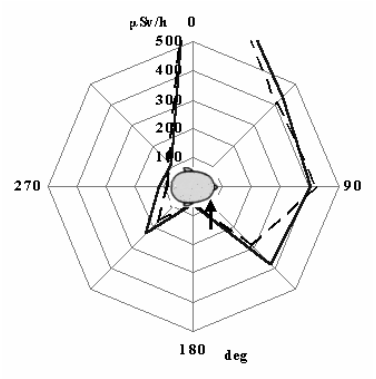
AEC test cassette

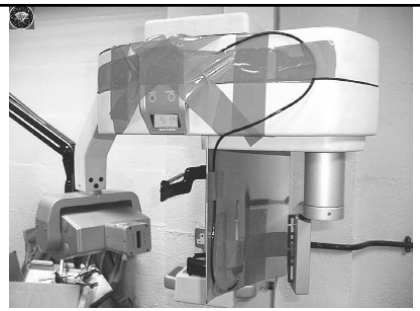
•X-tube attenuated with Cu : 1 to3 mm
* Dose measure in front of dominants
* Min 8 exposures (all dominants, with 2 absorbers)
* Densitometric film assessment

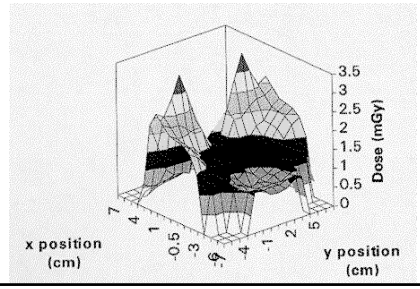
* density/dose ratio

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)

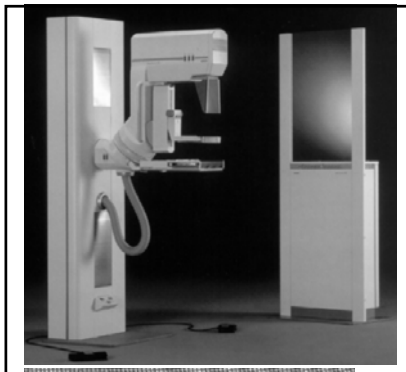
Intra-oral radiography : min 50 kV

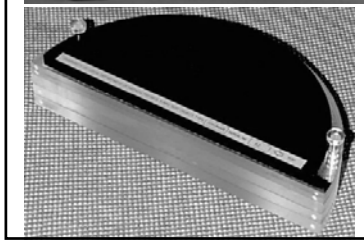
Min FSD 20cm @ 60kV (10cm <60)

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



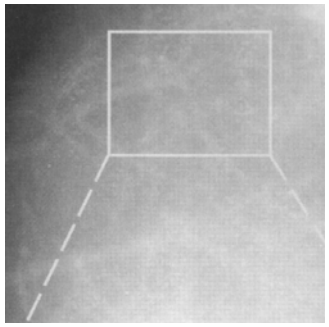


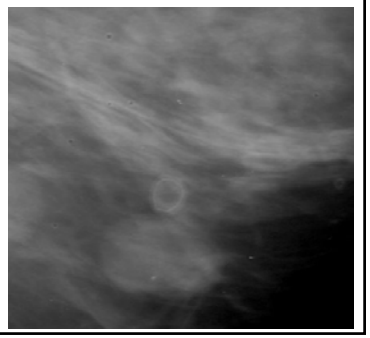
Requires test objects and special measuring equipment - kVp and Dose meter

Basic QC tests in Mammography

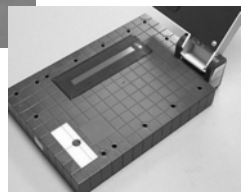
- Kilovoltage
- Exposure time
- Tube output
- Breast dose
- Alignement
- Image quality
- Sensitometry
- AEC
- Filtration
- Compression

