TG 108 WORKSHOP PART 2 | 20 MARCH 2023 | 12:00-15:00 (GMT)

OPTIMISATION OF RADIOLOGICAL PROTECTION IN DIGITAL RADIOLOGY TECHNIQUES FOR MEDICAL IMAGING

ICRP Digital Events

Radiography

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IMAGEM MÉDICA E RADIOTERAPIA
COIMBRA HEALTH SCHOOL

WHO Collaborating Centre for Radiation Protection and Health

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- The digital radiography system
- Optimisation of exposure factors and radiation quality
- Other aspects of optimisation
- Factors to consider in optimisation
- Image post processing
- Optimisation of the imaging workflow
- Basic quality assurance (QA)
- Approaches to Optimisation

Digital radiography systems

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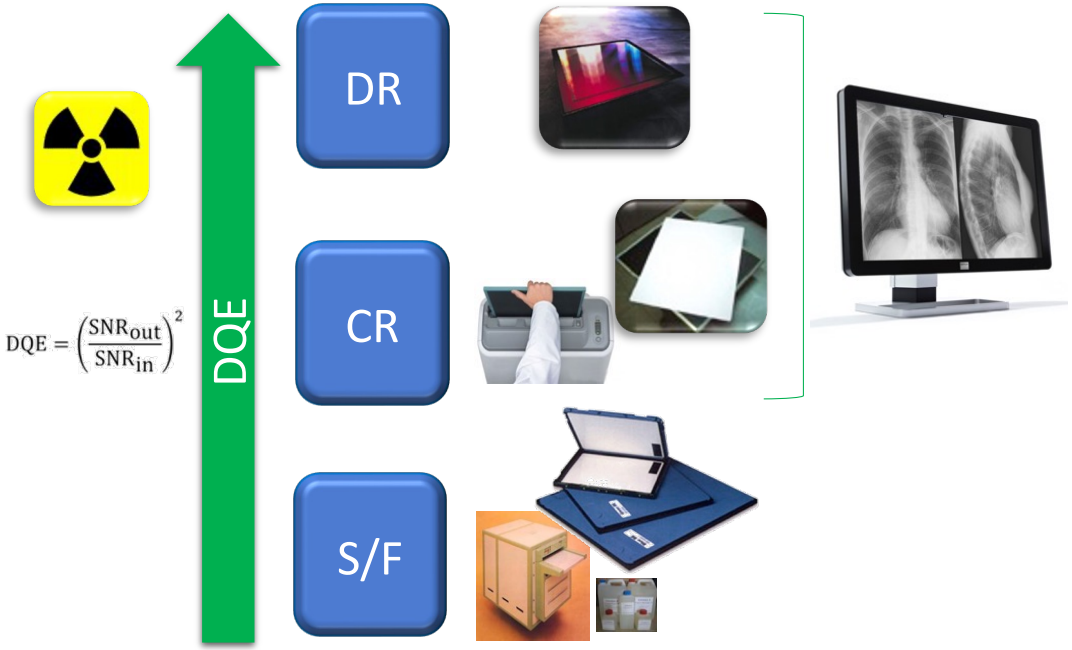
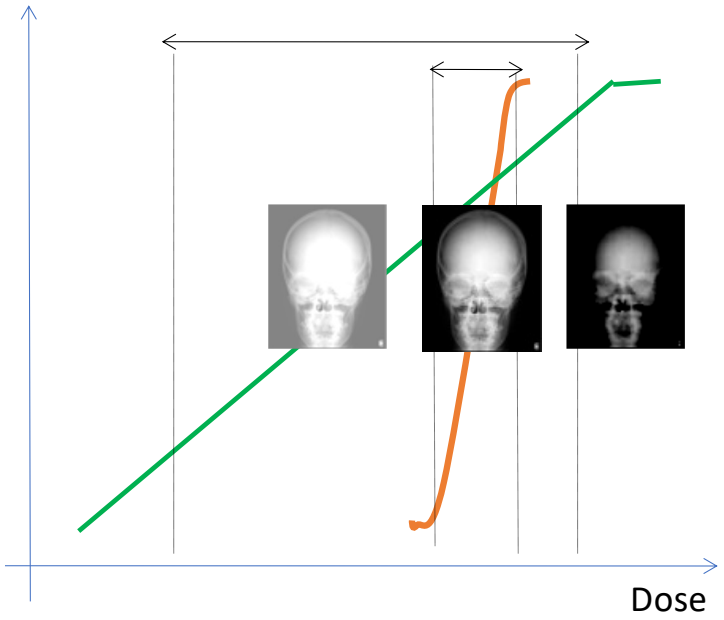
Radiography

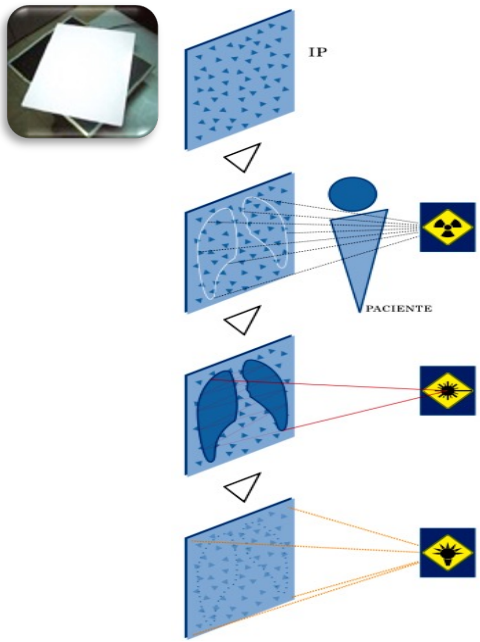
- Most frequent examination





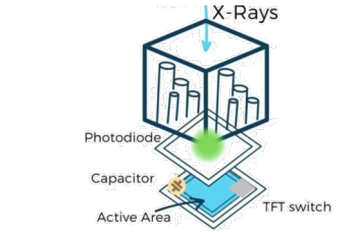
Digital Radiography

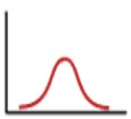
CR



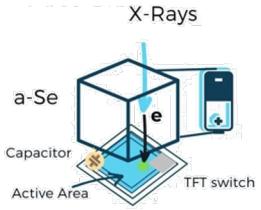
DR

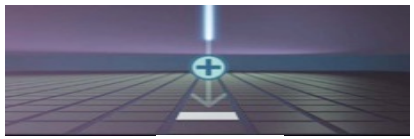
IDR Indirect X-ray capture digital radiography

