

Version

1.0

TechnicVR

shaderware.com

Student Workbook

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shaderware.com

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Introduction

This section will explain what virtual radiography is



TechnicVR is a fully featured simulation of the x-rays created during an exposure. It is important to find out about what the patient is subject to. As a practitioner, your patients might ask you questions about this, and you need to be able to alter the factors sensibly to get the right results every time. All types of projection radiographic procedure are possible to set up using TechnicVR. It can be quite rewarding to quickly experiment with extreme examples (without risking equipment or yourselves!).

This workbook contains 14 Laboratory sessions that can be used in class or for individual study. It is to be used in conjunction with the Student Guide and its use is supported by the Tutor Guide.

"[this software] allows students to work in an environment that safely simulates the conditions of an X-Ray unit",

Society of Radiographers, 2006

Introducing the TechnicVR syllabus

Across the world it is agreed that radiographers require a thorough understanding of the production of x-rays and their control and manipulation. It is an important part of any qualifying course for the protection of patients and staff. TechnicVR has been developed with these core curricula requirements in mind. This workbook addresses many of the requirements of the UK and USA radiography syllabus.

The syllabus

This package is for students with experience of radiographic equipment or some simulated experience (see virtual radiography™, shaderware, UK). These will be students on pre-registration Radiography programs, Practitioners and assistants extending their roles into radiography. It represents xx hours of learning time.

Aims

- Provide an authentic experience for the student that utilises experiential learning in a simulated, safe, environment facilitated by an academic radiographer to optimise clinical practice.
- Expose the students to a faithful simulation of radiographic science; enabling exploration and familiarisation with radiographic constructs such as ‘Dose’, ‘Ratings’, ‘Filtration’ etc.
- Foster student peer to peer collaboration where introduction of scientific concepts can de-motivate and confuse students who have little scientific background.
- Provide accurate formative objective feedback from the simulator for learning.
- Avoid any formulae or mathematical proof of concepts. Enabling students to truly experience the effects of changes and formulate their own ‘working knowledge’ that will transfer into optimal practice.

Indicative content

1. Physical Principles (25)
 - a. Radiation Production (3)
 1. Waveform characteristics
 2. Target design
 - b. X-Ray Beam Characteristics (4)
 1. Beam quality
 2. Radiation output
 3. Beam modification
 - c. Receptor Characteristics (4)
 1. Spectral matching
 - d. Special modality requirements
 1. Fluoroscopic requirements
 2. Dental equipment
 3. Full field digital mammography system
 - e. Tube Rating Chart
 1. Anode Storage Capacity
 2. Anode Cooling Curve
 - f. Factors governing tube life
 1. Overheating
 2. Tungsten Deposits
2. Collection and Analysis of QC Data (49)
 - a. Generator Performance (6)
 1. Timer accuracy and reproducibility
 2. kVp accuracy and reproducibility
 3. mA or mAs linearity
 5. Exposure reproducibility
 - b. Beam Characteristics (6)
 1. half-value layer
 2. mR / mAs
 3. Dose Area Product
 - c. Ancillary Equipment Evaluation (5)
 1. Grid performance
 2. Additional protective devices
 - d. Fluoroscopic Systems (4)
 1. Beam quality
 2. Tabletop exposure rate

Physical principles 1

This chapter contains 2 Labs that introduce concepts and terms and start to develop an understanding of the physics and operation of x-ray equipment. Students are also made aware of the diversity of equipment they will use.

Lab 1 – Waveform characteristics

Aims of Lab

- Discuss the history of x-ray generation
- Provide a clear demonstration of different wave forms and their effects on the x-ray beam
- Note the effect of different waveforms on exposure factor selection

Lab 2 – Target design

Aims of Lab

- Compare stationary and rotating anode designs.
- Introduce the concept of anode angle and the line focus principle
- Consider the anode heel effect

Lab 1 – Waveform characteristics

Aims of Lab

- Discuss the history of x-ray generation
- Provide a clear demonstration of different wave forms and their effects on the x-ray beam
- Note the effect of different waveforms on exposure factor selection

Worksheet 1 - Waveform characteristics

Outcomes: At the end of the Lab, students will be able to:

1. Record observations and reflections from simulated experiences to aid future learning on a provided worksheet
2. Access TechnicVR in the computer lab, the student guide and the student workbook.
3. List significant evolutionary steps in generator design
4. Identify the limitations of these generator designs on the x-ray beam output
5. Modify exposure factors according to generator design to maintain image quality for minimum patient Dose.

ACTIVITY

Chest, PA projection

(Try to do this from memory, if you can't, all the controls can be found in the student guide)

Open TechnicVR. Go to the view menu and deselect 'hide all'; select 'Dose' and 'Output' from the Beam characteristics menu.

You are using an older 3 Phase 6 pulse unit, so select this from the 'equipment' tab. Select 'Chest PA' from the 'Procedure' tab. Alter the exposure from the preset for a large man. Note down the exposure factors being applied:

Waveform	SID	kVp	mAs	Patient + bucky (cm)	Incident Dose (μGy)	Output (μGy/mAs @ 75cm)
S. Phase, Half	180	90	5	35		
S. Phase, Full	180	90	5	35		
3 Phase, 6 p	180	90	5	35		
3 Phase, 12 p	180	90	5	35		
High Freq.	180	90	5	35		

Table 1. Incident Dose and Output variation with tube potential difference waveform.

On the equipment tab, select each of the wave form types in turn, look at the spectrum and see how it changes as you select the different waveforms. Complete Table 1. by noting down the Incident Dose and the Output for each waveform.



As generators became more advanced, the radiation output per mAs set became HIGHER/LOWER (delete). If all other factors remain the same, the incident dose for this Chest X-Ray will need to be the same whatever the equipment.

This time, alter the mAs (on the exposure tab) until the Incident Dose is equal to the 3 Phase 6 pulse value across all generator types; note down the mAs and Incident Dose values :

Waveform	SID	kVp	mAs	Patient + bucky (cm)	Incident Dose (μ Gy)
S. Phase, Half	180	90		35	
S. Phase, Full	180	90		35	
3 Phase, 6 p	180	90		35	199
3 Phase, 12 p	180	90		35	
High Freq.	180	90		35	

Table 2. mAs variation required with tube potential difference waveform.

(It won't be possible to match the Incident Dose exactly, because not all mAs values are available)



If your department upgraded to a new High Frequency generator what would the effect on mAs values be for standard exposures?