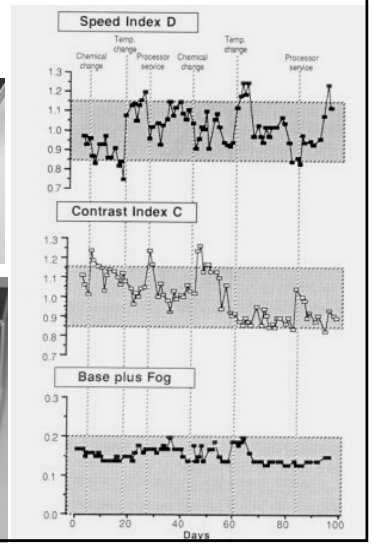
Focus to chamber distance in cm				43				Calculated
Target /	Set kV	Set mA	Set Time	Set mAs	Meas kV	Meas T	Air kerma	Output @1m
Filter	(kV)	(mA)	(ms)	(mAs)	(kV)	(ms)	(mGy)	(µGy/mAs)
			Variation of output with kilovoltage					
Mo/Mo	26	100	500	50	26.2	503	9.75	36.06
Mo/Mo	28	100	500	50	28.2	503	12.31	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





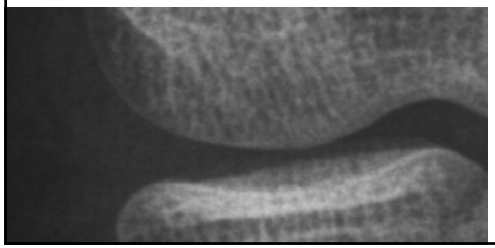
Computed Radiography – CR

More and more used, but still no unified QC

The digital image of CR allows archiving and share of images through PACS.

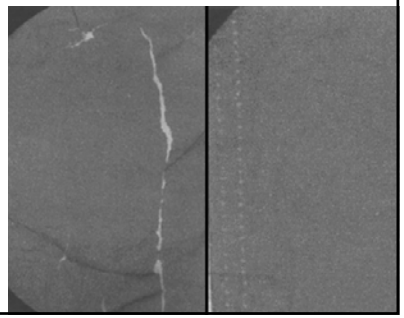
The hard-copy image of all these devices is still made on film (exposed with Laser Imager).

As in many places the diagnosis is still made from film, the final image quality will still depend on the film and imager….



Other QC tests

- Acceptance testing of new equipment
- Service engineer (radiographer)
- Documentation
- Check all operating modes and accessories
- Radiation safety
- Electrical safety
- Mechanical safety



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	VL 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

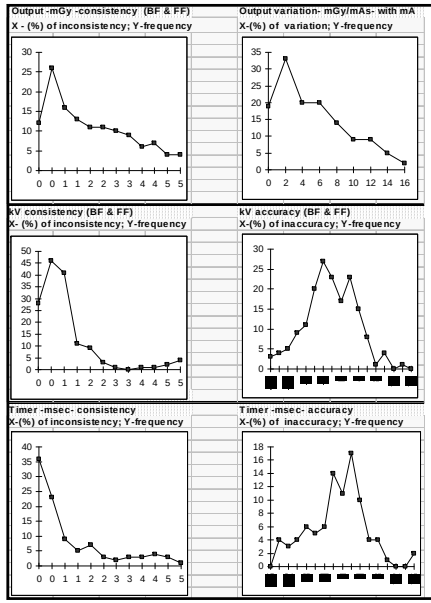
Radiological Protection and Quality Assurance Report

Hospital/Clinic:	Brook Hospital	**Unit type :**	Overcouch
Department :	X-ray	**Generator/Manuf.:**	Philips
		Type:	DR3T/500
Room/Unit:	3b	**X-Tube / Type:**	SRO 2550
		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"

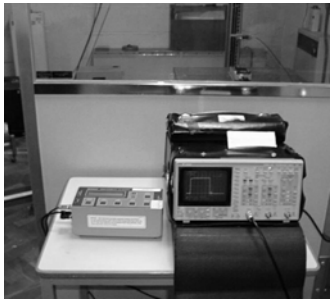
EMERALD
The Consortium of European Medical Radiation Learning Development

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

Effectiveness of Quality Control in Radiography

S Tabakov, M Stoeva



Often Hospital management accepts Quality Control (QC) of X-ray equipment as just a necessity linked to specific Regulations.

This might reflect in a superficial attitude to the QC tests linked mainly to "bureaucratic" collection of QC records.