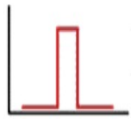




DDR Direct x-ray capture digital radiography







Optimisation of exposure factors and radiation quality

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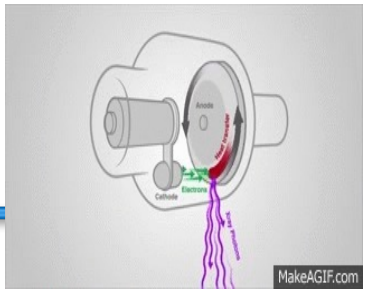
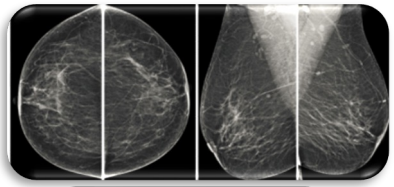
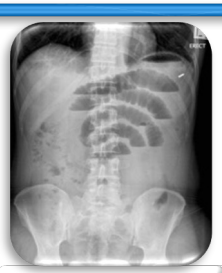
Exposure parameters optimisation



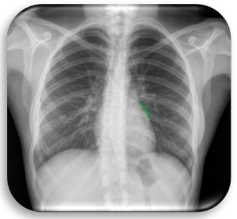


mamography



Trunk

Trunk

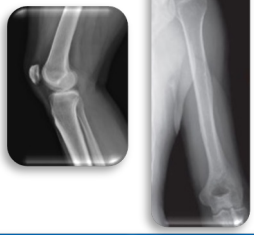


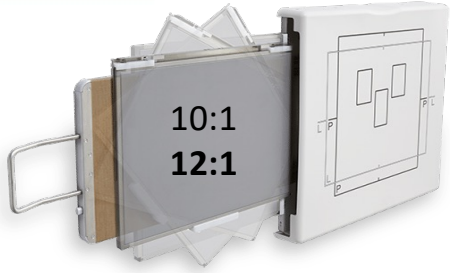
Chest

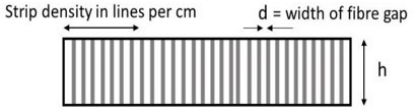
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145

Tube voltage (kV)

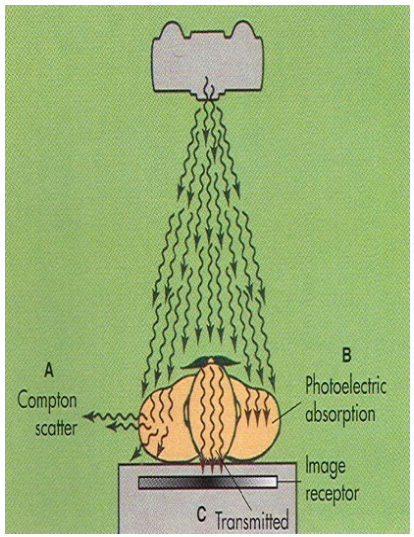
Extre



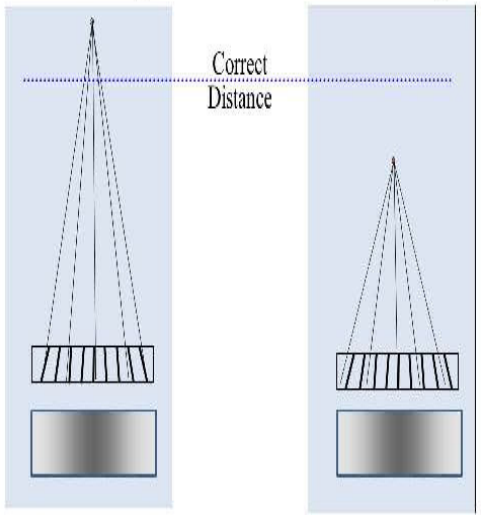




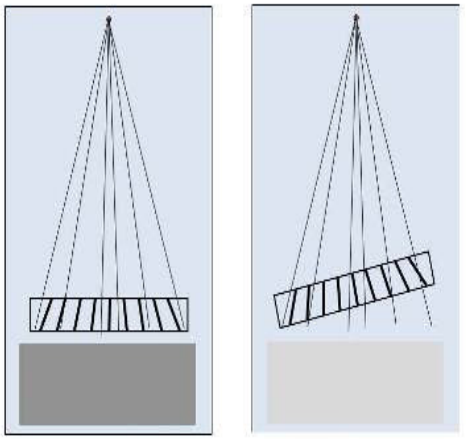
Grid



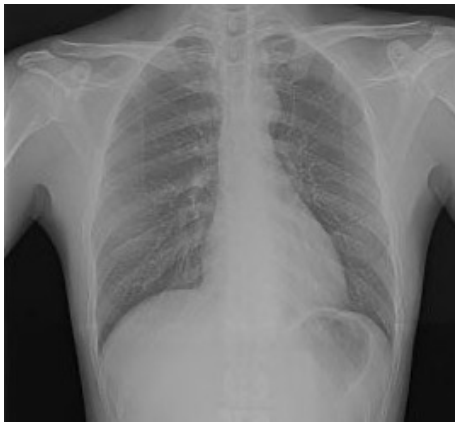
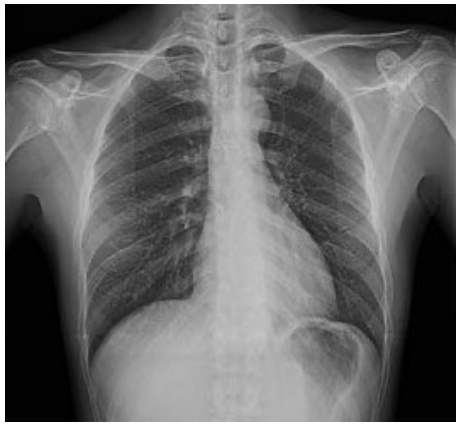
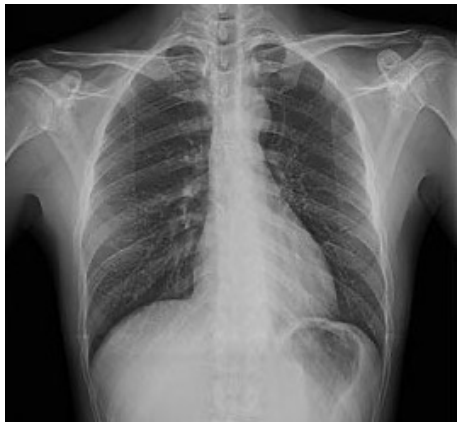
Source to Image Distance