NO EFFECT/RISE/FALL (circle right answer)

Further Reading

Evans, S.A., Harris, L., Lawinski, C.P., and Hendra, I.R., (1985) **Mobile X-Ray Generators: a review** Radiography, March/April Vol. 51 No: 506

Stears, J.G., Gray, J.E., Webbles, W.E. and Frank, E.D., (1985) **X-ray waveform monitoring for radiographic quality control**. Radiologic Technology. Sep-Oct; 57(1): 9-16. (14 ref)

Lab 2 – Target design

Aims of Lab

- Compare stationary and rotating anode designs.
- Introduce the concept of anode angle and the line focus principle
- Consider the anode heel effect

Worksheet 2 - Target design

Outcomes: At the end of the Lab, students will be able to:

6. Describe a stationary anode
7. Identify the design elements employed to increase the possible heat loading
8. Explain the benefits and pitfalls of a rotating anode

ACTIVITY

Orthopaedic Theatre – Spine fixation

Open TechnicVR. Go to the view menu and deselect 'hide all'; select 'Dose rate' from the View\Beam characteristics menu.

You are using a low cost stationary anode unit in your orthopaedic theatre to image a trans-pedicular spinal screw insertion; select this from the 'Procedure' tab. Set the exposure factors for fluoroscopy in the table. Make sure that pulsed fluoroscopy is switched off by ticking the 'continuous' option.

Hit the expose button and count out 10 seconds of cumulative exposure time, watch the focal track heat dial in the right hand panel and roughly estimate the peak temperature after 10 seconds. Fill in some of Table 3.

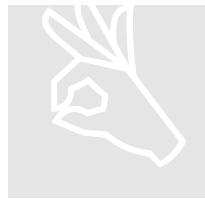
Anode Design	Cumulative exposure time (s)	kVp	mA	Incident Dose rate ($\mu\text{Gy/s}$)	Anode track Temp ($^{\circ}\text{C}$)
Stationary anode	10	90	1.0		
Rotating Anode	10	90	1.0		

Table 3. Comparison of target heating with different design.

PTO...

Select a more expensive rotating anode mobile image intensifier. This will come with added aluminium filtration as standard – so to make the comparison fair remove this by setting filtration in the ‘equipment’ tab to be 2mmAl. Make sure that pulsed fluorography is switched off by ticking the ‘continuous’ option.

Hit the expose button and count out 10 seconds of cumulative exposure time, watch the focal track heat dial and roughly estimate the peak temperature and complete Table 2.



Would it be worth spending more on a rotating anode machine for spinal work?

YES/NO (circle right answer)

Why?

Further Reading

Dewey, P., George, S. and Gray, A., (2005) **Ionising radiation and orthopaedics**. Current Orthopaedics, 19 (1), 1-12.

Thompson, T.T., (1983) **The abuse of radiographic tubes**, RadioGraphics; Vol 3:397-399

Worksheet 3 - Target design 2

Outcomes: At the end of the Lab, students will be able to:

9. Describe the line focus principle
10. Debate the benefits of a rotating anode

ACTIVITY

Orthopaedic Theatre – Spine fixation

Open TechnicVR. Go to the view menu and deselect 'hide all'; select 'Dose rate' from the View\Beam characteristics menu.

You are using a low cost stationary anode unit in your orthopaedic theatre to image a trans-pedicular spinal screw insertion; select this from the 'Procedure' tab. Set the exposure factors for fluoroscopy in the table. Make sure that pulsed fluoroscopy is switched off by ticking the 'continuous' option.

Note the anode angle for the tube in the exposure tab and complete the first line of Table 3.

The entrance surface detector can be moved along the x-ray field. Go to the 'Detector' tab and move the detector along 12.5cm toward the anode (-12.5), note the change in the spectrum and dose rate; complete the second line of the table.

Anode Design	Anode Angle	Detector position from CR (cm)	kVp	mA	Incident Dose rate ($\mu\text{Gy/s}$)
Stationary anode	12	0	90	1.0	
Stationary anode	12	-12.5	90	1.0	
Rotating Anode	16	0	90	1.0	
Rotating Anode	16	-12.5	90	1.0	

Table 4. The effect of target angle on the anode heel effect

Select a more expensive rotating anode mobile image intensifier. This will come with added aluminium filtration as standard – so to make the comparison fair remove this by setting filtration in the 'equipment' tab to be 2mmAl. Make sure that pulsed fluorography is switched off by ticking the 'continuous' option.

Complete lines 3 and 4 of the table by moving the detector.

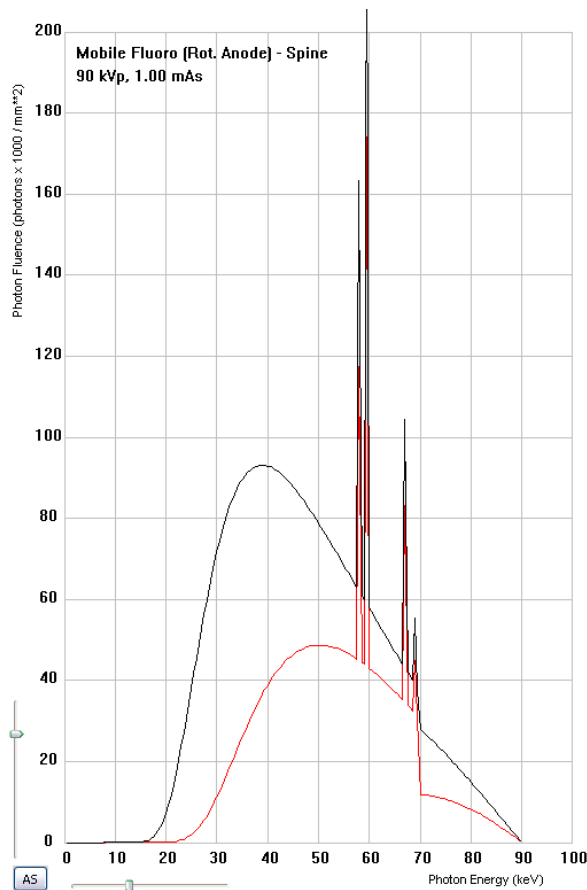


Figure 1. Differences in spectra at 15cm toward anode for two different target angles

The change in the spectrum is shown in Figure 1. The dose rate for the 12 degree target angle is HIGHER/LOWER than the 16 degree target angle at 12.5cm toward the anode.

The marked differences are due to the extra tungsten the beam must travel through.