Our study shows the effect of regular QC tests on the X-ray equipment performance and image quality, based on long term statistics, and compared with a period when no QC tests had been made

QC statistics made on the basis of :

- 63 X-ray generators&tubes (surveyed over 3 years) - from 1992-1995 (no QC have been carried out to these equipment for some 2 years before 1992)

-During the following 5 years 12 of those equipment have continued to be surveyed and analysed

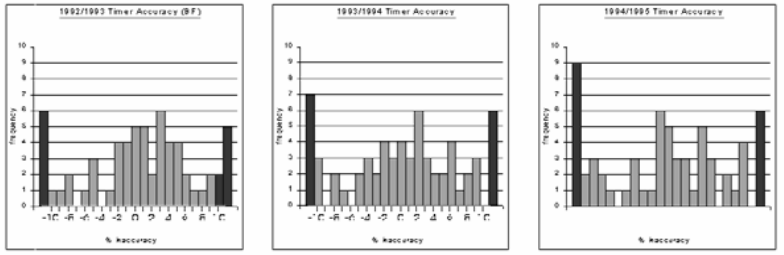
- All equipment had been in use for less than 15 years

- 27 new X-ray generators&tubes have been surveyed and analysed over 3 years (1997-2000)

- All equipment has been surveyed with identical tests (IPEM and Emerald) and all data presented to the X-ray service

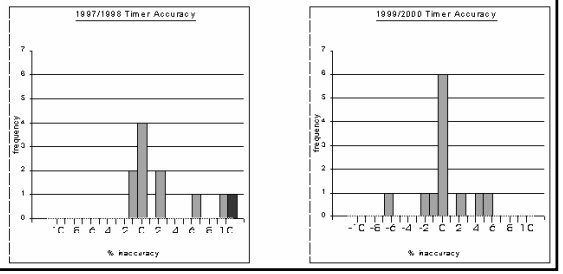
- The analysed parameters (statistics with SPSS package) are presented on the slides to follow

Timer Accuracy



Timer accuracy:

almost no reaction, often deteriorates



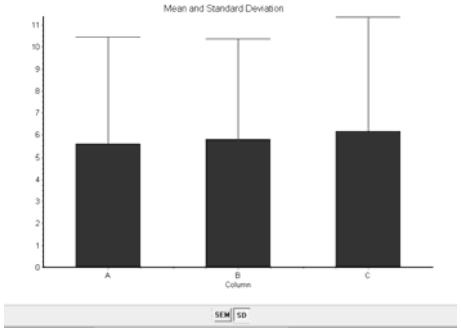
Timer Accuracy (abs. values) -100*(mean error)/(real value):

Year 1 >> Year 2 : P >0.05 (not significant)

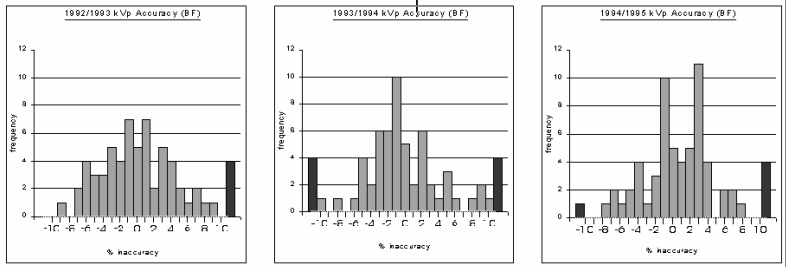
Year 1 >> Year 3 : P >0.05 (not significant)

Years 1 >2>3 : P >0.05 (not significant)

The parameter often deteriorates (equipment defects) and perhaps due to this reason the overall reaction (as a group) is not significant. Only some of the observed equipment show slow positive reaction.

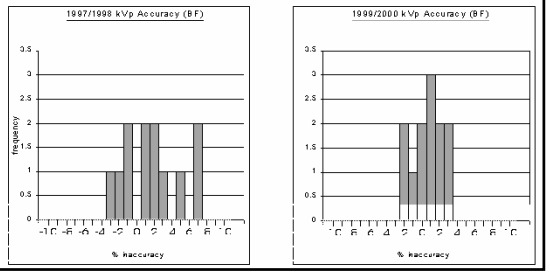


kVp Accuracy



kVp Accuracy:

Slow reaction, often deteriorates



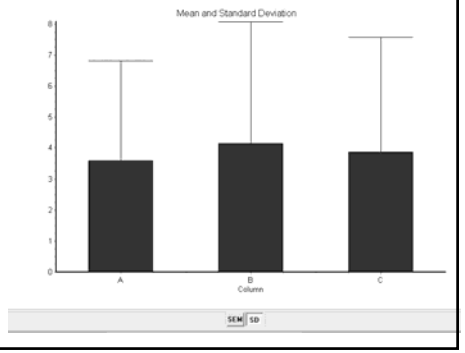
kVp Accuracy (abs. values) -100*(mean error)/(real value):