Centering

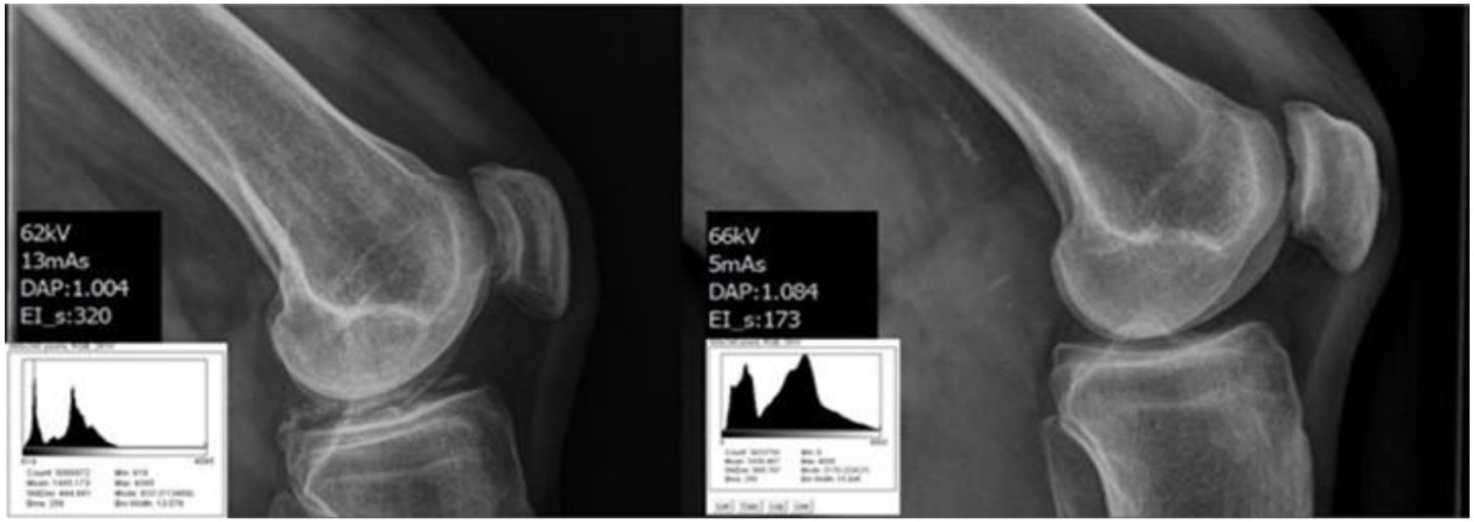


Grid

No grid	Virtual grid	Real grid
		



Grid

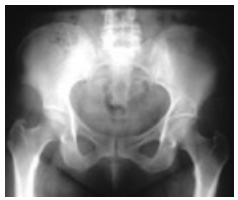


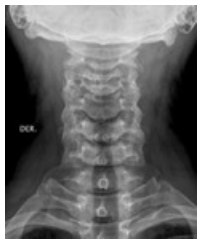
a b

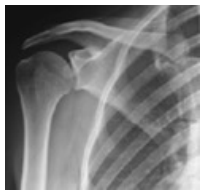
Fig. 2.5. Comparison of images of two patient knees obtained a) with an actual grid and b) with virtual grid software (Philips –Skyflow). Both radiographs show high image quality (Dean Pekarovic, University Medical Centre Ljubljana, Slovenia).

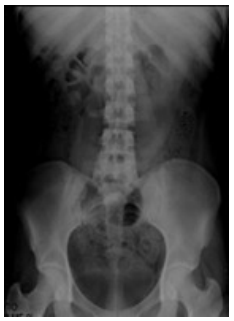
Automatic Exposure control (AEC)