The IEC have a standard that the whole x-radiation field must be 'uniform'. This requires that nowhere should the dose rate be less than 75% of the dose rate at the central ray (IEC 61267, 1994). The results from this lab show that the stationary anode target (12 degrees) was unable to cover a 25cm field, but the rotating anode machine (16 degree) was (the maximum field size for the 12 degree target at 100cm would be 18cm).

The reason that the stationary anode has a steeper target angle is to maximise the anode area that is exposed to the electron beam in the tube, for the same focal spot size. This is an attempt at spreading the heat as much as possible.

Further Reading

Fung, K.K., and Gilboy, W.B., (2000) **The "Anode heel effect" on patient dose in lumbar spine radiography**, British Journal of Radiography, Vol. 73 Issue 869:531-536

Physical Principles 2

This chapter contains 3 Labs that introduce concepts and terms and start to develop an understanding of the physics and operation of x-ray equipment. These labs deal with the main changes the radiographer can make to the radiation incident on the patient and detector.

Lab 3 – Radiation Output

Aims of Lab

- Compare the radiation output of different x-ray units.
- Identify the determinants of radiation output

Lab 4 – Beam Modification

Aims of Lab

- Discuss the appearance of the spectrum
- Explore the visual effect of easily modified factors on the x-ray beam (kVp, mA, s, SID)
- Explore the visual effect of other factors on the x-ray beam (filtration, voltage waveforms)

Lab 5 – Beam Quality

Aims of Lab

- Define ‘quality’ as it is applied to x-ray beams
- Identify the main determinants of beam quality
- Learn the meaning of ‘effective photon energy’, HVL, etc.

Lab 3 – Radiation Output

Aims of Lab

- Compare the radiation output of different x-ray units.
- Identify the determinants of radiation output

Worksheet 4 – Radiation Output

Outcomes

At the end of the Lab, students will be able to:

11. Rank x-ray machines in terms of their radiation output
12. Identify causes of output differences
13. Be aware exposure charts are equipment specific

ACTIVITY

Open TechnicVR. Go to the view menu and deselect 'hide all'; select 'Radiation Output' from the View\Beam characteristics menu.

Comparing the Radiation output of some very different x-ray machines, select General Radiography L. Spine Lateral. Alter the kVp to 70. Complete line 2 of Table 5.

Finish the table by setting all the other situations.

Unit	Filtration (mmAl)	Tube Age	Target angle	kVp	Radiation Output ($\mu\text{Gy/mAs}$)
General Rm.	3.2	New	16	90	
General Rm.	3.2	New	16	70	
General Rm.	3.2	Old	16	70	
Mobile	2.5	New	16	70	
Dental (Mod.)	2.5	New	12	70	
Dental (New)	1.5	New	12	70	
Dental (Old)	1.5	New	12	70	
Dental (Old)	1.5	Old	12	70	
Dental (Old)	1.5	Old	12	50	

Table 5. Factors determining Radiation Output @ 75cm.

Circle the correct part of the statements over the page:

1. 'Increasing tube filtration REDUCES/HAS NO EFFECT/INCREASES Radiation Output'
2. 'Increasing tube age REDUCES/HAS NO EFFECT/INCREASES Radiation Output'
3. 'Reducing target angle REDUCES/HAS NO EFFECT/INCREASES Radiation Output'
4. 'Increasing tube voltage (kV) REDUCES/HAS NO EFFECT/INCREASES Radiation Output'

Lab 4 – Beam Modification

Aims of Lab

- Familiarise students with the x-ray spectrum
- Explore the visual effect of easily modified factors on the x-ray beam (kVp, mA, s, SID)
- Explore the visual effect of other factors on the x-ray beam (filtration, voltage waveforms)

Worksheet 5 – Beam Modification

Outcomes

At the end of the Lab, students will be able to:

14. Discuss the appearance of the spectrum
15. Visualise the effect of easily modified factors on the x-ray beam (kVp, mA, s, SID)
16. Define 'Beam Homogeneity'

ACTIVITY

Open TechnicVR. Go to the view menu and deselect 'hide all'; select 'Beam Homogeneity' and 'Total Energy' from the View\Beam characteristics menu.

Comparing two types of CXR exposure, one using a 'high kV technique', the other using a 'low kV technique'. Select CXR PA from the 'Procedure' tab. Change the Filtration to 2.0mmAl. Select 'persist' on the 'Exposure' tab. Set the factors in the first line of the table. Hit the expose button. Now select the exposure factors in the second line, hit the exposure button again.

Unit	Filtration (mmAl)	SID	Patient Thickness	mAs	kVp	Total Energy (million keV/mm ²)	Beam Homogeneity
General Room	2.0	180	30	1	125		
General Room	2.0	180	30	5	70		
General Room	2.0	100	5	3.2	50		

Table 7. The effect of kV and mAs on Beam Energy and Homogeneity.

1. Which has the most energy? 125kV/1 mAs or 70kV/5mAs or NEITHER
2. Which has the wider spread of energies? 125kV/1 mAs or 70kV/5mAs or NEITHER
3. Which is 'taller'? 125kV/1 mAs or 70kV/5mAs or NEITHER
4. Which has characteristic photons? 125kV/1 mAs or 70kV/5mAs or NEITHER

Set a typical wrist exposure (use the values in the third line of Table 7.), compare this exposure to the other two.

5. What effect does reducing kV have on the spectrum?

NONE/'TALLER' AND NARROW/'LOWER' AND WIDE

Lab 5 – Beam Quality

Aims of Lab

- Define ‘quality’ as it is applied to x-ray beams
- Identify the main determinants of beam quality
- Learn the meaning of ‘effective photon energy’, HVL, etc.

Worksheet 6 – Beam Quality

Outcomes

At the end of the Lab, students will be able to:

17. Discuss penetration of x-rays through matter
18. Consider Filtration as an exposure factor
19. Define the term ‘Quality’
20. Define ‘HVL’