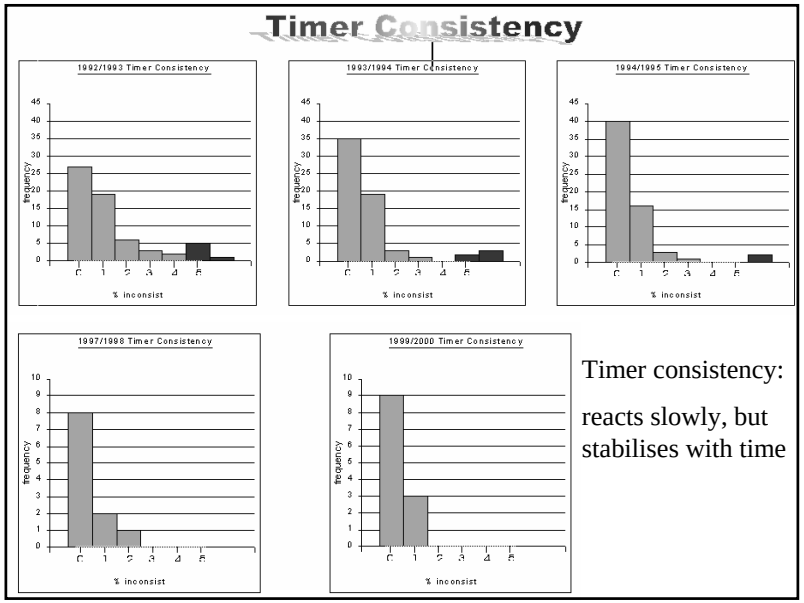
Year 1 >> Year 2 : P >0.05 (not significant)

Year 1 >> Year 3 : P >0.05 (not significant)

Years 1 >2>3 : P >0.05 (not significant)

The parameter often deteriorates (equipment defects) and perhaps due to this reason the overall reaction (as a group) is not significant. However observing equipment without defects shows slow positive reaction.





Timer consistency:

reacts slowly, but stabilises with time

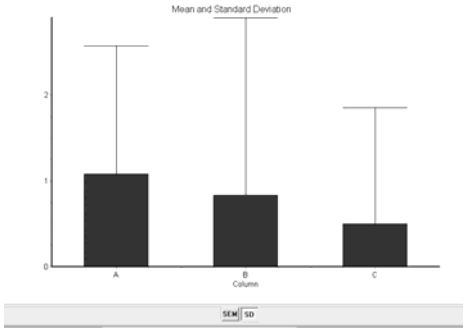
Timer Consistency - 100*(st.dev)/(average) :

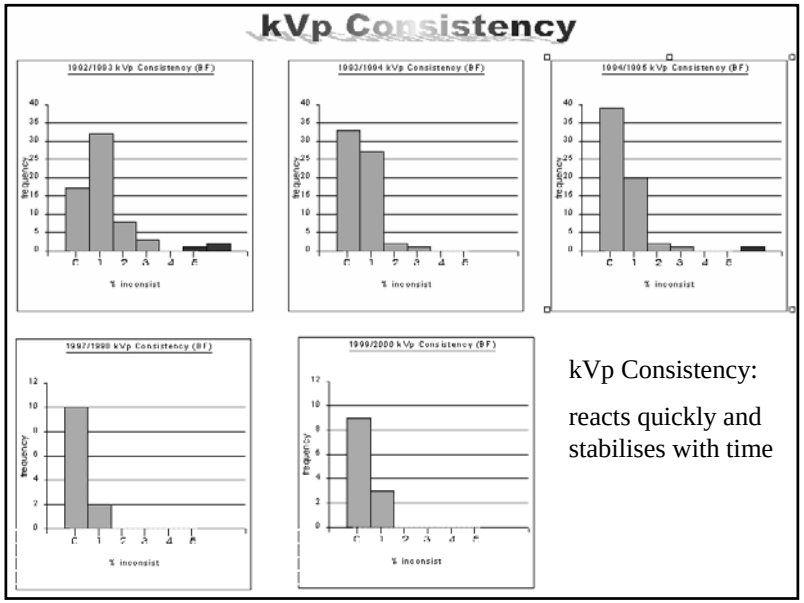
Year 1 >> Year 2 : P >0.05 (not significant)