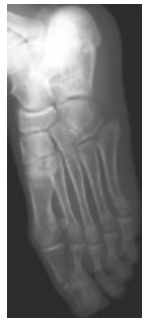
Proper patient positioning

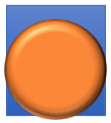






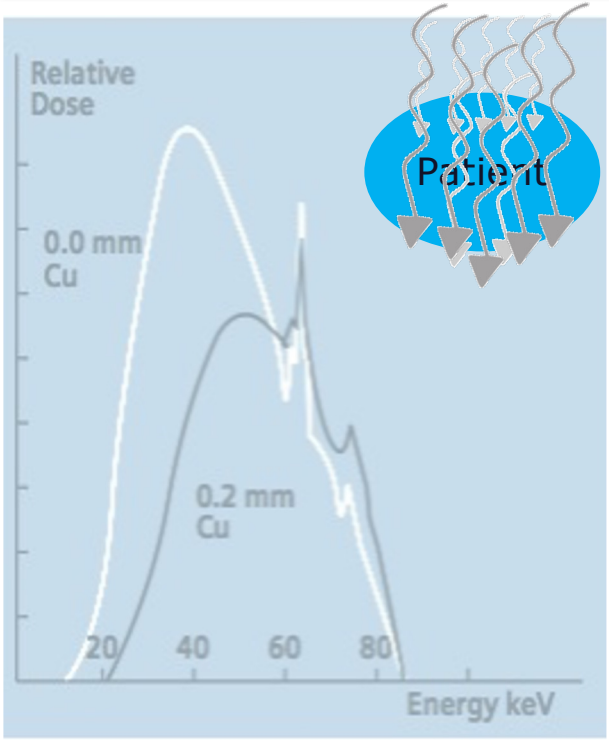


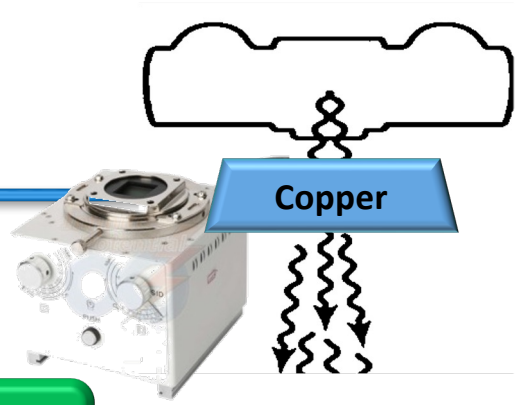




IC need to be calibrated according to the image receptor

Additional metal filters

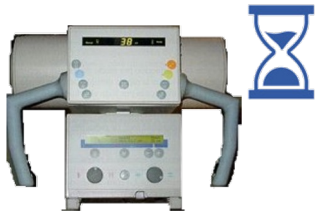




Use of additional copper filtration reduce the ESAK and KAP in DR

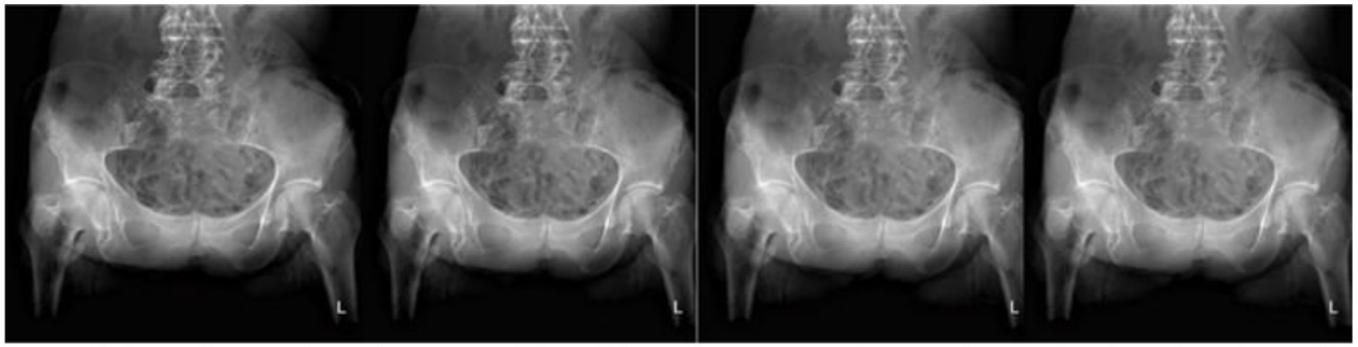
mAs must be increased to maintain same level of quantum noise

0.1 Cu	> 15-20%
0.2 Cu	> 20-30%



Additional metal filters

0 mm Cu	0.1 mm Cu	0.2 mm Cu	0.3 mm Cu
34 cGy cm^2	22 cGy cm^2	14 cGy cm^2	11 cGy cm^2



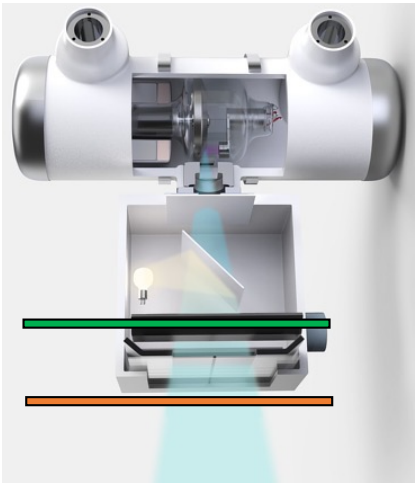
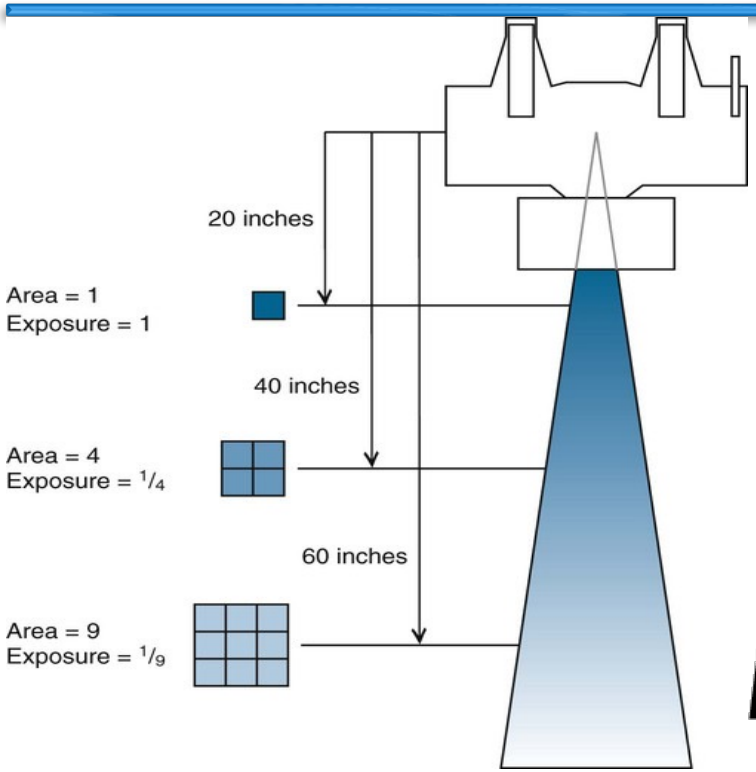
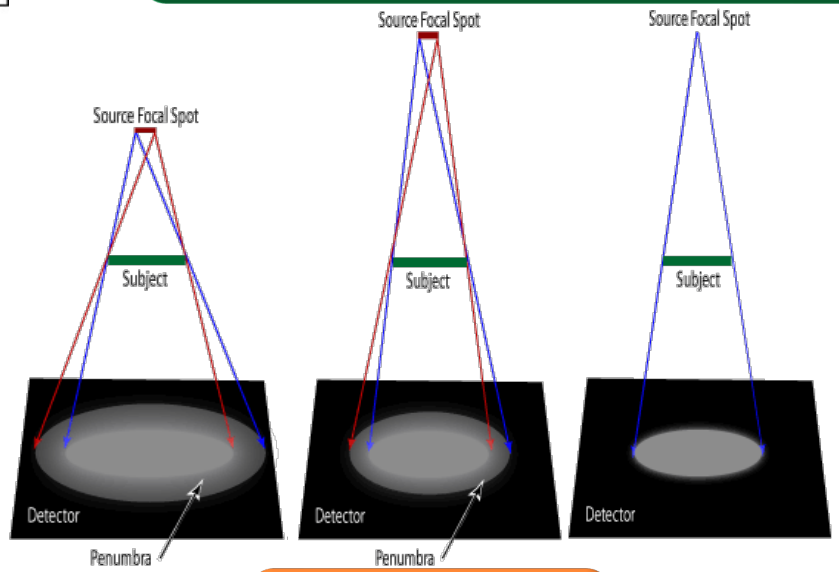