ACTIVITY

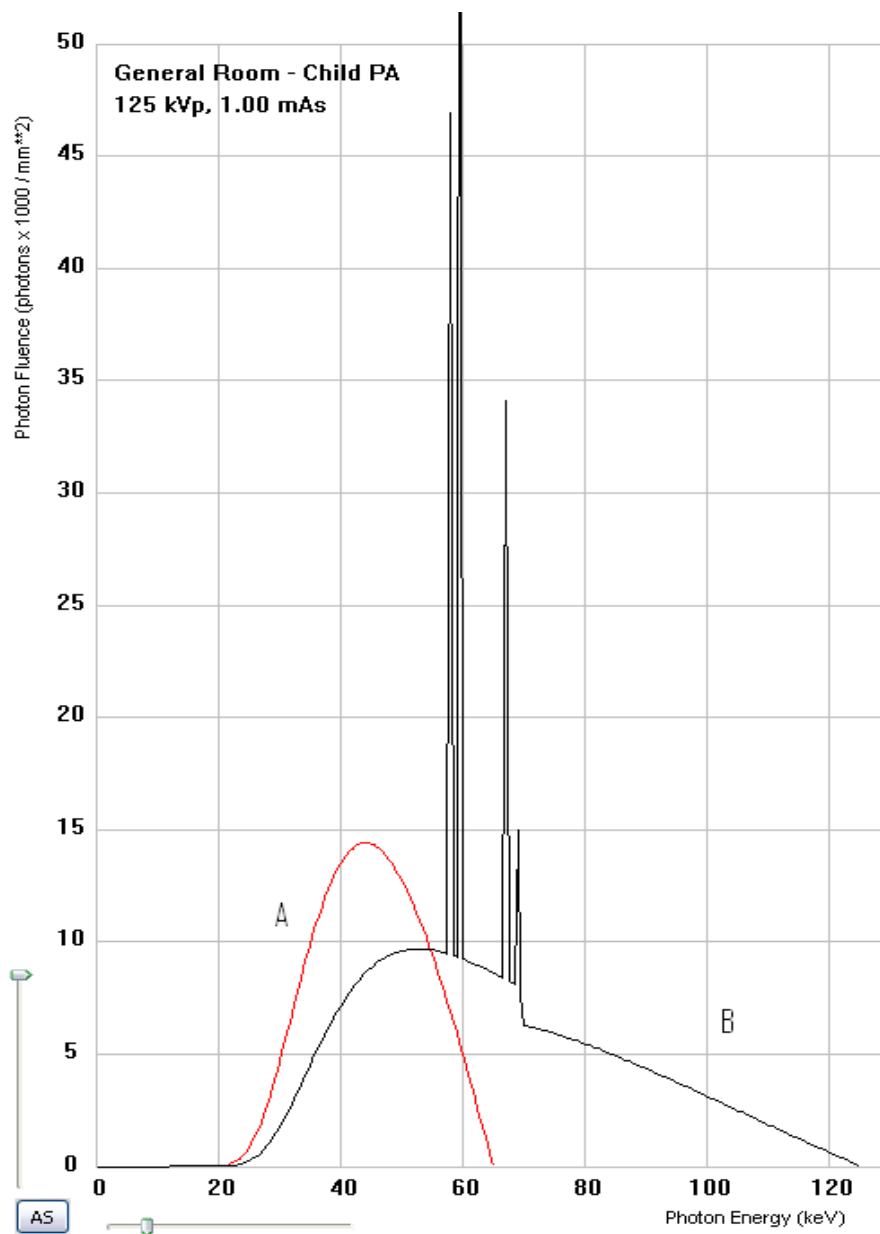
Open TechnicVR. Go to the view menu and deselect ‘hide all’; select, ‘Total Energy’, ‘Effective Beam Energy’, ‘Penetration’ and ‘HVL’ from the View\Beam characteristics menu.

Compare an adult and child PA Chest x-ray exposure; the Adult CXR uses a ‘high kV technique’, the child PA uses a ‘low kV technique’, in a dedicated Paediatric room. Select CXR PA from the ‘Procedure’ tab. Select ‘persist’ on the ‘Exposure’ tab. Set the factors in the first line of the table. Hit the expose button. Now select Child PA CXR from the ‘Procedure’ tab. Set the exposure factors in the second line, hit the exposure button again.

Exam	Filt.	Patient Thick.	mAs	kVp	Pen. %	HVL	Eff. Beam Energy (keV)	Tot. Energy (keV/mm ²)
General Room PA CXR	3.2	30	1	125				
Paediatric Room PA CXR (child)	3.2+ 0.2Cu	15	5	65				
Paediatric Room PA CXR (Adult)	3.2+ 0.2Cu	30	1	125				
Paediatric Room PA CXR (Adult)	3.2+ 0.2Cu	30		125				

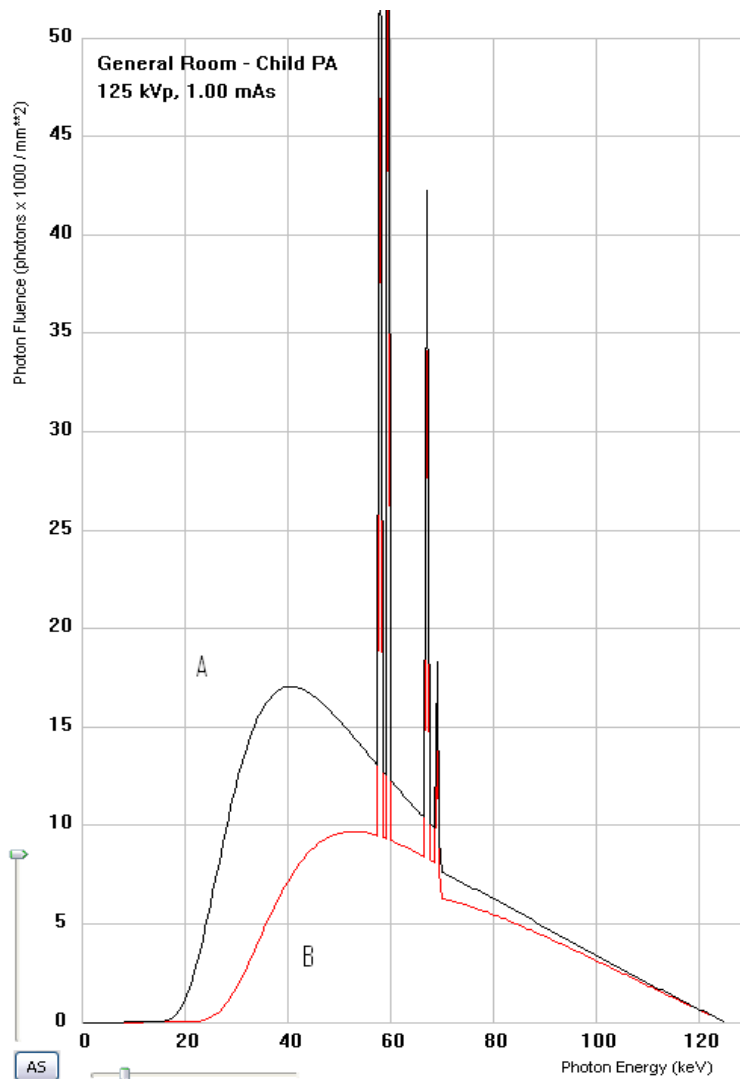
Table 8. Factors determining penetration and energy of an x-ray beam

If the General Room were busy, or being serviced, perhaps an adult would be taken into the Paediatric room for a PA CXR; set the adult exposure factors in line 3 of Table 8. and complete that line of Table 8.