Year 1 >> Year 3 : P<0.01 (very significant)

Years 1 >2>3 : P <0.05 (significant)

The parameter stabilises after the second QC test - both in terms of mean value (small inconsistency) and in terms of concentration of results (small SD).





kVp Consistency:

reacts quickly and stabilises with time

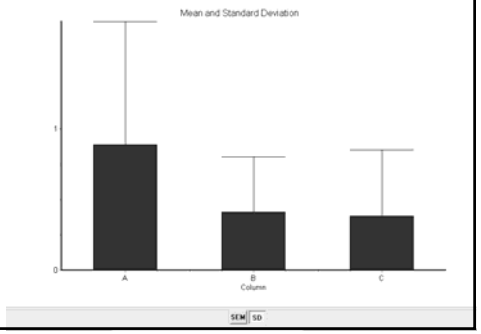
kVp Consistency - 100*(st.dev)/(average) :

Year 1 >> Year 2 : P<0.01 (very significant)

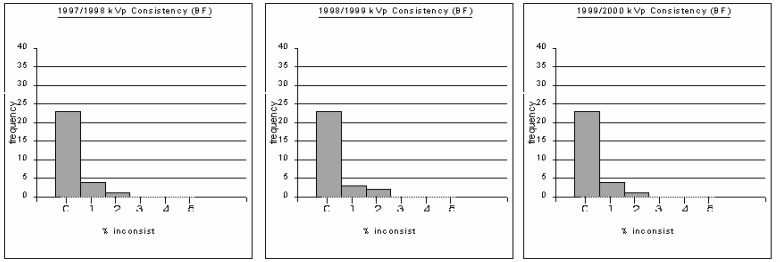
Year 1 >> Year 3 : P<0.01 (very significant)

Years 1 >2>3 : P<0.01 (very significant)

The parameter stabilises after the first QC test - very fast reaction. The consistent results does not exclude absolute error (to be seen with the accuracy tests).



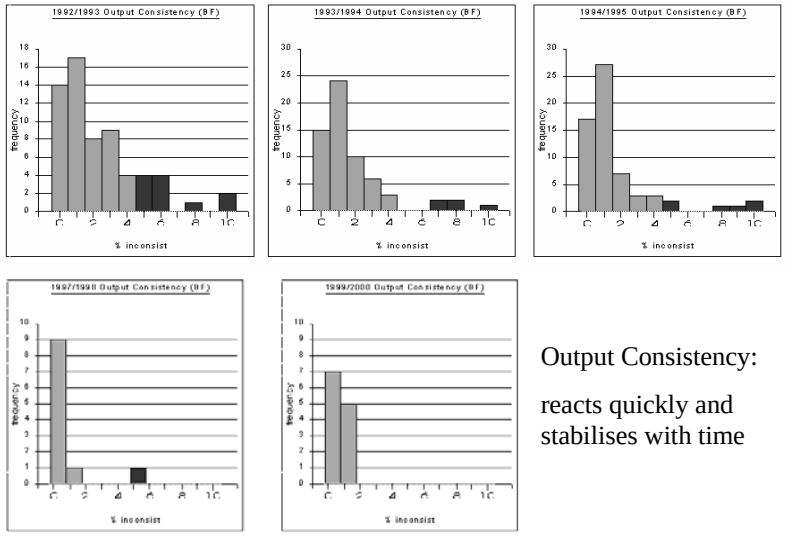
kVp Consistency



kVp consistency:

in new X-ray equipment (with regular QC) the parameter maintains stable low values.

Output Consistency



Output Consistency:

reacts quickly and stabilises with time

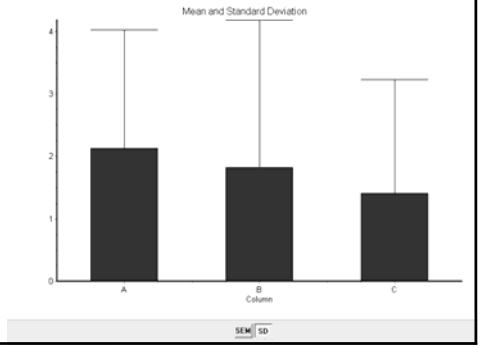
Dose Output Consistency - 100*(st.dev)/(average) :

Year 1 >> Year 2 : P~0.05 (close to significant)