Fig. Pelvic radiographs taken at 81 kV with a Siemens Axiom Aristos FX showing the effect of additional copper filters. Exposures from left to right were taken with the following thicknesses of copper 0 mm, 0.1 mm, 0.2 mm, and 0.3 mm, and KAP values are 34 cGy cm^2, 22 cGy cm^2, 14 cGy cm^2, and 11 cGy cm^2, respectively (cadaver study- Dean Pekarovic, University Medical Centre Ljubljana, Slovenia).

SID and focal spot size



SID 110–115 cm decrease ESAK and detector dose in 20%



Inverse Square Law

Expose more tissues
Higher KAP
Less image quality

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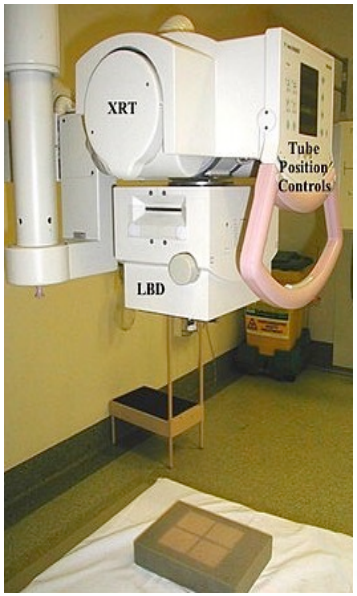
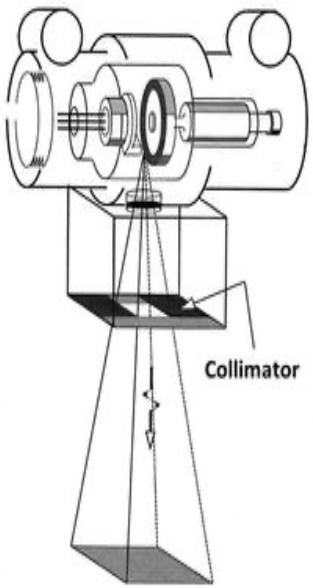
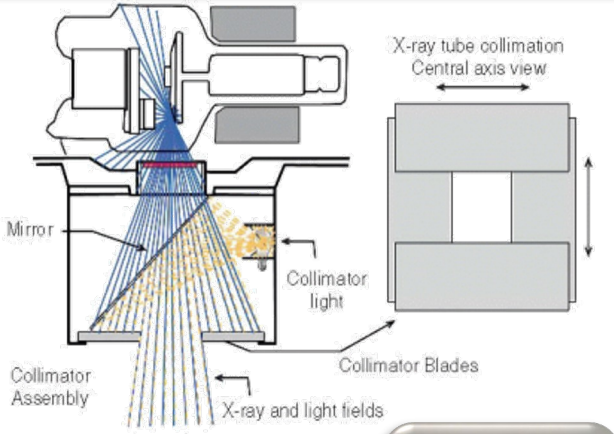
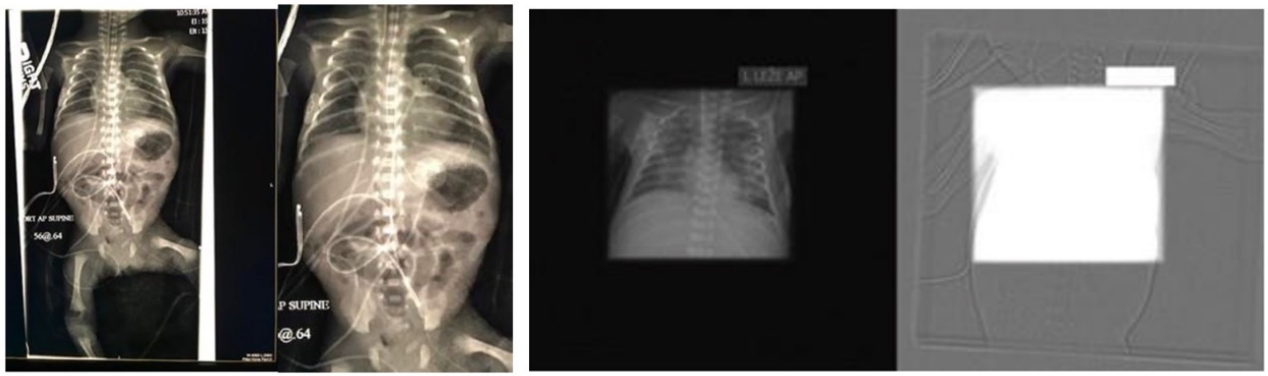
FOV and collimation







FOV and collimation



a b c d

Fig. 2.3. Issues in image collimation. 2.3a and b show a portable babygram in a neo-natal intensive care unit to determine umbilical vein catheter placement position; a) The original image which is poorly collimated, and b) image with the appropriate collimation (Kimberly Applegate, USA). 2.3c and d exemplify very poor practice. They show an ostensibly collimated image which is in fact cropped. C shows the image with a normal window width and level, whilst d shows the image with an adjusted window width and level, demonstrating the actual radiograph as exposed. Images of this type can be used for auditing poor collimation practice where this is an issue (Dean Pekarovic, University Medical Centre Ljubljana, Slovenia).

Table 2.1. Exposure factors and expected dose levels for a range of imaging tasks.

Anatomy	Projection	kV	Grid	Additional filtration (mm Cu)	ESAK* (mGy)	KAP* (Gy cm^2)
Chest	PA	120–140	Yes		0.05–0.2	0.06–0.1
Chest	PA	75–85	No		0.3–0.5	0.06–0.1
Lumbar spine	AP	75–90	Yes		2–6	0.7–1.5
Lumbar spine	lateral	80–95	Yes		5–10	1.4–2.5
Abdomen	AP	75–90	Yes		2.5–5	1.4–2.5
Pelvis	AP	75–90	Yes		2–4	1.3–2.2
New-born <5 kg	AP/PA	56–65	No	0.1–0.2	0.03–0.07	0.003–0.015
Infant 5-15 kg chest (4 m–3 y)	AP/PA	60–80	No	0.1–0.2	0.04–0.08	0.005–0.022
Infant 5–15 kg abdomen pelvis (4 m–3 y)	AP	60–80	No	0.1–0.2	0.3–0.6	0.05–0.15
Child 15-30 kg chest (4 y–10 y)	AP/PA	70–85	No	0.1–0.2	0.06–0.12	0.008–0.05
Child 15–30 kg abdomen pelvis (4 y–10 y)	AP	70–80	Yes	0.1–0.2	0.5–1.5	0.15–0.25

*Dose quantities represent a range of average values (1st and 3rd quartile values in a dose survey) and the adult ones are for a 70 kg patient. If an indirect DR system with CsI is used, then values should be towards the lower end of the range or lower. PA – postero-anterior, AP - antero-posterior. Doses from improved modern systems may go below the values listed.

Exposure parameters must be adequated to:

- Detector type
- Anatomic region
- Patient size
- Clinical question

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Exposure indicators

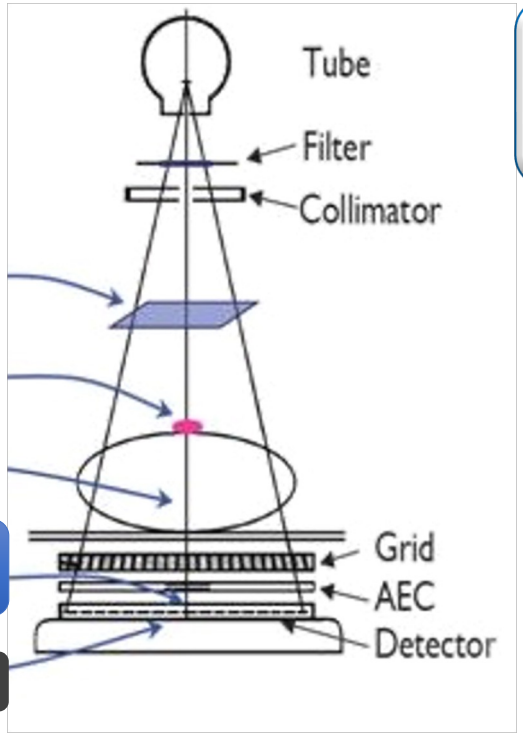
KAP

ESAK

Effective Dose

Detector exposure

EI



Exposure index (EI) is related to the air kerma in µGy at the IR in the anatomical region of interest within the image and so is a linear function of tube current.

$$DI = log_{10}\left(\frac{EI}{EI_T}\right)$$ → Target EI for a particular body part and task

Table 2.2. Recommended values of Deviation Index (DI) for determining acceptable imaging settings and required actions (AAPM, 2009)

DI	Action required
> +3	Excessive patient radiation exposure. Repeat only if relevant anatomy is clipped or "burned out". Require immediate quality assurance (QA) management follow-up
+1 – +3	Overexposure. Repeat only if relevant anatomy is clipped or "burned out".
−0.5 – +0.5	Target range
<−1	Underexposure. Consult Radiologist for possible repeat
<−3	Repeat (consider QA programme)

Dose and EI

Procedure	Number	KAP_average ($\mu Gy.m^2$)	KAP_median ($\mu Gy.m^2$)	DRL ($\mu Gy.m^2$)	KAP_med/DRL	EI_average
T084 Pelvis AP	238	44.7	39.4	200	0.20	340
T084 Pelvis AP	188	48.1	42.6	200	0.21	322
T026a Lumbar-spine AP	171	43.6	35.4	130	0.27	327
W019a Cervical-spine AP	147	7.04	6.0	30	0.20	269
T090a Hip AP	137	25.5	24.0	95	0.25	312
W019b Cervical-spine Lat	131	6.25	5.7	35	0.16	326
W050 Shoulder joint AP	131	8.7	7.6	30	0.25	387
L026b Lumbar-spine Lat	130	187	155	230	0.68	360
L026b Lumbar-spine Lat	124	163	150	230	0.65	395
T026a Lumbar-spine AP	106	56.1	47.7	130	0.37	321

Fig. 2.2. A spreadsheet chart used for monitoring KAP and EI values for selected radiographic examinations. The exposure index target value (EI_T) was set at 250, but could be modified by the user for each projection. (Urban Zdešar, University Medical Centre Ljubljana, Slovenia, reproduced with permission).

Patient shielding

Table 2.3. Recommendations for patient shielding in diagnostic radiology (Hiles et al, 2020, 2021)

Scenario	Recommendation	Comments
Patient contact shielding for protection of breast	Not recommended	Use PA positioning rather than shielding for spinal and chest examinations where possible. If using AP projection then a Scoliosis shawl may be considered.
Patient contact shielding for protection of thyroid	Not generally recommended	May be used for paediatric patients in cephalometric radiography if evaluation of the cervical spine is not needed or obscured. The effectiveness of shielding outside the FOV is minimal and potential interference of the shield with the AEC must be avoided.
Patient contact shielding for protection of gonads	Not recommended	Male adult and paediatric patients: May be considered where gonads are less than 5 cm from the primary beam. Female adult and paediatric patients: Not recommended for imaging in the pelvic region.
Patient contact shielding for protection of eye lens	Not recommended	Use PA skull positioning, no recommendations for shielding.
Pregnant patients	Not recommended	For examinations within pelvic region (from diaphragm to knee), consider non-ionising imaging alternatives. If ionising radiation must be used carry out a thorough justification and risk assessment process.

Factors to consider in optimisation

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Factors to consider in optimisation

Table 2.4. Actions that can affect patient dose and image quality

Action	Effect on dose	Influence on image quality or diagnostic information
Increase mAs to reduce noise perception	Increase	Improvement in SNR
Increase mAs further to give significant reduction of noise (with detector saturation in some areas)	Increase	Deterioration, retakes
Use appropriate tube potential and establish correct radiographic techniques for digital systems	Decrease	May change appearance of image (optimisation)
Increase kV and reduce mAs to maintain same noise level	Decrease	Decrease in contrast (process of optimisation)
Inclusion of 0.1 mm or 0.2 mm copper filter in beam with increased mAs to maintain noise level	Decrease	Minimal effect, possible increase in exposure time
Implementation of dose and image quality indicators (KAP, EI, DI) on the console of x-ray system or PACS	Decrease	Potential improvement, potential decrease in retakes

Factors to consider in optimisation

Table 2.4. *(continued)*

Action	Effect on dose	Influence on image quality or diagnostic information
Reduction in number of images per procedure (e.g., avoiding the lumbosacral spine image)	Decrease	Remains unchanged
Increase source to detector distance	Decrease	Improve geometry
Increase in size of x-ray tube focus	Unchanged	Reduced spatial resolution, decrease in exposure time
Decrease in size of x-ray tube focus	Unchanged	Improved spatial resolution
Expose full DR image plate and crop image to required anatomy (poor practice)	Increase	Loss of contrast due to scatter from other tissues
AEC system not set up for correct image receptor type or calibration incorrect	Increase or decrease	Potential degradation
AEC system not used	Increase or decrease	Degradation, retakes
AEC chambers not checked regularly	Increase or decrease	Degradation, retakes
Use of CR storage-phosphor plates beyond the recommended lifetime	Increase	Loss of quality, retakes

Factors to consider in optimisation

Use of a grid with too high a grid ratio	Increase	Susceptibility to grid misalignment faults
Use of a grid with too low a line density	Possible decrease	Risk of aliasing artefacts
Use of virtual grid software	Reduce	Poorer image quality than using a grid
Deletion of image files at the viewing station or workstation of apparently non-useful images	Possible increase	Loss of information that might be useful in reject/retake analysis
Poorly adjusted / optimised diagnostic monitor (e.g., insufficient brightness, contrast, or resolution)	Possible increase	Loss of information, potential for repeats
Use of workstation with more facilities to visualise images (window, level, inversion, magnification)	Potential decrease	Obtain more information from the same image and decrease no. of repeats
Implementation of reject and retake analysis programme	Decrease	Possible improvement
Problems in postprocessing: hardware, network, etc. during archiving of images	Increase	Occasional loss of images or retakes
Loss of images in the network or the PACS due to improper identification or other reasons	Increase	Retakes
Use of incorrect post processing introducing false lesions or pathologies due to artefacts	Possible increase	Loss of information and need for retakes, potential misdiagnosis
Availability of workstation for post processing (and for radiographers) to avoid some retakes	Decrease	Improvement

Factors to consider in optimisation

Table 2.4. *(continued)*

Action	**Effect on dose**	**Influence on image quality or diagnostic information**
Allowing easy access to the PACS and teleradiology to look at previous images	Decrease	Improvement
Use of alternative post processing option, which can sometimes avoid repetitions.	Decrease	Improvement
Inability to post process images stored in the PACS, so that re-analysis of images is not possible	Potential increase	Potential need for retakes

Image post processing

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Image post processing

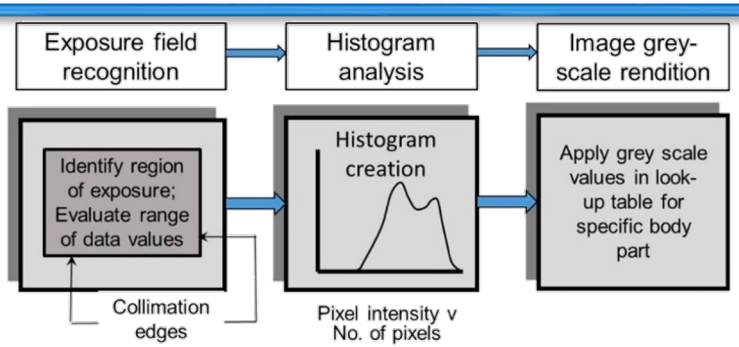
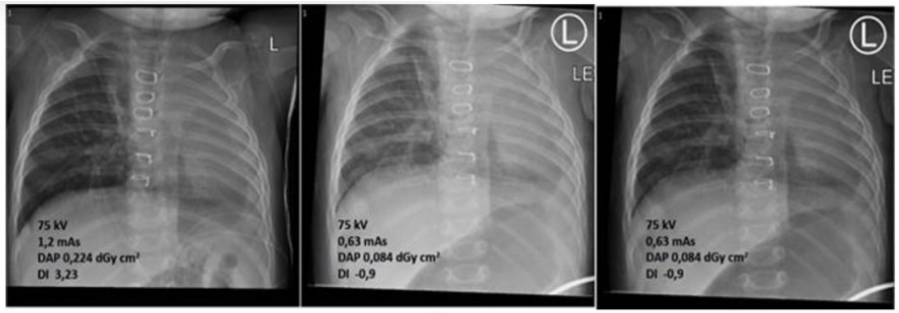
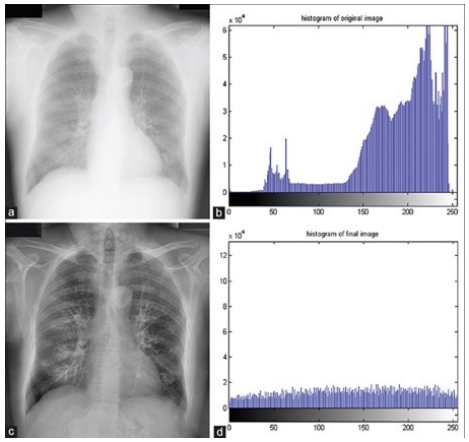


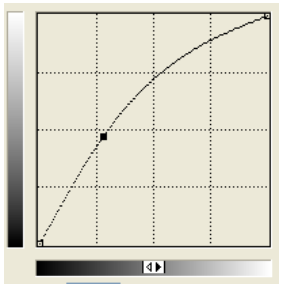
Fig. 2.6. The basic steps in processing of digital x-ray image (Colin Martin, University of Glasgow)



a b c

Fig. 2.7. Windowing adjustment example. Paediatric chest images in NICU (a) with a higher mAs dose, and b) with a lower mAs dose, and c) where windowing has been used to improve contrast of the lower dose image (Dean Pekarovic, University Medical Centre Ljubljana, Slovenia).





$$\frac{1}{16}\begin{bmatrix}1 & 2 & 1\\ 2 & 4 & 2\\ 1 & 2 & 1\end{bmatrix} \Rightarrow \begin{bmatrix}1/16 & 1/8 & 1/16\\ 1/8 & 1/4 & 1/8\\ 1/16 & 1/8 & 1/16\end{bmatrix}$$

Optimisation of the imaging workflow

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Examination

Prior to start

During

Immediately after

Complete

Box 2.4. Safety steps to image and verify for your patient (adapted from Image Gently)
Prior to Starting the Exam 1. Patient name selected from the worklist 2. Patient properly identified (two-point verification) 3. Appropriateness of request checked 4. Explained the exam to patient/parent 5. Verified Last Menstrual Period/pregnancy status if appropriate
Image Capture During the Exam 1. Beam body part image receptor aligned, SID checked, use of grid determined 2. Patient positioned and body part measured, cassette positioned (CR only) 3. Beam collimated 4. Technical factors selected 5. Shielding and markers placed 6. Final adjustment of tube and settings made 7. Breathing instructions given 8. Exposure taken
Image Critique Immediately After Exposure 1. Cassette transported to and processed in reader (CR only) 2. Images displayed and reviewed; identification confirmed 3. Image quality reviewed 4. Exposure indicator/index checked; deviation index compared to target exposure index 5. Image reprocessed or repeated as necessary
Following Completion of the Examination 1. Post-processing performed only if necessary 2. Exam verified and images archived to PACS for reporting

Basic Quality Assurance

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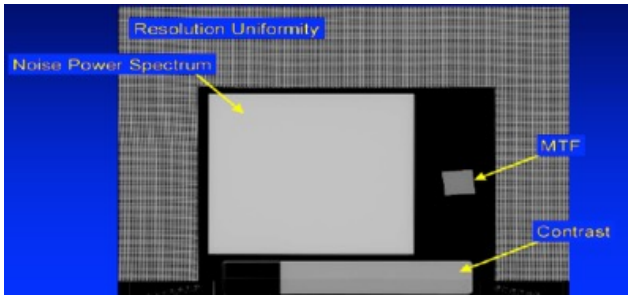
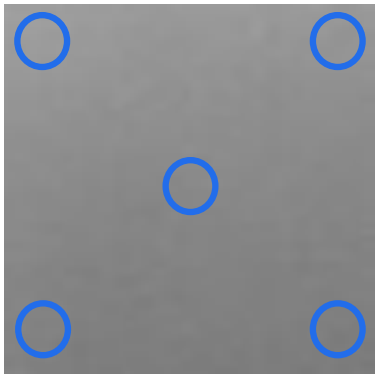
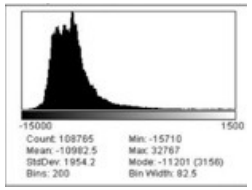
Example of detector tests



- Uniformity
- Special Resolution
- Contrast Noise Resolution
- Geometric acuity
- Artefacts

DICOM viewer





Mean and SD of pixel values
Analysis of EI

Approaches to optimisation

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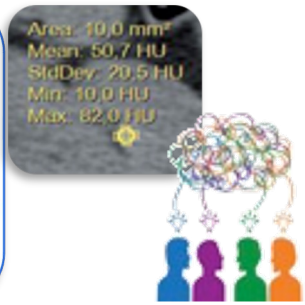
Levels of optimisation

Basic

Intermediate

Advanced



ICRP Digital Events

Box 2.5. Arrangements that should be in place for facilities at different levels of optimisation, together with aims that would be pursued.
C: Basic • Established protocols with appropriate tube potential and mAs settings for all common examinations • Perform regular QC/QA tests on all digital x-ray units and CR readers • Radiographers have received comprehensive training and receive further update training whenever new units or features are implemented
B: Intermediate • Radiographers have access to diagnostic quality workstations • Full range of protocols established based on specific clinical indications • Image quality / exposure levels in protocols identified as low, medium or high based on clinical indication • Exposure index values recommended for a wide range of examinations and monitored regularly. • Continual development of protocols through regular radiographer / radiologist / medical physicist communication • A quality management system is implemented to maintain performance levels • Reject and repeat analysis programme implemented
A: Advanced • Unified guidelines for clinical indication-specific examination protocols throughout organisation • Utilisation of dose monitoring system for an organisation wide on-line monitoring of patient exposures and analysis of exposure parameters for optimisation • Standard, objective and ongoing processes for evaluating optimisation undertaken with defined timelines • Development of objective and quantitative image quality metrics based on diagnostic image quality criteria. Establishment of more comprehensive and consistent optimisation based on this. • Use of anthropomorphic phantoms in optimisation. • Use of a generic approach, whereby the optimisation of exposure and post-processing parameters, and related exposure index values could be included in the commissioning of new equipment.

Conclusion

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Conclusion

- A review of the exposure parameters and their impact on examination dose and image quality in radiography;
- How to optimise considering the imaging workflow;
- Different levels of optimisation to promote a continuous cycle.

TG 108 WORKSHOP PART 2 | 20 MARCH 2023 | 12:00-15:00 (GMT)

OPTIMISATION OF RADIOLOGICAL PROTECTION IN DIGITAL RADIOLOGY TECHNIQUES FOR MEDICAL IMAGING

ICRP Digital Events

Thank you

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