Both these spectra are from the Paediatric room:

6. Which spectrum is the Adult CXR? A/B
7. Which beam is more penetrating? A/B
8. What is the effect of kV on the beam?



One of these Adult CXR exposures is in the general room; one is in the Paediatric room:

9. Which one is in the Paediatric Room? A/B
10. Which beam is more penetrating? A/B
11. What is causing the effect?
12. Which CXR would be un-diagnostic? A/B

Why?

Modify the tube charge (mAs) to compensate. Write the new factors to complete Table 8.

Worksheet 7 – Beam Quality 2 (option)

Outcomes

At the end of the Lab, students will be able to:

21. Discuss penetration of x-rays through matter
22. Consider Filtration as an exposure factor

ACTIVITY

Open TechnicVR. Go to the view menu and deselect 'hide all'; select, 'Total Energy', 'Effective Beam Energy', 'Penetration' and 'HVL' from the View\Beam characteristics menu.

Select CXR PA from the 'Procedure' tab; Select 'persist' on the 'Exposure' tab. Set the factors in the first line of the table. Hit the expose button. Now choose some of the following additional filtration materials; PMMA (a type of plastic), Erbium, Niobium, Iron, Aluminium, Rhodium. Alter the thickness to achieve 11.5% Penetration (the field accepts typed values)

1. Complete Table 9. below.

Filter	Add. Filt. (mm)	Patient Thick.	mAs	kVp	Pen. %	HVL	Eff. Beam Energy (keV)	Rad. Output ($\mu\text{Gy}/\text{mAs}$)	Tot. Energy (keV/mm^2)
PA CXR 3.2mmAl	0	30	1	125	9.6	5.1	42	312	106
PA CXR 3.2mmAl + PMMA		30	1	125					
PA CXR 3.2mmAl + Al		30	1	125					
PA CXR 3.2mmAl + Iron		30	1	125					
PA CXR 3.2mmAl + Erbium		30	1	125					
PA CXR 3.2mmAl + Niobium		30	1	125					
PA CXR 3.2mmAl + Rhodium		30	1	125	-	-	-	-	-

Table 9. Effects of various materials on a diagnostic x-ray beam

- Complete table 10. with your opinion as to the suitability of the particular material as a filter for diagnostic radiography.

Filter Material	Thickness Req. (mm)	Cost (\$/kg)	Opinion
PMMA		2	
Al		3	
Iron		50	
Erbium		650	
Niobium		470	
Rhodium		300,000	

Table 10. Suitability of material as a diagnostic x-ray filter

Further reading:

Wakoh, M., Farman, A.G., Kelly, M.S., and Kuroyanagi, K., (1993) **Diagnostic image quality and dose reduction using niobium filtration for cephalometric radiography**, Dentomaxillofacial Radiology, Vol 22, Issue 4 189-194

Thierens, H., Kunnen, M., Van der Plaetsen, A., and Segaert, O., (1991) **Evaluation of the use of a niobium filter for patient dose reduction in chest radiography**, British Journal of Radiology, Vol 64, Issue 760 334-340

Dobbins, J.T., Samei, E., Chotas, H.G., Warp, R.J., Baydush, A.H., Floyd, C.E., and Ravin, C.E., (2003) **Chest Radiography: Optimization of X-ray Spectrum for Cesium Iodide-Amorphous Silicon Flat-Panel Detector Radiology**, 226(1):221-230

Vassileva, J., (2004) **A phantom approach to find the optimal technical parameters for plain chest radiography**, British Journal of Radiology, 77(920):648-653

Physical principles 3

This chapter contains 3 Labs that introduce concepts and terms and start to develop an understanding of the physics and operation of x-ray equipment. Students are also made aware of the diversity of equipment they will use.

Lab 6 – Spectral Matching

Aims of Lab

- Using filtration and kV to match the beam spectrum for different receptor technologies

Lab 7 – Specialist Requirements (Mammo)

Aims of Lab

- Comparing target materials, and their effect on the x-ray spectrum.

Lab 8 – Specialist Requirements (Fluoro)

Aims of Lab

- Identifying issues with high frame rate angiography
 - Dosimetry
 - Tube heating

Lab 6 – Spectral Matching

Aims of Lab

- Using filtration and kV to match the beam spectrum for different receptor technologies

Worksheet 8 – Spectral Matching 1

Outcomes

At the end of the Lab, students will be able to:

23. Select Tube Voltage (kV) appropriate for detector technology
24. Consider appropriate filtration (extremity) for different detectors

ACTIVITY

Four different detector technologies are used in a particular hospital;

- BaStF1(BrI)+^{Eu} Imaging plates (used with a CR reader)
- CsI/aSi Indirect capture DR detector
- Direct capture aSelenium DR
- Film/screen GdOBr.

Consider the attenuation coefficients of differing detector types as displayed in figure 2. Look at the shape of each curve; although they all do attenuate higher energy beams less than lower energy beams, it is noticeable that some have specific ‘absorption’ edges. At these points, small increases in photon energy are actually *more* attenuated. It is because of these that the x-ray spectra need to be ‘tuned’ for each detector type. When detectors are changed, for example when film screen is replaced by CR, the same exposure factors should not simply be applied.