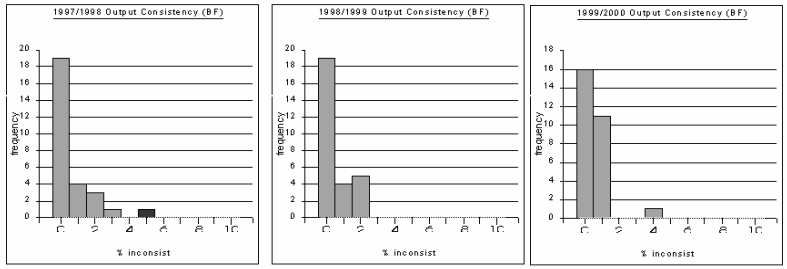
Year 1 >> Year 3 : P<0.05 (significant)

Years 1 >2>3 : P~0.05 (close to significant)

The parameter improves with time (statistically observed after the second QC test).



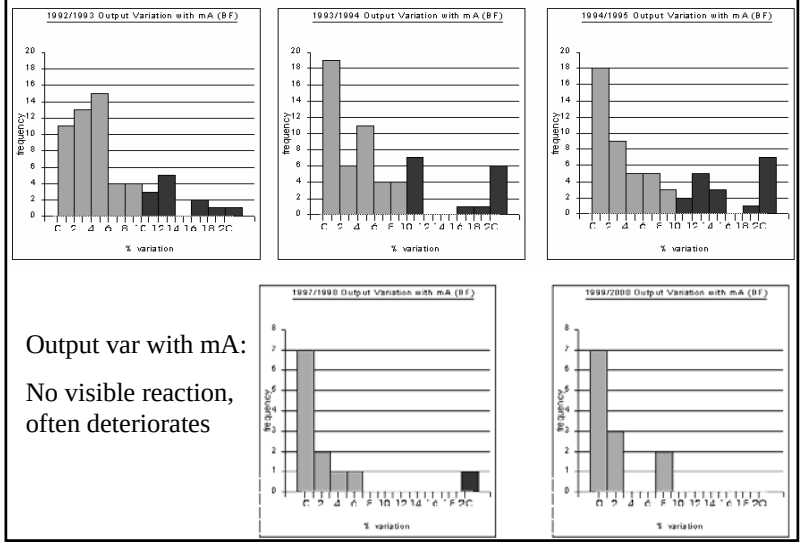
Output Consistency



Output consistency (as overall parameter):

in new X-ray equipment (with regular QC) maintains stable parameters

Output Variation with mA



Output var with mA:

No visible reaction, often deteriorates

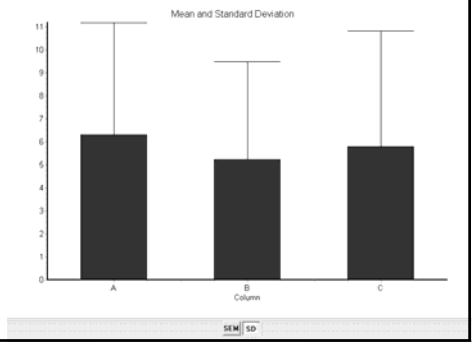
Output variation with mA - 100*(st.dev)/(average) :

Year 1 >> Year 2 : P>0.05 (not significant)

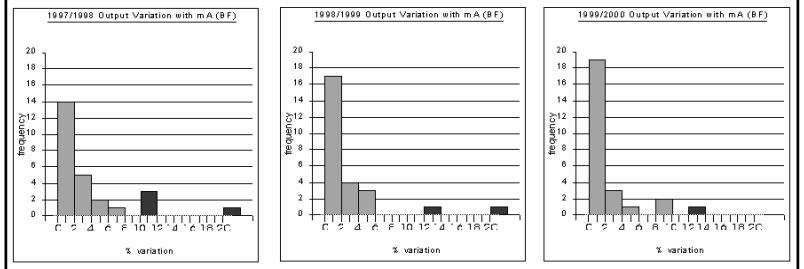
Year 1 >> Year 3 : P>0.05 (not significant)

Years 1 >2>3 : P>0.05 (not significant)

The parameter is linked not only to equipment performance but also to stability of the electrical supply. Significant faults observed at mobile equipment (perhaps tested in different rooms). No trend for improvement observed.



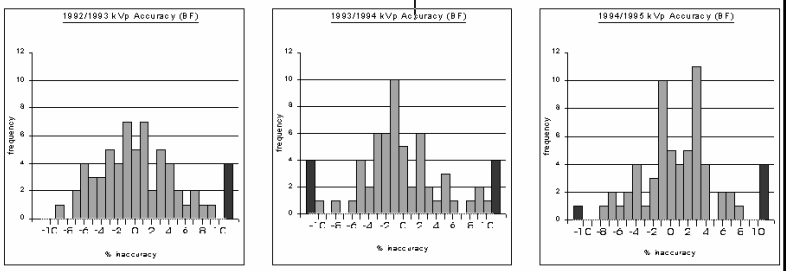
Output Variation with mA

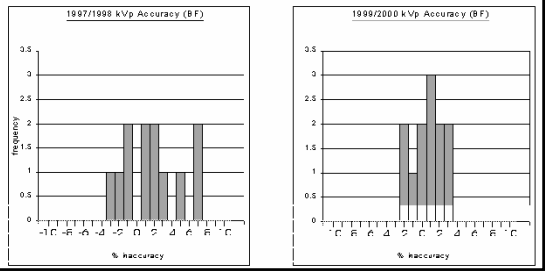


Output variation with mA:

in new X-ray equipment does not show reaction of stabilising the parameter

kVp Accuracy

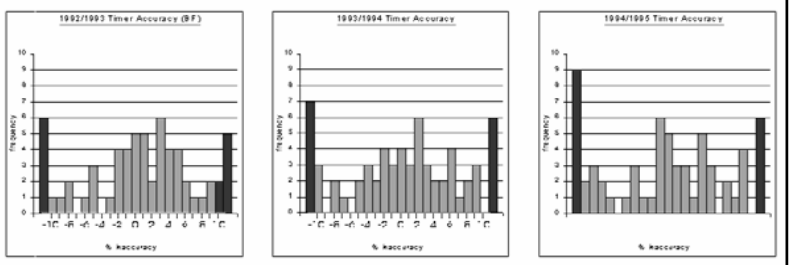


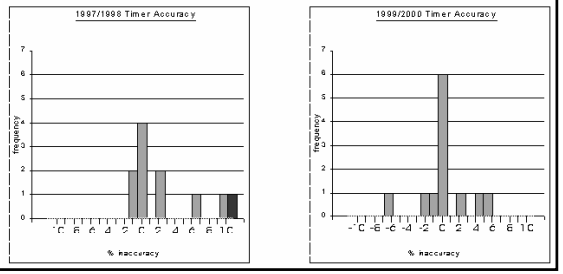


kVp Accuracy:

reacts slowly, but improves with time, often deteriorates

Timer Accuracy

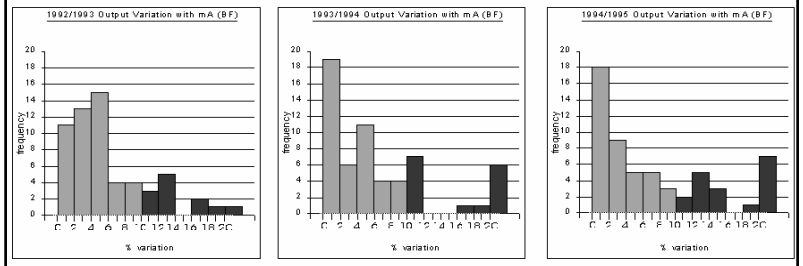


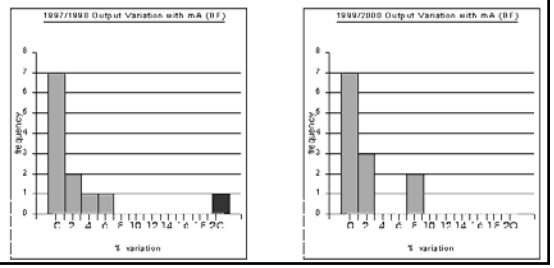


Timer accuracy:

almost no reaction, often deteriorates

Output Variation with mA

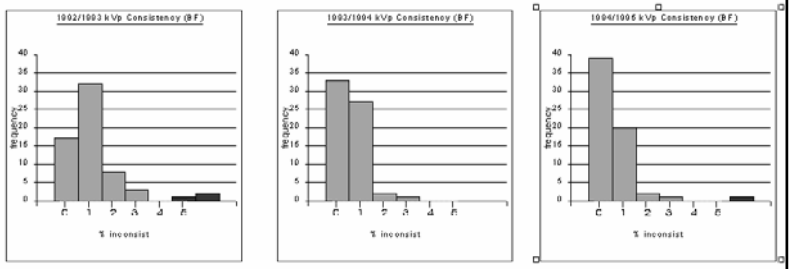


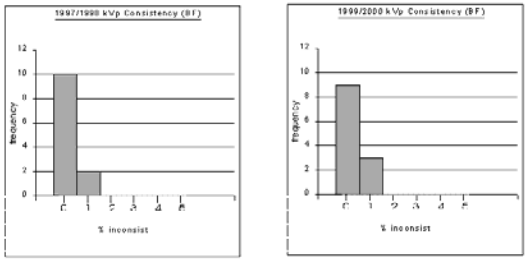


Output var with mA:

reacts slowly, but stabilises with time, often deteriorates

kVp Consistency

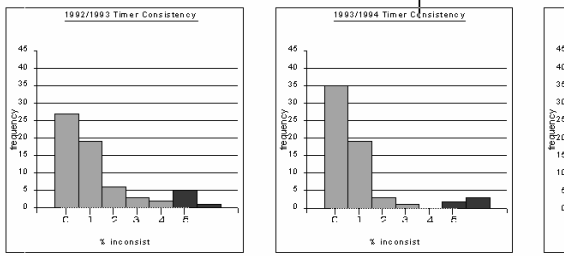


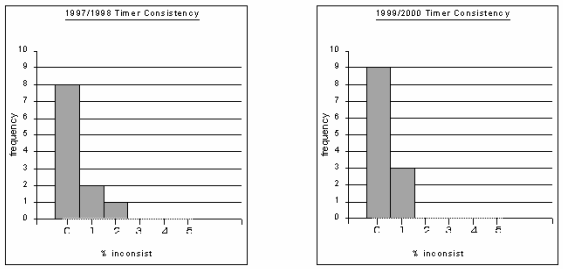


kVp Consistency:

reacts quickly and stabilises with time

Timer Consistency

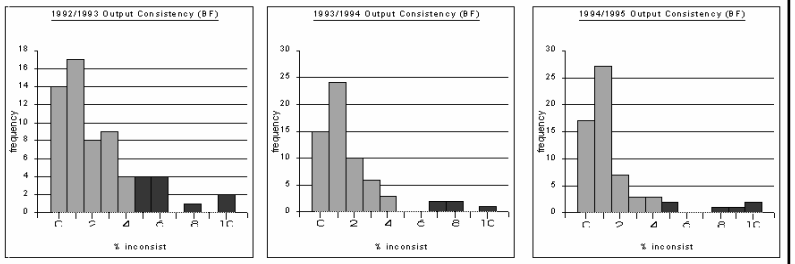


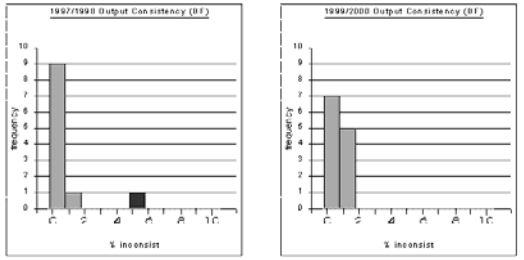


Timer consistency:

reacts slowly, but stabilises with time

Output Consistency



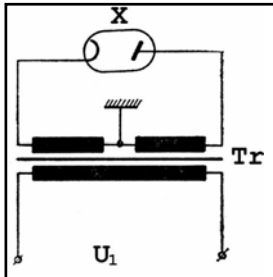


Output Consistency:

reacts very quickly and stabilises with time

Conclusions

- Without regular QC all parameters of X-ray systems deteriorate (pre 1991 data)
- Regular QC maintains the consistency of X-ray systems parameters within specification
- More frequent QC would have a quick positive effect on the improvement of the less stable parameters and therefore - on the overall X-ray equipment performance.



TASK:

High Voltage (HV) Transformer ratio ~ 1:500

Input from main - 200 V

Main cables resistance - 0.2 ohms

***Calculate with how many kV will drop the HV, if the Exposure is 100 kV and 100 mA (for 0.1 s)**

**** Calculate the % kV variation with mA and Output variation with mA (using data from sl.13)**

*****What will be the overall effect on the X-ray image (and patient dose)**

***** *How this voltage drop can be compensated?**