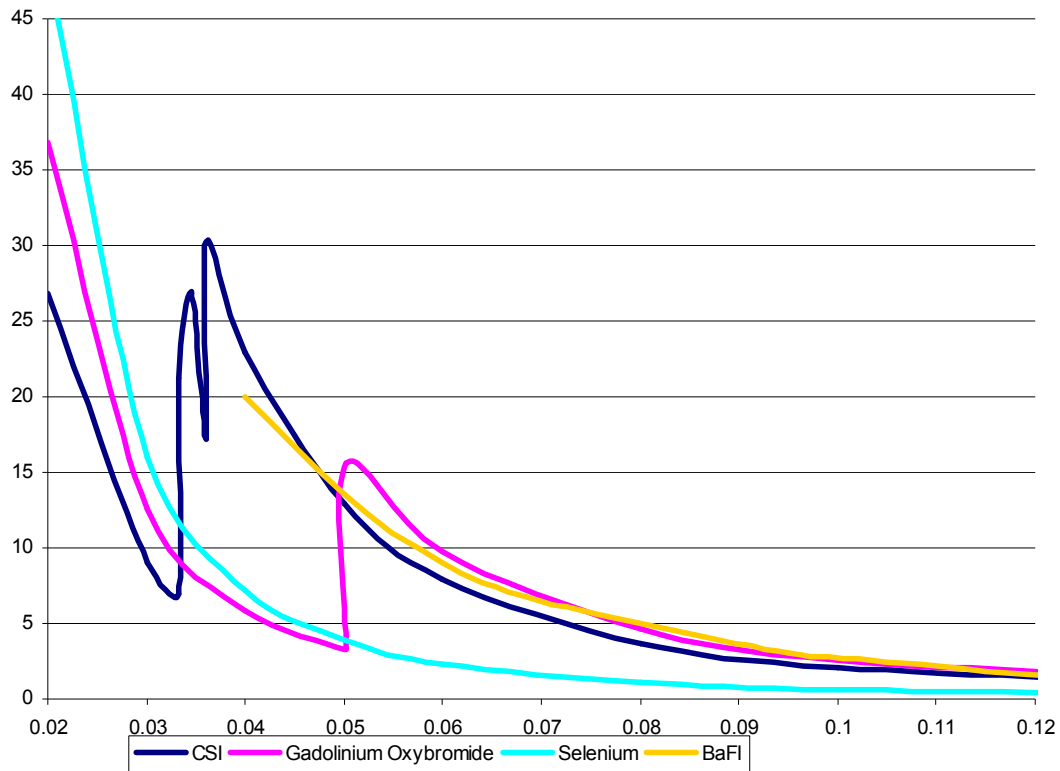


Figure 2. The relationship between mass attenuation and photon energy for different receptor materials

ACTIVITY

Open TechnicVR. Go to the view menu and deselect 'hide all'; select, 'Effective Beam Energy' and 'Dose' from the View\Beam characteristics menu.

Select General fine settings from the 'Procedure' tab; Select 'persist' on the 'Exposure' tab.

Select the appropriate soft tissue & bone for a finger examination (10mm ST, 2mm Bone) as additional filter materials.

Choose an exposure for a finger (kV, mAs, etc.). Set SID to 100cm and Patient thickness as 0cm on the 'procedure' tab. Aim to get a system dose of 10uGy.

Look at the different lines in figure 2. Alter your exposure using kV, mAs, Filtration, SID, etc. (you can choose quite unusual materials) to match the beam spectrum to the first receptor type (gadoliniumOS). Write the resulting kV, mA, etc, in Table 11. and repeat for each receptor type.

Complete Table 11.

Detector	Peak attenuation (keV)	Attenuation above 20% (keV)	Range	kV, mAs	Filtration (mm, material)	Eff Beam Energy (keV)	System Dose (μ Gy)
GadoliniumOS	52	50-60	10				App. 10
CsI	38	35-55	20				App. 10
aSe	20	20-35	15				App. 10
BFIBr	40	40-55	15				App. 10

Table 11. Identifying optimum photon energies for various detectors.

Some of these exposure settings look quite odd for a finger! What is the actual incident dose to the patient?

To find this out, remove the ‘finger’ additional filtration (Soft Tissue and Bone), and increase patient thickness to 2cm. The new Dose figure will be the Incident dose on the patient’s finger – this is similar to the Entrance Surface Dose.

Repeat the exposure settings in Table 11. and complete Table 12.

Detector	kV, mAs	Filtration (mm, material)	Eff Beam Energy (keV)	System Dose (μ Gy)	Incident Dose (μ Gy)
Gadolinium				App. 10	
CsI				App. 10	
aSe				App. 10	
BFIBr				App. 10	

Table 12. Incident doses for different spectra

IT IS IMPORTANT NOT TO CHANGE EXPOURE FACTORS FROM PROTOCOLS ESTABLISHED AT YOUR BASE HOSPITALS

Conclusion

In fact, all these receptors will produce an acceptable image with standard exposure factors, but the aSelenium detector will be the least optimised. Increased filtration is the most effective method of optimisation, followed by adjusting tube voltage. Any changes to protocols should be properly researched and involve radiographers, radiologists, medical physicists and the equipment manufacturers.

Further reading:

Honey, I., Mackenzie, A., and Evans, D.S., (2005) **Investigation of optimum energies for chest imaging using film–screen and computed radiography** British Journal of Radiology, Volume 78, Number 929, pp. 422-427(6)

Nobuhiro, O., Hajime, N., Seiichi, M., Kunihiro, T., Katsumi, N., and Akira, Y., (1996) **Optimal beam quality for chest radiography**. Investigative Radiology; Vol. 31:126–31.

Dobbins, J.T., Samei, E., Chotas, H.G., Warp, R.J., Baydush, A.H., Floyd, C.E., et al. (2003) **Chest radiography: optimisation of x-ray spectrum for caesium iodide – amorphous silicon flat panel detector**. Radiology; Vol. 226:221–30.

Asai, Y., Uemura, M., Matsumoto, M., and Kanamori, H., (2008) **Dependence of radiographic sensitivity of CR imaging plate on X-ray tube voltage** Radiology Physics and Technology (2008) 1:100–105

Worksheet 9 – Spectral Matching 2 (option)

Outcomes

At the end of the Lab, students will be able to:

25. Select Tube Voltage (kV) appropriate for detector technology
26. Consider appropriate filtration (CXR) for different detectors

ACTIVITY

Open TechnicVR. Go to the view menu and deselect 'hide all'; select, 'Effective Beam Energy' and 'Dose' from the View\Beam characteristics menu. Select General Chest PA from the 'Procedure' tab; Select 'persist' on the 'Exposure' tab. Select the appropriate soft tissue for a CXR examination (100mm soft tissue) and a grid (40lpcm 2mm thick) as additional filter materials.

Choose an exposure for a high kV chest (125kV, 14mAs, etc). Set SID to 180cm and Patient thickness as 0cm on the 'procedure' tab. Aim to get a system dose of 5uGy.

	Peak attenuation (keV)	Attenuation above 20% (keV)	kV, mAs	Filtration (mm, material)	Eff Beam Energy (keV)	System Dose (μ Gy)	Incident Dose (μ Gy)
BFIBr (GRID)	40	40-55	125, 14	3.2mmAl	67	App. 5	

Table 13. A comparison of incident dose using a standard exposure without spectral matching

Now change patient thickness to 30cm and remove the soft tissue and grid extra filtration. Complete Table 13 with the Incident Dose

Look again at the different lines in figure 2. Alter your exposure using kV, mAs, Filtration, SID, etc. (you can choose quite unusual materials) to match the beam spectrum to the first receptor type (gadoliniumOS). Write the resulting kV, mA, etc, in Table 14. and repeat for each receptor type, completing Table 13.

	Peak attenuation (keV)	Attenuation above 20% (keV)	kV, mAs	Filtration (mm, material)	Eff Beam Energy (keV)	System Dose (μGy)	Incident Dose (μGy)
GadoliniumOS (with GRID)	52	50-60				App. 5	
CsI	38	35-55				App. 5	
aSe	20	20-35				App. 5	
BFIBr	40	40-55				App. 5	

Table 14. Identifying optimum photon energies for various detectors

Lab 7 – Specialist Requirements (Mammo)

Aims of Lab

- Comparing target materials, and their effect on the x-ray spectrum.

Worksheet 10 – Mammography

Outcomes

At the end of the Lab, students will be able to:

27. Name three different target materials
28. Apply knowledge of the spectrum to choose target material

ACTIVITY

Open TechnicVR. Go to the view menu and deselect 'hide all'; select, 'Effective Beam Energy', 'Penetration', 'Output' and 'Dose' from the View\Beam characteristics menu.

Select Mammo - Craniocaudal from the 'Procedure' tab; Select 'persist' on the 'Exposure' tab. Expose this. Complete line one of table 15. For the second exposure select Mammo – Mediolateral from the 'Procedure' tab; this simulates a large breast examination. It is possible on some mammography units to change the target track material (dual track tubes). Rhodium offers a slightly higher energy spectrum, and this can be used. Change the target material and the filtration material to rhodium. And complete line 2 of table 15.

For comparison select lateral lumbar spine (from the 'Procedure' tab) using a tungsten target and expose this; complete the final line of table 15.

	Tube Voltage (kV)	Tube Charge (mAs)	SSD (cm)	Filtration (mm, material)	Eff. Beam Energy (keV)	% Pen	Output (μGy/mAs)	Incident Dose (μGy)
Mammo - Craniocaudal	28	71	61	0.01mmMo				
Mammo – Mediolateral (Large)	28	160	57	0.01mmRh				
L.Spine Lateral	75	50	50	3.2mmAl				

Table 15. Identifying optimum photon energies for various detectors.

1. Which has the highest Incident Dose? Mammo (large) or L spine lateral
2. Which beam is most penetrating? Mammo or L spine

Lab 9 – Specialist Requirements (Fluoro)

Aims of Lab

- Identifying issues with high frame rate angiography
 - Dosimetry
 - Tube heating

Worksheet 11 – Fluoroscopy

Outcomes

At the end of the Lab, students will be able to:

29. Quantify the incident doses in cardiac angiography
30. Consider the heat capacity requirements of interventional units

Cardiac Angiography

Open TechnicVR. Go to the view menu and deselect 'hide all'; select 'Dose rate' from the View\Beam characteristics menu. Make the Dose Area Product (DAP) visible.

You are using a single plane cardiac angio unit to image a coronary artery study; select this from the 'Procedure' tab. Set the exposure factors for fluoroscopy in the table. Set pulsed fluoroscopy at 25 (30) fps. Fluoroscopy is used to position the catheter and guide-wire prior to diagnostic image acquisition.

Hit the expose button and count out 10 seconds of cumulative exposure time, watch the focal track heat dial in the right hand panel and record temperature after 10 seconds. Fill in some of Table 16.

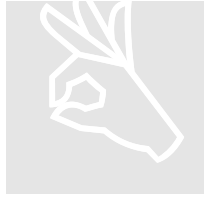
Exposure type	Cum. exposure time (s)	kVp	mA	Incident Dose rate (uGy/s)	Anode track Temp (after 10s) (C°)	DAP (after 10s) (cGy cm ²)
Fluoroscopy	10	70	28			
Fluorography	10	70	630			

Table 16. Comparison of target heating with different design.

Select fluorography, this is higher dose and better image quality for archival and review to make diagnosis.

Hit the expose button and count out 10 seconds of cumulative exposure time, watch the focal track heat dial and roughly estimate the peak temperature and complete Table 14.

1. Which is higher Dose? Fluoroscopy/Fluorography



Would it be worth spending more on a rotating anode machine for spinal work?

YES/NO (circle right answer)

Why?

Further Reading

Wagner, L., Archer, B., and Cohen, A., (2003) **Management of Patient Skin Dose in Fluoroscopically Guided Interventional Procedures.** Journal of Vascular and Interventional Radiology , Volume 11 , Issue 1 , Pages 25 - 33

Physical principles 4

This chapter contains 3 Labs that introduce students to Quality assurance and care of the equipment they use day to day.

Lab 10 – Tube Ratings Charts

Aims of Lab

- Understanding the limitations to exposure factors from some equipment.
- Consider equipment specification and workload

Lab 11 – Preserving Tube Life

Aims of Lab

- Introducing tube warm up sequences.
- Instil a duty of care on the radiographer

Lab 12 - QA testing and the causes of variation

Aims of Lab

- Show how variation in tube output can be caused over time
- Identify the need for QA procedures and frequent testing

Lab 10 – Tube Ratings Charts

Aims of Lab

- Understanding the limitations to exposure factors from some equipment.
- Consider equipment specification and workload

Worksheet 12 – Tube Ratings Charts

Outcomes

At the end of the Lab, students will be able to:

31. Identify the three types of tube ratings
32. Set exposure factors within the ratings
33. Select equipment capable of the exposure required

The Mobile Abdomen

Open TechnicVR. Go to the view menu and deselect 'hide all', select 'Output', 'Dose' and '%Penetration' from the view menu.

Select '3 knob' control from the 'Equipment' tab. Set the mA to 100 (at least one popular mobile machine has the mA fixed at 100). Select the exposure factors in Table 17 and complete line 1. Select the general unit and repeat the exposure at 800mA. Complete line 2.

Unit	exposure time (ms)	kVp	mA	% Pen.	Tube Output	Incident Dose
Mobile		80	100			
General		80	800			

Table 17. A comparison of exposure times.

1. Which unit produced the fastest exposure time? Mobile or General

Set any SINGLE exposure you like

2. Can you manage to overheat the anode track or disc? Yes/No

Repeatedly expose the tube to this maximum exposure

3. Will this lead to overheating of the anode track or disc? Yes/No

Repeat the exposure on a general unit

4. Is it easier or harder to overload? Easier/Harder.

The difference between these two units is the speed of anode rotation. The mobile conserves battery power by spinning the anode at only 3000 rpm. The general room can spin the anode at nearly 9000 rpm (the actual value is displayed on the 'Exposure' tab).

There are two possible limitations to maximum power applied to the anode; the focal track temperature and the whole housing temperature. The focal track radiates most of its heat, and the hotter it becomes the quicker it cools. The housing has to convect and conduct its heat away in oil and air. It does not get that much more efficient as it gets hotter. The unit can be limited by the housing heating, when the anode track is not at maximum. There will be a time limit until a new exposure is allowed.

Worksheet 13 – Tube Ratings Charts 2

Outcomes

At the end of the Lab, students will be able to:

34. Identify the three types of tube ratings
35. Set exposure factors within the ratings
36. Select equipment capable of the exposure required

ACTIVITY

Open TechnicVR.

Select the General Unit – fine settings from the ‘Procedure’ tab. Select ‘3 knob’ control from the ‘Equipment’ tab. Set the mA to 800.

Set 50kV and 1mAs – will the unit allow this? Yes/No

1. What is the limiting factor? Anode Heat/Power/Filament current
2. What is the highest mA allowed? To achieve 50kV and 1mAs

Try the same experiment with the Angio Tube. Set 50kV and 1mAs with 800mA.

Select the Mammo Unit. Select 3 knob control.

3. In what circumstances can an exposure be made at 100mA?

The limitation identified here has nothing to do with anode target heat or housing heat, it is called ‘filament ratings’. The filament is heated to boil off electrons. If the kV is not sufficient to move the electrons from the filament, they will form a –ve charged cloud around the filament which will prevent more electrons being boiled off. The filament reaches its maximum temperature and this then limits the mA. It is called the space charge effect.

Lab 11 – Preserving Tube Life

Aims of Lab

- Introducing tube warm up sequences.
- Instil a duty of care on the radiographer

Worksheet 13 – Tube Warm Up

Outcomes

At the end of the Lab, students will be able to:

37. competently select safe exposures on a cold x-ray tube

ACTIVITY

“If the selected x-ray exposure technique will require a high mA (400 or higher), and the x-ray machine has not been used within the last two hours, then a tube warm-up procedure should be performed to prolong tube life. If the users manual does not have recommended warm-up techniques, use a low mA (50 for the small focal spot or 100 for the large), low kVp (60-70) and a long exposure time (2 seconds). This procedure will heat the anode uniformly so that higher subsequent exposures will not damage it.”

Open TechnicVR. Select General from the ‘Procedure’ tab. Follow the instructions above.

1. Is this effective in warming the anode? Yes/No

Now try “70, 200mA for 2 seconds, then wait 10 seconds and repeat.”

2. Is this effective in warming the anode? Yes/No

Now try “80kV, 200mA, 1 second, wait 3 seconds and repeat, wait another 3 seconds then repeat” Seeram, 2001:60

3. Is this effective in warming the anode? Yes/No

Which of these 3 are most effective?

Some tips for enhancing tube life...

Minimize filament boost (“prep”) time

Boost time will usually exceed the actual exposure time. High filament current applied for too long will shorten filament life and will lead to unstable operation as evaporated tungsten from the filament is deposited onto the glass envelope. This is especially the case at high mA stations.

Limit rotor start/stop operations

Rotor start/stop operations especially to/from high speed (150/180 Hz) generate considerable heat in the stator windings, which will lead to stator damage in extreme cases. Generally there should be a minimum of 30 to 40 seconds between starts. Tubes equipped with a heat exchanger will be less sensitive to this potential problem because oil circulation will help prevent hot spots from occurring around the stator windings.

These two can be summarised as “be decisive”

Use lower tube current (mA)

The high filament current required to produce high tube current (mA) will shorten filament life and will lead to unstable operation as evaporated tungsten from the filament is deposited on to the glass envelope. Whenever possible, use a lower mA station and a longer exposure time to arrive at the desired mAs.

Limit operation to 80% of maximum single exposure ratings

Although higher power levels are both possible and permitted, this reduction will help assure long focal track life. Also, it will minimize the reduction in radiation output associated with a roughened focal track.

These two can be summarised as “work well within the units capabilities”

Do not make high mA exposures on a cold target

Uneven expansion caused by thermal stress from a high power exposure can result in a cracked target. Do not assume that a “thermally relieved” target design provides absolute protection. Always follow the recommended warm-up procedure. The procedure may need to be repeated between patients, if the “idle” time is long enough, in addition to being performed at the beginning of the work day.

Lab 12 - QA testing and the causes of variation

Aims of Lab

- Tube age and its effect on exposure factors.
- Identify the need for QA procedures and frequent testing

Worksheet 14 – Tube Age

Outcomes: At the end of the Lab, students will be able to:

38. Identify reasons that exposure factors should be reviewed regularly
39. Quantify the effect of tube age on exposure factor selection

ACTIVITY

Scenario 1 - 15 year old general x-ray room. The radiation output repeatability has been consistently good throughout its life (it is a medium frequency generator, microprocessor controlled.) The following table shows the baseline values for radiation output for this machine on commissioning. The remedial action level for this test is $\pm 20\%$ and the suspension level is $\pm 50\%$. (IPEM, 2005) and the minimum output should be $50 \mu\text{Gy}/\text{mAs}$ at 80kV with 2.5mmAl (European Commission, 1997)

Open TechnicVR. Go to the view menu and deselect 'hide all', select 'Output', 'Dose', 'HVL1' and '%Penetration' from the view menu.

Select General Room – Fine settings and set an exposure for an AP Supine Abdomen (80kV and 25mAs @ 100cm SID; patient thickness set to 20 with 7cm added for bucky to table top)

Set the tube age to 0% - and expose on a new tube. Complete Table 18. for all Tube ages.

Unit	kVp	mAs	% Pen.	HVL1	Tube Output (@75cm)	% Dif. from Baseline	Incident Dose
New unit (Baseline)	80	25					
5 year old (25%)	80	25					
10 year old (50%)	80	25					
15 year old (75%)	80	25					

Table 18. A comparison of tube output and age

1. At what point does the unit require remedial action? 5 years/10 years/15years?
2. What would that remedial action be?
Change exposure factors/remove aluminium filtration/other

Further Reading

European Commission (1997) **Criteria for acceptability of radiological (including radiotherapy) and nuclear medicine installations**. Radiation Protection 91. [Online]

Institute of Physics and Engineering in Medicine (2005) Recommended Standards for the Routine Performance Testing of Diagnostic X-ray Imaging Systems, IPEM Report 91., York: