



# Guidance on using shielding on patients for diagnostic radiology applications



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A joint report of the British Institute of Radiology (BIR), Institute of Physics and Engineering in Medicine (IPEM), Public Health England (PHE), Royal College of Radiologists (RCR), Society and College of Radiographers (SCoR) and the Society for Radiological Protection (SRP).

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Published March 2020

BIR Registered charity number 215869



## Contents

Executive summary	5
1. Introduction	6
1.1 Background	
1.2 Scope	
1.3 Aim	
2. General requirements for patient contact shielding	8
2.1 Radiation safety culture	
2.2 Context for applying shielding	
2.3 Medical device and product marking	
2.4 Recommendations for local practice	
3. Radiation dose and risk	12
3.1 Historical perspective	
3.2 Stochastic and hereditary risk	
3.3 Introduction to levels of risk	
3.4 Optimisation and applying the ALARP principle	
4. Sources of radiation exposure	21
4.1 Primary radiation	
4.2 Secondary radiation	
4.3 Summary	
5. Operator responsibilities	31
5.1 Overview	
5.2 Communication	
5.3 Consent	
5.4 Patient complaints and duty of candour	
5.5 Summary	
6. Clinical service requirements for patient shielding	38
6.1 Overview	
6.2 Priorities in imaging	
6.3 Training	
6.4 Continuing Professional Development (CPD)	
6.5 Procurement, storage and maintenance of patient contact shields	
6.6 Applying patient contact shielding	
6.7 Leadership	
6.8 Continuous Quality Improvement (CQI)	
6.9 Repeat exposures	
6.10 Summary	
7. Shielding in general radiography	45
7.1 Organs at risk	
7.2 The anatomy and concept behind shield application	

7.3	In-beam protection (Primary beam)	
7.4	Outside beam protection	
7.5	Influence of shielding on equipment function and image quality	
7.6	Special patient groups	
7.7	Recommendations for local practice	
8.	Shielding in diagnostic and interventional fluoroscopy	50
8.1	Organs at risk	
8.2	The anatomy and concept behind shield application	
8.3	Influence of shielding on equipment function	
8.4	Special patient groups	
8.5	Recommendations for local practice	
9.	Shielding in CT	54
9.1	Organs at risk	
9.2	The anatomy and concept behind shield application	
9.3	In-beam protection (Primary beam)	
9.4	Outside beam protection	
9.5	Influence of shielding on equipment function and image quality	
9.6	Special patient groups	
9.7	Recommendations for local practice	
10.	Shielding in mammography	78
10.1	The anatomy and concept behind shield application	
10.2	Influence of shielding on equipment function and image quality	
10.3	Special patient groups	
10.4	Recommendations for local practice	
11.	Shielding in dental radiography	80
11.1	Organs at risk	
11.2	The anatomy and ideas behind shield application	
11.3	In-beam protection (primary beam)	
11.4	Outside beam protection	
11.5	Influence of shielding on equipment function and image quality	
11.6	Special patient groups	
11.7	Recommendations for local practice	
12.	Glossary	86

## Executive summary

Over the last 70 years or so, it has been a common practice amongst radiological professionals to place radiation protective material directly on the surface of a patient during radiodiagnostic procedures to help reduce the dose to critical organs. This has led to the expectation amongst patients and professionals alike that this would continue. However, an increasing number of studies have raised concerns regarding the efficacy and effectiveness of such 'contact shielding'. This has led to an inconsistency in application and, in some cases, friction between patients demanding shielding and professionals judging it is unnecessary or even potentially harmful.

Therefore a working party consisting of representatives from various UK radiological professional bodies was established to consider the evidence-base for patient contact shielding and produce a consensus of opinion as to what constitutes best and agreed practice, with the aim of improving consistency in application of such shielding.

This work challenges the historical perspective that using contact shielding only provides a benefit for the patient. Rather it suggests that contact shielding can adversely interfere with the imaging (leading to a repeat test) and, if misplaced or allowed to move during an examination, can actually lead to increased patient radiation exposure, rather than the reverse. Overall, the findings suggest that contact shielding provides minimal or no benefit and professionals should concentrate on other areas of radiation protection which are more effective in optimising the patient radiation exposure.

The recommended cessation of the widespread practice of applying patient contact shielding requires a major cultural change in outlook regarding radiation safety and practice amongst medical professionals, educators, regulators and the public alike. The adoption of these guidelines into clinical practice will therefore also require a suitable education programme which could incorporate some of the material provided here.

## Chapter 1 Introduction

### 1.1 Background

The use of shielding, generally in the form of lead rubber, applied directly to patients has been practised for many years to reduce the dose to critical organs, notably the gonads. However, some studies have questioned the efficacy of using such shielding,<sup>1,2,3</sup> while others have highlighted the inconsistencies in application.<sup>4</sup> These self-same studies have called for national guidance to help reduce variations in approach. In addition, new designs, applications and materials for patient contact protection have appeared on the market.<sup>5</sup> Therefore a working party consisting of representatives from various UK radiological professional bodies was established to consider the evidence-base for patient shielding and produce a consensus of opinion as to what constitutes best and agreed practice, with the aim of improving consistency in application of such shielding.

### 1.2 Scope

This guidance is intended to cover radiation protection applied directly to patients undergoing diagnostic and interventional X-ray procedures within the healthcare sector, hereafter referred to as **patient contact shielding**. It does not include shielding built into the imaging equipment or in the room design and excludes ad hoc protection not actually placed on the patient (e.g. the use of shielding on incubators in neonatal intensive care units, as it does not touch the baby).

### 1.3 Aim

The aim of this document is to provide general guidance on why patient contact shielding may be required and when and where it might be used, with the intention of reducing confusion and improving consistency in practice across the UK. The number of X-ray procedures is vast, thus providing advice for each examination and individual projection would be problematic. Therefore the approach taken is to provide generalised reasons and evidence (where available) for why protection may or may not be applicable.

The overriding consideration throughout this guidance is the patient's needs, both in terms of risk reduction and reassurance. The guidance therefore starts by addressing what levels of risk might be involved, the place of shielding within an imaging task, and what sources of radiation require attenuating. The area of staff/patient interaction, including the patient's expectations and staff concerns regarding physically applying shielding to a person, is also addressed (see chapters 5 and 6). This is followed by several chapters describing how these issues relate to specific imaging modalities. These have been designed to be read by those

who may only be interested in an individual modality and so they intentionally include some repetition of text.

In order to provide a clear way forward, recommendations for local practice are provided at the end of each chapter, along with the relevant evidence (references).

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## Chapter 2 General requirements for patient contact shielding

### 2.1 Radiation safety culture

In the UK, the exposure of patients is governed by the Ionising Radiation (Medical Exposure) Regulations,<sup>1,2</sup> IR(ME)R. These regulations encapsulate the fundamental radiation safety principle of keeping patients doses '*as low as reasonably practicable*', or ALARP.<sup>3</sup>

In general terms this is achieved by:

- First, ensuring practitioners and operators are suitably trained, entitled and competent.
- Second, requiring each individual X-ray examination to be 'justified', meaning the benefits outweigh the risks of the exposure. Justification involves making sure the most appropriate examination takes place, including considering other imaging modalities which do not involve ionising radiation.
- Third, requiring the exposure to be 'optimised', to ensure that patient doses arising from the exposure are kept as low as reasonably practicable (ALARP) consistent with the intended purpose. This includes both exposure parameters and equipment maintenance.

In applying these principles to the area of patient protection it is important to recognise that optimisation of protection is not about minimising radiation dose, but rather balancing detriments and benefits.<sup>4</sup> It therefore involves managing the patient dose in line with the intended medical purpose. For example, applying protection to reduce the dose while increasing the risk of obscuring important diagnostic information is contrary to good medical practice and is not sound radiological protection.

### 2.2 Context for applying shielding

It is important that the application of patient contact shielding, if required, should only take place once all other dose reduction techniques (e.g. selection of exposure factors, collimation) have been applied.

It is often assumed that shielding always improves patient safety, but this is not necessarily the case. The use of shielding in diagnostic imaging should be guided by the supporting evidence and the focus should be on what is safest for the patient. This guidance aims to illustrate best practice and provides the scientific evidence to enable IR(ME)R<sup>1,2</sup> operators (e.g. radiographers, radiologists, dentists, radiology assistant practitioners) to communicate with patients and those who care for them to provide adequate information in order to reach agreement on the appropriate use of shielding. Every individual has a right to request or refuse shielding and should be supported to make their own decision.<sup>5</sup>



While any dose reduction is desirable, in the context of the low levels of dose from diagnostic radiology, other factors must be considered as strong influences on the decision to use or withhold shielding. These are considered throughout this document. For example: psychological factors such as whether it is a reassuring or alarming process to use a shield; accuracy of imaging relating to the proximity of the shield to the imaged area; and practical and comfort issues such as the position and weight of the shielding.

Appropriately trained staff with the knowledge and skills to listen as well as provide adequate information should facilitate all discussions around the use of patient contact shielding. Where appropriate, for example if the individual is particularly anxious or requires additional reassurance, operators should take time to explain the function of shielding as part of a multifactorial and overarching dose reduction strategy. The priority remains to achieve a suitable diagnostic image, where benefit outweighs risk. If the patient/individual chooses a course of action that might increase their risk in terms of radiation dose, it is the operator's responsibility to take action to prevent harm. Each decision to use shielding should be relevant to the individual circumstances.

### **2.3 Medical Device and product marking**

Patient contact shielding devices should be available, where appropriate, and may include proprietary gonad shields and aprons and various in-house modified lead-rubber shapes. If they are to be procured they require suitable marking (such as CE<sup>6</sup>) to indicate that the manufacturer has declared that these products conform to the relevant safety, health or environmental requirements. By this means the manufacturer is confirming that the product is suitable to be sold throughout the specified market. At the time of writing (February 2020), the UK and EU are negotiating product safety marking.<sup>7</sup>

Users should be aware that if an item is placed on the market with the intention of placing it on a patient to protect them from radiation then it is a medical device<sup>8</sup> and should be marked as such. This includes gonad, eye, thyroid and breast protective products. The manufacturer of such products will provide appropriate operating instructions, including details of the maintenance requirements and when it should be used<sup>9</sup>.

If, however, an item is placed on the market with the intention of using it for occupational protection and as a patient shield, then it is both a medical device and personal protective equipment (PPE).<sup>8</sup> This could include "half-aprons" and dental aprons. In such cases the product should be marked as a medical device. The manufacturer must also fulfil the relevant requirements for the production of personal protective equipment.

In the case of shielding designed in-house for a particular application then, provided it is not then transferred or sold as a product, it is not currently classed as a medical device with

regard to the legislation and controls<sup>8</sup>. It will apply from 26 May 2020 when the new device regulations apply in full.<sup>10,11</sup>

## 2.4 Recommendations for local practice

**The overall conclusion from the available evidence is that patient contact shielding is not generally required in diagnostic and interventional radiology.** The fundamental reason being to protect the patient, given that the use of patient contact shielding can often actually lead to an increase in patient dose (due to the need to repeat an examination or interference with automatic dose control systems). Even outside the primary radiation beam, efforts spent on correct positioning and optimising protocol parameters can lead to dose savings which are more significant than applying patient contact shielding. This overall conclusion is in line with the recent American Association of Physicists in Medicine position statement regarding gonad and fetal shielding.<sup>12</sup>

Few exceptions have been identified, but these may occur where a particular patient care pathway requires a number of repeat examinations where patient contact shielding may be applied, particularly in the case of paediatric patients.

The recommended cessation of the widespread practice of applying patient contact shielding requires a major cultural change in outlook regarding radiation safety and practice amongst medical professionals, educators, regulators and the public alike. The adoption of these guidelines into clinical practice will therefore also require a suitable education programme which could incorporate some of the material provided here.

Scenario	Recommendation	Comments
Patient contact shielding in diagnostic and interventional radiology	Not recommended	Anticipate very few specific situations where this does not apply.

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## Chapter 3 Radiation dose and risk

### 3.1 Historical perspective

Past practice in radiation protection has been based on the dose range and associated risk estimates prevalent at the time. However, the levels of dose and estimates of risk have changed over the years (e.g. since some operators qualified), requiring continuous revision of local practice in-line with current knowledge and advice. For example, in the UK the mean entrance surface dose for an AP pelvis radiograph (where gonad protection may be considered) dropped by a factor of 10 between 1900 and 1958<sup>1,2</sup> and then by a further factor of 6 by 2010<sup>3</sup>, see Figure 3.1.

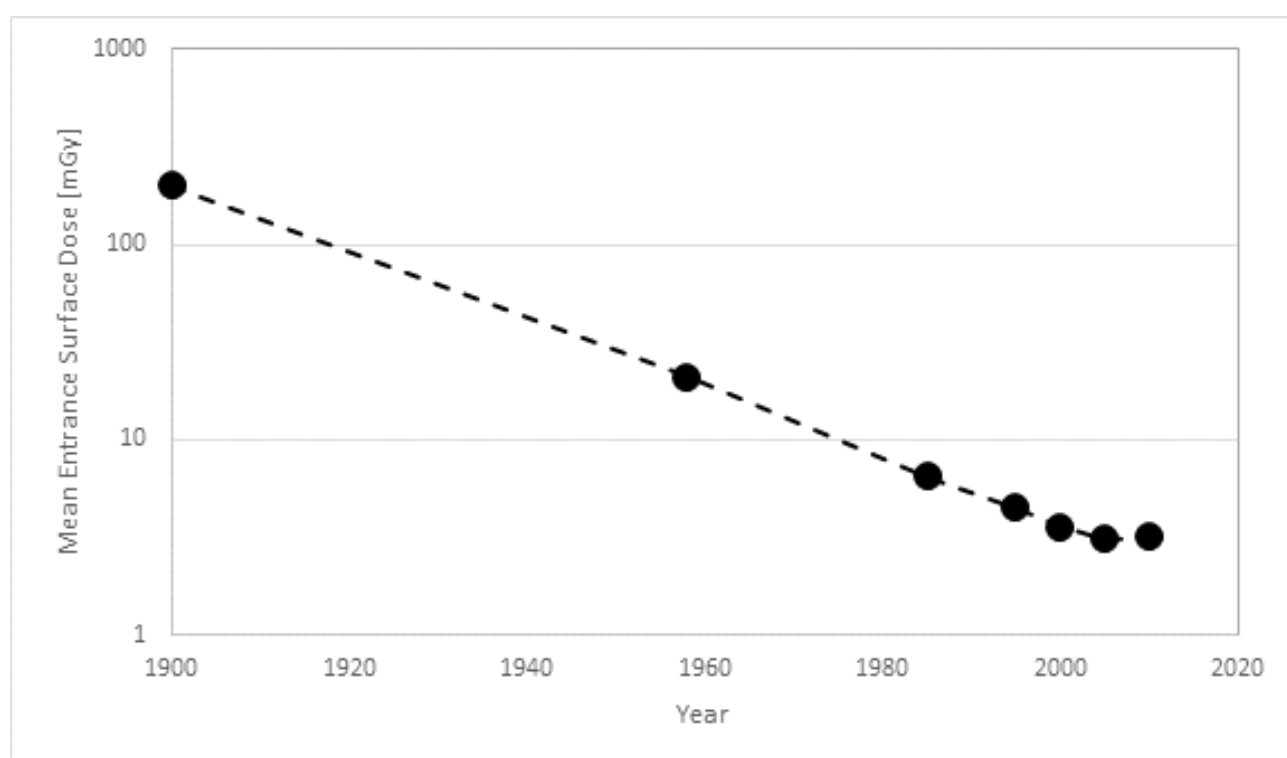


Figure 3.1 Example change in mean entrance surface dose values with time for an AP Pelvis radiograph. Based on doses reported in the literature.<sup>1,2,3</sup>

#### 3.1.1 Organs at risk (OAR)

Knowledge of the radiosensitivity of various tissues and organs has also changed with time as new information and evidence became available. For example, the tissue weighting factor ( $W_T$ ), is a relative measure of the risk of stochastic effects (see section 3.2) that might result from irradiation of that specific tissue. Table 3.1 summarises the tissue weighting factors recommended by the International Commission on Radiological Protection (ICRP) over a thirty year period.<sup>4,5,6</sup>

*Table 3.1 Changes in the International Commission on Radiological Protection (ICRP) recommended tissue weighting factors with tissue/organ and time*

Tissue or organ (in order of wT)	ICRP recommended tissue weighting factor (wT)		
	ICRP 26 (1977) <sup>4</sup>	ICRP 60 (1990) <sup>5</sup>	ICRP 103 (2007) <sup>6</sup>
Bone marrow (red)	0.12	0.12	0.12
Breast	0.15	0.05	0.12
Colon		0.12	0.12
Lung	0.12	0.12	0.12
Stomach		0.12	0.12
Gonads	0.25	0.20	0.08
Bladder		0.05	0.04
Liver		0.05	0.04
Oesophagus		0.05	0.04
Thyroid	0.03	0.05	0.04
Bone surface	0.03	0.01	0.01
Brain			0.01
Salivary glands			0.01
Skin		0.01	0.01
Sub Total	0.70	0.95	0.88
Remainder tissues*	0.30	0.05	0.12
Total	1.00	1.00	1.00

\* From ICRP 103<sup>6</sup>, remainder tissues are mean doses to adrenals, extrathoracic (ET) region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (male), small intestine, spleen, thymus, uterus/cervix (female)

Organs such as colon and stomach have been given specific weighting factors in recent years, but of particular importance for these guidelines are the significant changes in  $w_T$  for the gonads and breast tissue (see Figure 3.2). These figures would suggest that dose optimisation processes should concentrate on those organs with the highest  $w_T$  and much less on those with a low  $w_T$ , such as the gonads. The latest  $w_T$  figures in Table 3.1 suggest contributions from just five organs (bone marrow, breast, colon, lung and stomach) make up 60% of the total risk.

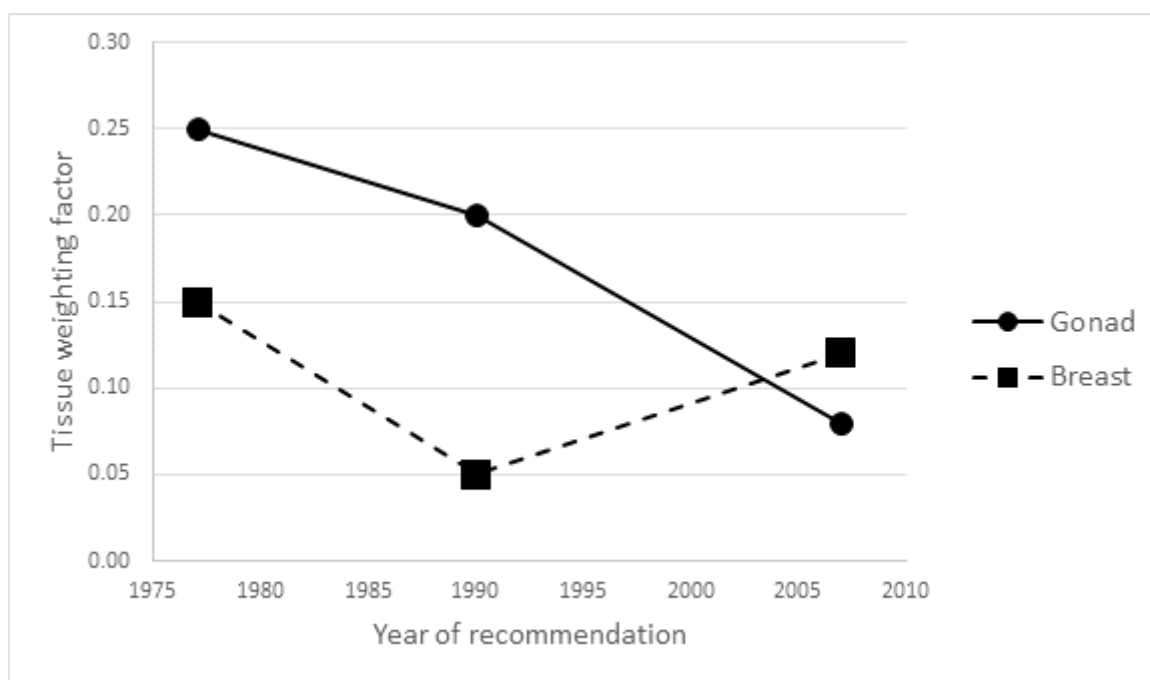


Figure 3.2 Tissue weighting factor versus year of recommendation by the ICRP for two particular tissue types.<sup>4, 5, 6</sup>

### 3.1.2 Heritable effects

Information on hereditary (or genetic) effects of radiation was developed almost entirely from animal experiments in the 1950s. This gave rise to considerable interest in measuring gonad doses (e.g. the *Committee on Radiological Hazards to Patients* set up in 1956 under the chairmanship of Lord Adrian<sup>2</sup>) and the introduction of gonad shielding methods during the next few decades. However, more recently genetic risk estimations in human populations have concluded that there is no direct evidence of a radiation associated excess of heritable disease.<sup>6</sup> This change in emphasis is illustrated in Figure 3.3 where the decrease in estimated genetic risk has led directly to the significant reduction in the tissue weighting factor for the gonads from 0.2 to 0.08 (see also Table 3.1).

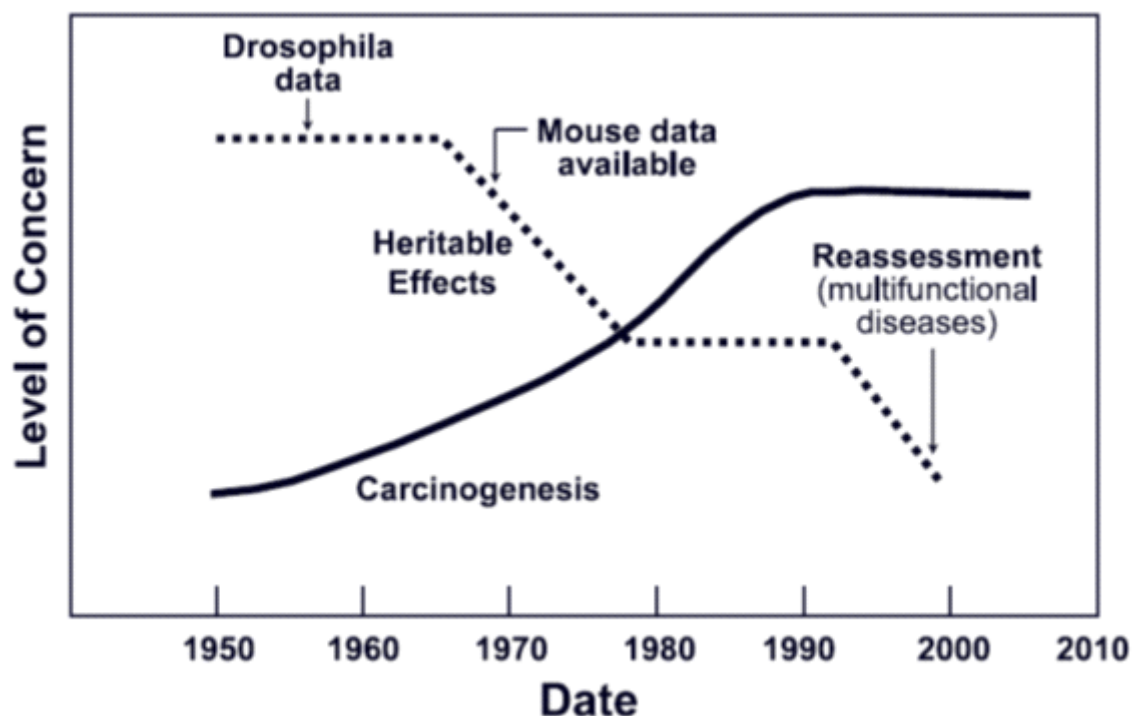


Figure 3.3. Illustrating how, over the past half century, the concern regarding exposure to ionising radiation has changed from heritable (genetic) effects to carcinogenesis. [Used with permission from Hall 2009.<sup>7</sup>]

The effects and risks from exposure to ionising radiation depend upon many factors, such as the absorbed dose, the dose rate, quality of radiation, specifics of the tissue irradiated and other factors such as the age and sex of the individual. The hereditary risks from irradiation that might result in effects to offspring of humans appear to be much lower than the stochastic effect of cancer induction and are now so low they are rarely considered. Therefore carcinogenesis is currently considered the most important stochastic effect at absorbed doses of less than 1 Gy. The risk of cancer induction varies widely across different tissues; however, the risk of fatal radiation-induced cancer for a general population following chronic exposure<sup>6</sup> is about 5% Sv<sup>-1</sup>. Due to difficulties in obtaining accurate evidence, quantification of cancer risk at doses of less than 0.1 Gy remains problematic.<sup>8</sup>

### 3.1.3 Eye lens risk

For a long time the lens of the eye has been regarded as radiosensitive in a deterministic manner and therefore requires a threshold radiation dose to be exceeded before lens opacities will develop. In recent years, a number of new studies have suggested an elevated risk for cataract development in populations exposed to doses of ionising radiation below the previously assumed thresholds.<sup>9</sup> Deterministic thresholds for the lens of the eye (radiation induced cataract) are now considered to be 0.5 Gy,<sup>6,9,10</sup> with some authors raising the possibility of no threshold at all.<sup>11</sup> The particular form of cataract associated with

ionising radiation is Posterior Subcapsular Cataract (PSC). Therefore minimising the eye lens dose remains an important consideration in radiation protection.

### 3.2 Stochastic and hereditary risk

Radiation effects are divided into the categories of stochastic effects, tissue effects (deterministic) and genetic effects. At dose levels commonly found in diagnostic radiology, the overwhelming effect in both adult and paediatric patients is believed to be an increased incidence and associated mortality from stochastic effects.<sup>12</sup> Heritable effects to offspring can be considered a negligible risk for the expected gonad doses associated with diagnostic radiology (including CT).<sup>6</sup>

The significance of these radiation effects is dependent on the biological sex and age of the patient at the time of the exposure and generally the younger the patient the more important the effect is. The increased risk for a given dose for younger age groups reflects the increased radiation organ sensitivity during development and the longer life expectancy of the child, during which time a cancer can become established and develop.

Cancer incidence also varies considerably between the different organs, with the female breast being the most radiosensitive at birth and the thyroid and female breast showing the greatest decrease in radiosensitivity with age (see Figure 3.4).

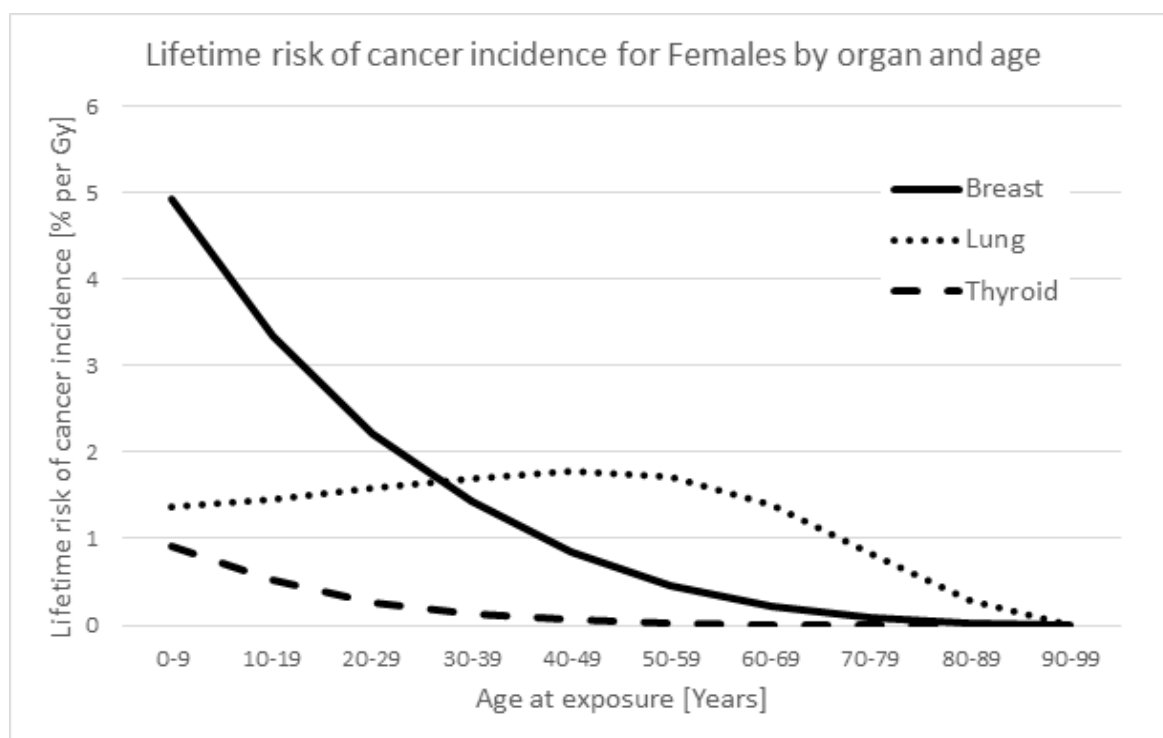


Figure 3.4 Lifetime risk of cancer incidence by organ and age for a composite Euro-American female population (% per Gy) (data from the Health Protection Agency 2011.<sup>13</sup>)



### 3.3 Introduction to levels of risk

In order to help prioritise dose reduction techniques, such as the use of patient contact shielding, it may be useful to consider a general scale of risk related to radiation dose, such as that provided in Table 3.2. Although the tabulated radiation dose is related to effective (whole body) dose, whereas patient shielding is used to minimise individual organ doses, the risk levels and descriptions are nevertheless a useful general guide. For instance, where the estimated examination dose is already in the 'negligible' risk category, then to provide shielding which halves the dose will have little, if any, effect on the overall risk to the patient and would suggest optimisation efforts would be better employed elsewhere.

Table 3.2 Lifetime cancer induction risk categorisation for medical exposures, based on Martin et al.<sup>14</sup>

Effective dose (mSv)	Lifetime cancer induction risk	Risk description	Example radiological procedure
<0.1	<1 in 1 million	Negligible	Radiographs: Chest, Limbs, shoulder, teeth
0.1 to 1.0	<1 in 100,000	Minimal	Radiographs: Head, neck, spine, abdomen, pelvis
1.0 to 10	<1 in 10,000	Very low	Fluoroscopy contrast studies; CT Head; CT thorax, abdomen and pelvis; cardiac angiography; interventional radiology
10 to 100	<1 in 1,000	Low	CT thorax, abdomen and pelvis; Interventional radiology
≥100s	<1 in 100	Moderate	Multiple procedures

#### 3.3.1 Paediatric risk

The increased risk due to the age of paediatric patients must be considered and therefore there is necessarily a higher emphasis on protecting radiosensitive organs (for example the paediatric female breast) due to the increased radio-sensitivity of the developing breast tissue. The cancer risk drops markedly as the age of the population increases. To illustrate this, at the age of 5 it has been estimated that approximately 9 breast cancers per mGy of absorbed dose would be induced if 100,000 patients were exposed. For a 40 year old female this drops to approximately 1 radiation induced breast cancer per 100,000.<sup>15</sup>

### 3.4 Optimisation and applying the ALARP principle

How are we to balance risk and benefit and how far do we go to achieve ALARP? It is not just about aiming for radiation doses 'as low as' conceivably possible, but keeping in mind the idea of 'reasonably practicable'.<sup>16</sup>

Some useful advice regarding ALARP has been provided by the Health and Safety Executive,<sup>17</sup> who suggest that ALARP does not mean that every measure that could possibly be taken (however theoretical) to reduce risk must be taken and it does not represent zero risk. The risk from an activity can never be entirely eliminated unless the activity is stopped. Applying the ALARP principle is dependent upon the exercising of professional judgement and experience, as well as following any consensus on 'good practice' established by stakeholders. In addition, decisions about what is ALARP should be affected by changes in knowledge about the size or nature of the risk presented by a hazard. If the evidence shows the hazard presents a significantly lower risk than previously thought, then a relaxation in controls may be accepted provided the new arrangements ensure the risks are ALARP.

Therefore, the process of applying optimisation and ALARP in diagnostic radiology should concentrate on minimising the primary beam dose and prioritising protection for the 'high risk' organs mentioned in sections 3.1 and 3.2. In the context of applying surface shielding this includes the eye lens and breast tissue (and thyroid in paediatric patients). However, primary beam shielding has the potential to increase dose when using automatic exposure controls and risks obscuring pathology and adversely affecting clinical findings, potentially leading to repeat exposures.

These considerations should guide clinical practice. For example, in comparing AP and PA projections for abdominal radiography,<sup>18</sup> the anatomically anterior positioning of the stomach, colon and liver mean they would receive higher organ doses in an AP projection than a PA projection and thus make a greater contribution to effective dose. Similarly, in the selection of tube potential (kV) or filtration for a radiographic examination, increasing the kV will give more penetrating radiation, lowering the dose to more superficial tissues, while the effect on doses to tissues deep within the body near to the image receptor will be minor.<sup>19</sup>

The decision regarding whether any further dose reduction (e.g. from secondary radiation) is necessary, should take into account the levels of risk highlighted in section 3.3. It is suggested that if the dose has been reduced to the 'negligible' risk level, no further action need be taken to satisfy ALARP.

Other considerations which might influence the optimisation process could include cases where a patient is likely to undergo multiple or sequential examinations.

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## Chapter 4 Sources of radiation exposure

Effective use of protective equipment requires a clear understanding of the sources of ionising radiation that a patient is exposed to while undergoing a radiological investigation. These sources include the primary beam and secondary radiation from several sources. Knowledge of the relative intensity of each of these sources should guide radiation protection practice. There has been confusion evident in the literature concerning the terminology, generation process, and relative intensity of some of these sources of secondary radiation. This chapter aims to provide the current knowledge available to help guide protection practice for all professional groups engaged in the examination of patients.

### 4.1 Primary radiation

This is the radiation emitted from the X-ray tube in the intended field of irradiation. Dose rates within the primary beam can be relatively high. There are broadly three categories of dose rate commonly delivered to the surface of the patient as primary radiation in radiological examinations. One is between 1 and 10 mGy s<sup>-1</sup> and would include fluoroscopic exposures. The second category typically ranges between 15 and 25 mGy s<sup>-1</sup> and would include projection radiographs, dental examinations, angiographic acquisitions, fluorography acquisitions and mammograms. The third can deliver 50 to 100 mGy s<sup>-1</sup> and is exclusively for computed tomography (CT) examinations. These dose rates are at least fifty times the dose rate from even the most significant source of secondary radiation, it is therefore extremely important to limit the area of the primary beam.

#### 4.1.1 Collimation

The size of the primary beam is controlled by means of a collimation system. An example of the effectiveness of the collimators in general radiography is given in Figure 4.1, which demonstrates the steep decline in radiation output close to the collimator edge. The insert in this figure illustrates the low output levels measured outside of the collimated region, in this case dropping to less than 1% of the primary beam output within approximately 25 mm. Therefore efficient use of collimators is a significant contributor to optimisation of patient dose.

Operators must include all anatomy and pathology indicated by the examination protocol. Ensuring this is achieved in just a single exposure is a skilled task. Inadequate collimation (use of large field sizes, or too small a field size requiring a repeated exposure) has been shown to be a major cause of increased risk to patients, especially children and neonates.<sup>1,2,3</sup> There is a fine balance between adequate visualisation of anatomy and pathology on the one hand and beam size limitation for radiation protection purposes on the other.

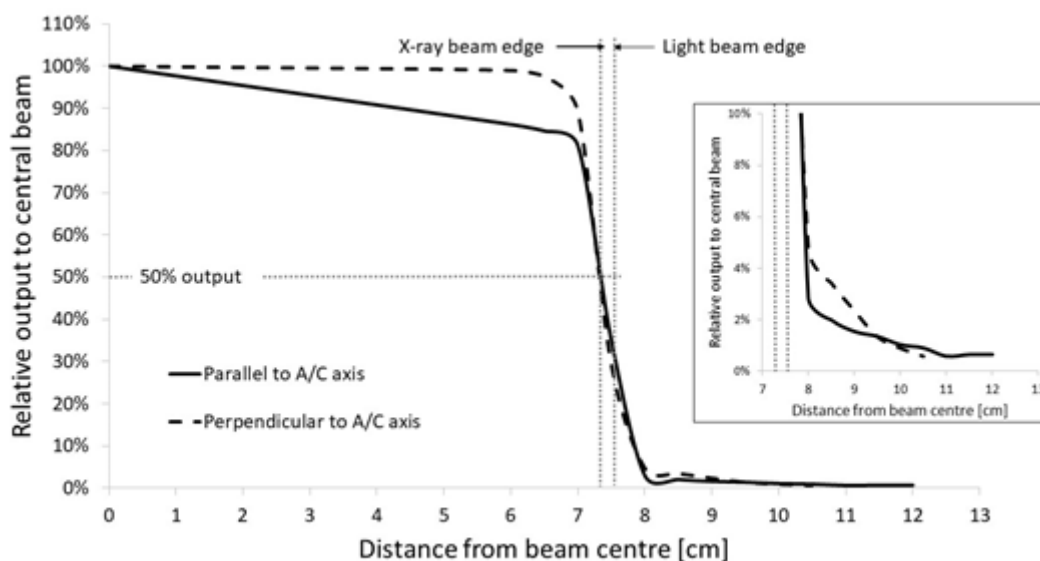


Figure 4.1 An example of the change in radiation output with distance from the centre of the X-ray beam for a conventional radiographic X-ray tube, in the directions parallel to and perpendicular to the X-ray tube Anode Cathode (A/C) axis. The collimated X-ray beam edge in this example is within 3 mm of the light beam edge, as shown. The insert highlights the response close to the field edge, where the radiation output falls to less than 1% within 25 mm.

## 4.2 Secondary radiation

All other sources of radiation within the X-ray room are termed secondary radiation. Figure 4.2 highlights secondary sources of radiation for a projection radiography situation, namely tube leakage, extra focal radiation and several sources of scattered radiation. These secondary sources are also present in other modalities, such as CT and fluoroscopy.

Patients may be completely unaware of these sources. Conversely, they may be unnecessarily anxious about the risks posed by them. Therefore, the absence of measures to protect against them may need to be explained.

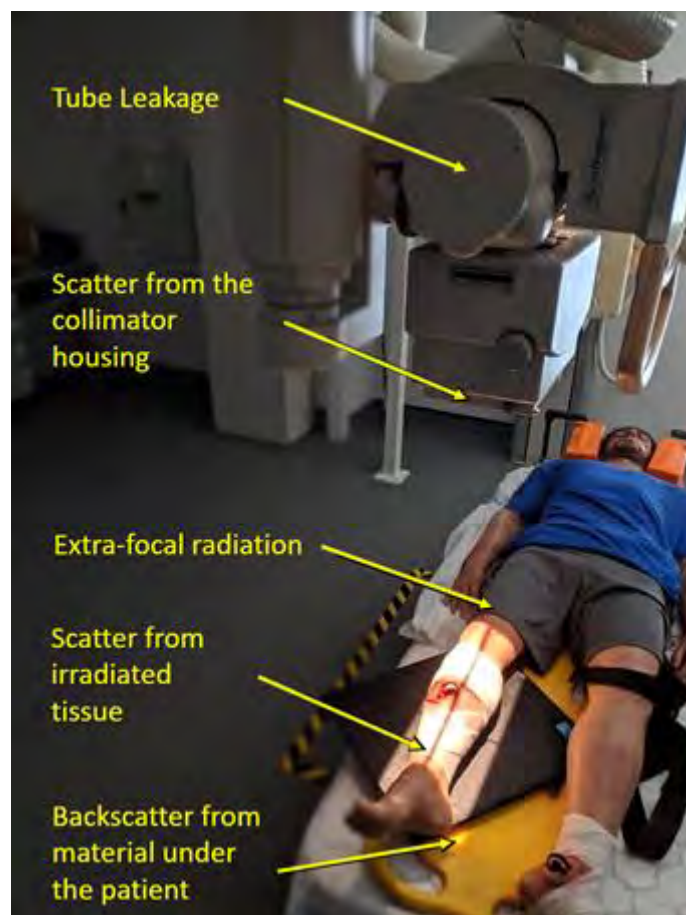


Figure 4.2 Secondary sources of radiation present during projection radiography.

#### 4.2.1 Tube housing radiation leakage

Leakage radiation is the term given to radiation escaping the X-ray tube housing other than through the tube port. This must be limited to less than  $1 \text{ mGy hr}^{-1}$  averaged over an area of  $1 \text{ m}^2$  at a distance of 1 metre from the focal spot.<sup>4</sup> In practice, the dose rate from leakage radiation in a properly designed and maintained system<sup>5</sup> will be less than  $0.3 \text{ mGy hr}^{-1}$ .

#### 4.2.2 Scatter from tube, filtration and housing

Scatter in the tube and housing is a well-known source of secondary radiation; it is generated as the primary beam passes through the construction elements of the tube, coolant, tube housing and the collimator. This scatter will give rise to very low levels of additional dose for the patient. It is common to have a transmission ionisation chamber attached to the front of the collimator. This can be a source of additional scattered radiation.

#### 4.2.3 Extra-focal radiation

This occurs adjacent to the collimated X-ray field and is generated by energised electrons in the tube that interact with parts of the anode other than the focal spot. This should not be confused with the penumbra of the primary beam; it is of lower intensity but affects a much larger area.

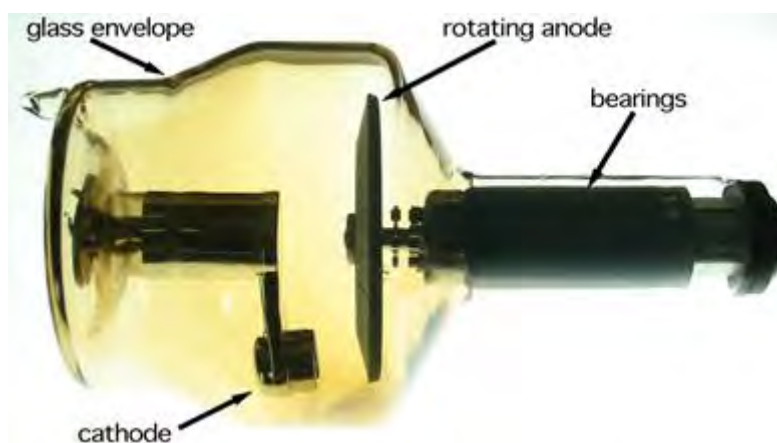


Figure 4.3. A typical rotating anode X-ray tube. The cathode is the source of energised electrons, which travel to the anode on initiation of exposure ([https://upload.wikimedia.org/wikipedia/commons/d/d5/Rotating\\_anode\\_X-ray\\_tube\\_%28labeled%29.jpg](https://upload.wikimedia.org/wikipedia/commons/d/d5/Rotating_anode_X-ray_tube_%28labeled%29.jpg)).

Figure 4.3 identifies the components of a typical rotating anode X-ray tube. Electrons released from the heated cathode filament are accelerated across the near total vacuum in the tube by electrostatic forces. Various design elements help to focus the majority of accelerating electrons to interact with the anode in a very small area, known as the focal spot. However, this focusing is not perfect. Electrons can diverge from the accelerated electron beam. Because they are generated away from the focus, any X-ray photons generated from these electron interactions are termed extra-focal, or off-focus radiation. Their exit trajectory from the tube housing and collimator are different from that expected and illuminated by the light field. They can emerge from the collimator more divergent from the central ray than the primary field. These photons are therefore present across the illuminated field and also beyond it. Modern multi-leaf collimators are designed with extra collimation leaves close to the tube port (Figure 4.4, C1) to reduce the area irradiated by extra-focal radiation as much as possible.



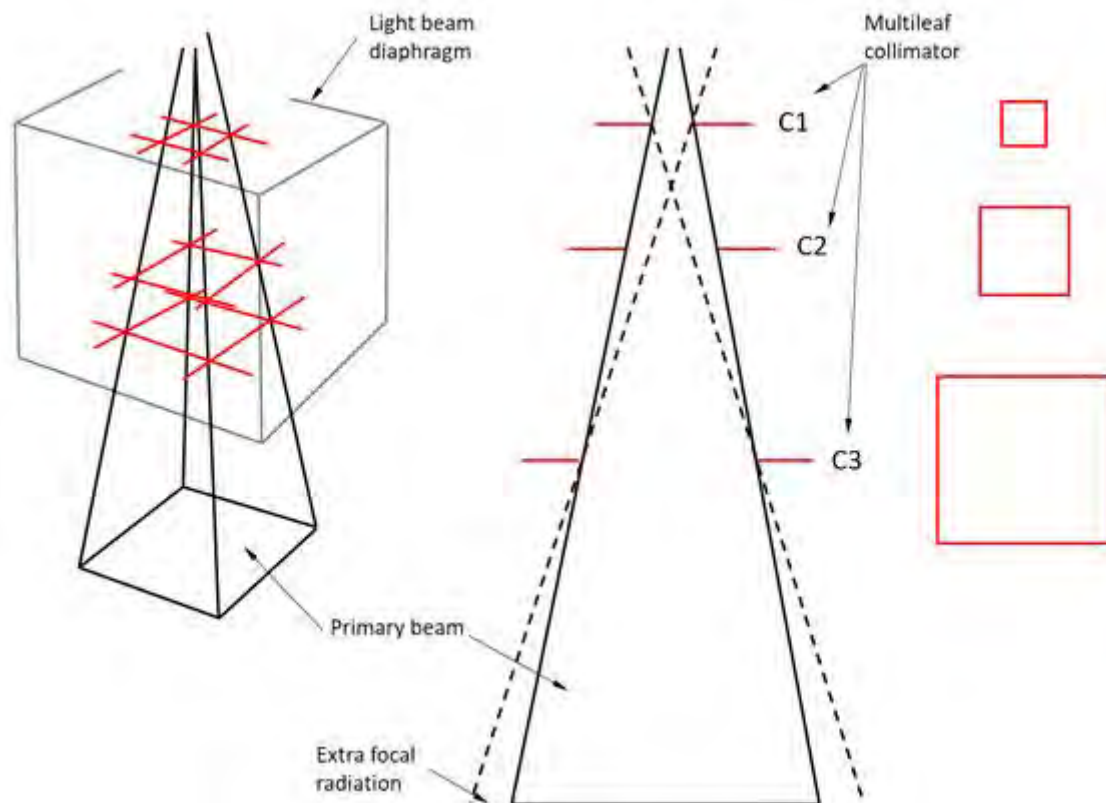


Figure 4.4 Extra-focal radiation and its trajectory from the X-ray tube and collimator. This diagram shows a multi-leaf collimator designed to reduce off-focal radiation to the minimum.

The effects of extra-focal radiation can clearly be seen using modern digital detectors with a wide dynamic range (Figure 4.5). The use of extra-focal shielding immediately adjacent to the collimated primary beam has been advocated by several authors.<sup>6,7</sup> However, risks to the patient from the focal/extra-focal radiation is generally agreed to be small, due to the primary to extra-focal radiation ratio being of the order of 500:1.<sup>8,9,10</sup>



*Figure 4.5 The window width of this image has been decreased. The image of soft tissue and bone from extra-focal radiation outside of the primary field of irradiation is now evident.*

#### *4.2.4 Scatter from irradiated objects*

The patient themselves and the patient support are a source of secondary radiation during exposure. Internal scatter within the patient is difficult to quantify but can be the major source of secondary radiation to an organ outside the primary beam. It is very difficult to shield one part of the patient from another internally. Work by Iball and Brettle (2010)<sup>11</sup> provides evidence to suggest that it is the predominant component of any radiation dose measured within the patient close to the primary beam (<17 cm). This will be unaffected by the application of local shielding.

Culp and Barbara<sup>12</sup> identified scatter from objects under the patient (Bucky surfaces, mattresses, spine boards, etc.) to be responsible for approximately a tenth of the dose rate measured as extra-focal radiation.

Scatter from the patient is most commonly seen as a risk to the clinical staff conducting the examination rather than the patient themselves. However, there have been some concerns raised about the possibility of backscatter to the patient from the underside of any contact protection applied to the patient surface. Matyagin and Collins (2016)<sup>13</sup> considered the

theoretical possibility that scatter leaving the patient might be backscattered towards the patient from any shielding applied, such as a drape or pad for the protection of cardiologists fingers. Their modelling suggests there may be an effect, but it is small, superficial, and falls off rapidly away from the primary X-ray field (Figure 4.6).

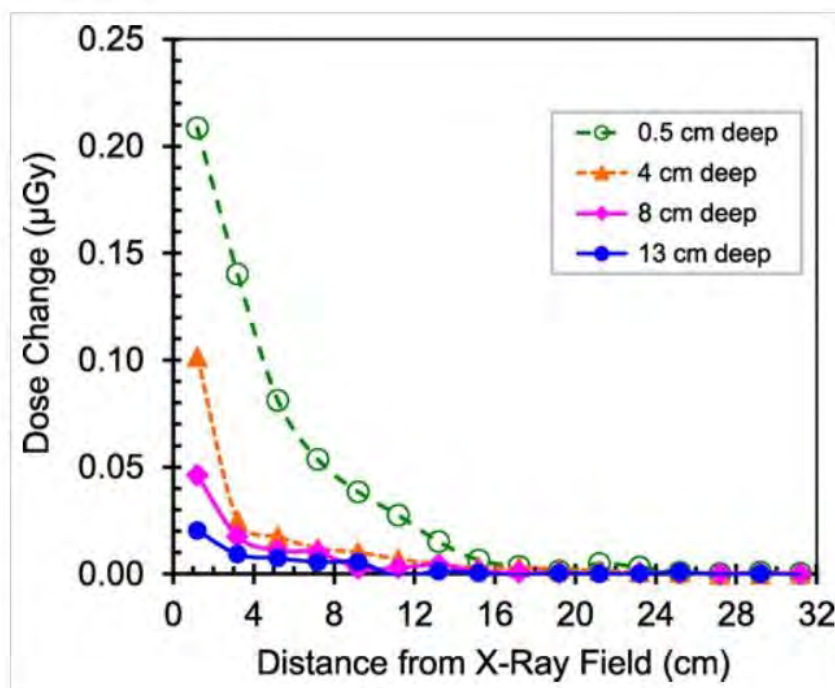


Figure 4.6 Reduction in radiation dose with distance from the primary X-ray field (from reference 13, used with permission).

Iball *et al* (2008)<sup>14</sup> modelled patient dose from secondary sources of radiation in Computed Tomography, where the dose rates and duration of the primary beam are high. Figure 4.7 shows the relative contribution of the three types of scatter (internal, external, and backscatter from an applied shield) to the fetus. This shows that the backscatter from the applied shielding towards the patient is the smallest and its insignificance as a contributor to patient dose is apparent when it is remembered that all these contributions are many magnitudes smaller than the incident primary beam dose rates.

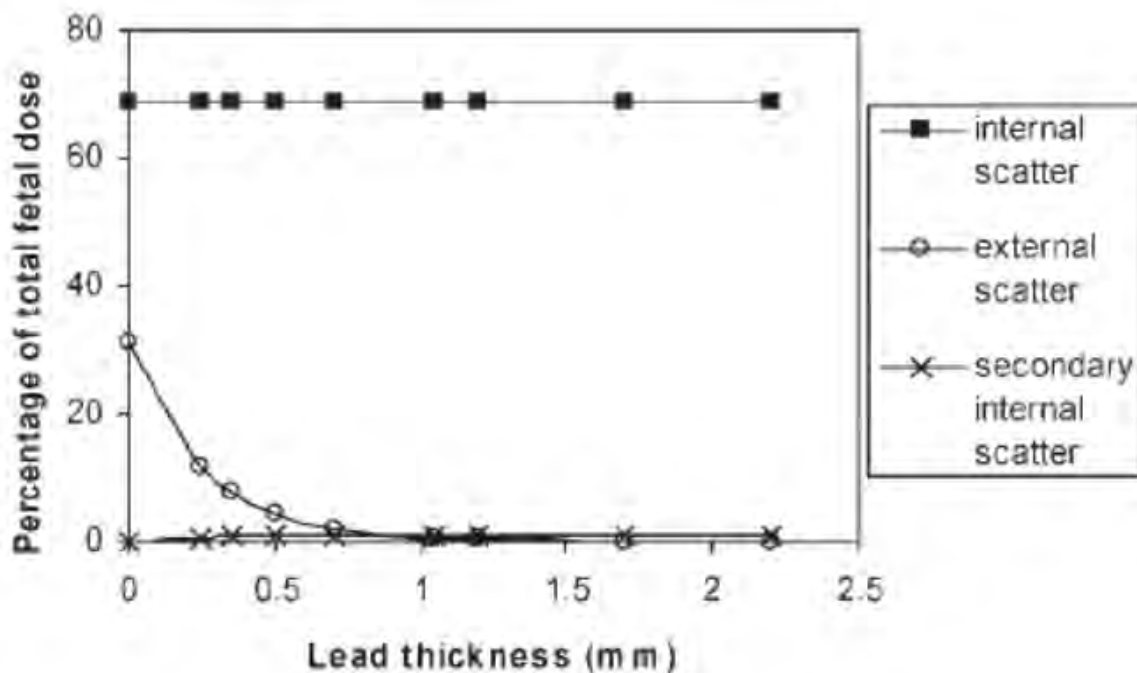


Figure 4.7 The relative contributions of the three sources of secondary radiation to the total fetal dose at 140 kVp. Used with permission from Iball et al (2008).<sup>14</sup>

### 4.3 Summary

The primary beam provides significantly higher dose rates than all sources of secondary radiation, as illustrated in Table 4.1. Therefore optimisation techniques which limit the primary beam size and position will have far greater impact upon patient dose than any efforts spent reducing the exposure from secondary radiation sources. After that, if additional shielding is deemed necessary to reduce secondary radiation, then it will be most effective close to the beam edge.

Table 4.1 provides a comparison of the three categories of primary beam dose rates typically encountered and the likely dose rates from secondary sources thus generated. It is useful for comparison. However, it is important to remember that patient dose will depend on the duration of the exposure as well as the dose rate. This can be as short as a few milliseconds in projection radiography, compared with CT sequences of several seconds and fluoroscopy exposure times with a potential duration of many minutes. Any risk benefit calculation regarding the potential application of any contact shielding must take into account the likely dose rate (and duration of exposure) of the sources the shielding might attenuate.

Table 4.1 Example dose rates (in  $mGy s^{-1}$ ) at 75 cm from the tube focus, due to various radiation sources, for three X-ray imaging modalities.

Source of radiation exposure	Dose Rate ( $mGy s^{-1}$ ) at 75 cm		
	Fluoroscopy	Projection Radiography	CT
Primary beam	5	25	50
Extra-focal (0.2% of primary)	0.01	0.05	0.10
Scatter from irradiated objects	0.001	0.005	0.010
Tube housing leakage	0.0001	0.0001	0.0001

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## Chapter 5 Operator responsibilities

### 5.1 Overview

The rare application of patient contact shielding should be justified and employers should develop clear criteria for its use. The operator must be adequately trained (see chapter 6) and aware of their responsibilities when using patient contact shielding. In general this should be covered by education at pre-registration level, local training and Continuous Professional Development (CPD) programmes.

Patients should experience the same high standards of care regardless of where their medical exposure takes place. Guidance provides scientific evidence to support assistant practitioners (AP), radiographers, radiologists and others acting as IR(ME)R<sup>1,2</sup> operators to offer safe, high quality and consistent radiographic care to patients.

The operator should be familiar with the guidance and employers should support the operator by providing written procedures, time and suitable equipment for staff to carry out their duties as IR(ME)R operators.

The operator is an IR(ME)R-entitled duty holder responsible for practical aspects of the exposure and for complying with the employer's procedures.<sup>1,2</sup> The use of patient contact shielding in diagnostic imaging is a practical aspect. This guidance recommends its use only in specific circumstances informed by recent and relevant evidence. Operators should be further guided by what matters to the patient,<sup>3</sup> taking care to ensure operator actions result in an overall net benefit to the patient.

Operators should take care to ensure the patient understands the function of shielding as the final element in a comprehensive and individualised dose reduction strategy. Where indicated, it should be integral to the benefit risk conversation with the patient. Operators should be respectful of individual choice and non-judgmental; the operator has a responsibility to keep the patient safe and to take action to prevent harm. Shielding devices should be appropriately used and accurately positioned to provide efficient protection to the relevant body part.<sup>4</sup>

It is considered good practice to have a written procedure for the use of patient shielding which should contain inclusion criteria. It may be helpful to incorporate scenarios to illustrate how and when patient shielding should be used. It is important to note that local procedures should allow for the professional judgement of the operator in individual circumstances. The operator should document reasoned decisions that do not comply with the procedure. Procedures should include a process to manage the need for repeat exposures and how this is recorded (see chapter 6).

## 5.2 Communication

Historical practice means that for some time there is likely to be a natural expectation that patient contact shielding is used. Operators may need to take time to explain to the patient the rationale for not using it until this becomes normalised practice. In the rare circumstances where its use is advocated, operators should be adequately trained to do so.<sup>1,2</sup> The application of shielding directly onto the skin or clothing of a patient can be a sensitive task. The patient should be provided with adequate information, prior to placement, which explains the associated benefits and risks of using the shielding. Good communication, where the conversation is supported by knowledge and evidence, helps nurture trust between the patient and the operator and is likely to result in a higher rate of acceptable diagnostic images. The priority should always be achieving a high quality diagnostic image where benefit outweighs risk.<sup>5</sup>

When communicating the benefit and risk of using patient contact shielding the following points should be considered:

- Is the patient/their representative/the referrer asking for patient contact shielding contrary to recommended guidelines? In these circumstances, is the operator confident to respond to challenges regarding the absence of shielding and if not why not?
- Does the evidence support the use of patient contact shielding for this examination? (See chapter 3.)
- Is there a local procedure for this examination? (See chapter 6.)
- Does the patient meet the inclusion criteria? (See chapter 6.)
- Is the operator/trainee adequately trained/supervised to use the shielding? (See chapter 6.)
- Has the application of local procedures for transgender or gender non-conforming individuals been considered?
- Is there anything in the clinical information for this patient that precludes the use of patient contact shielding?
- Is its use justified? (Consider the risk of the patient being unable to comply and the effect on image quality.)
- Is the patient contact shielding fit for purpose? (Approved for use, free from defect, clean and the correct size – include special considerations in neonatal care.)
- Will it do any harm to the patient or adversely affect image quality if it is used contrary to local procedures or professional guidance? Decisions made in these circumstances should be documented along with the rationale for doing so.
- Is it safe to delay the examination if the patient is still insisting on the use of patient contact shielding contrary to advice? Is the patient likely to be significantly reassured if patient contact shielding is used, even if it is unlikely to afford them any radiation protection? **(N.B. it is not recommended that patient contact shielding is used as a**



**means of reassurance.** This should be addressed through appropriate one to one communication.)

The specific needs of paediatric patients should be taken into consideration and techniques used to aid communication and nurture confidence (for example play specialists and distraction techniques). The use of patient contact shielding, where indicated, must be the final step in an overarching optimisation strategy.

The following scenarios are provided to illustrate some of the challenges and suggested outcomes operators may experience in practice.

### Scenario 1

A two year old child arrives for a chest X-ray. They are upset and distracted by the unfamiliar environment. The operator, who is a radiographer in this case, explains the benefits and risks of the exposure to the child's parent. In accordance with the locally agreed procedure, patient contact shielding is not required for this examination. The radiographer provides assurance that the potential harm from a repeat exposure is considered a greater risk than the exposure from scattered radiation. They further explain that the priority for optimising the child's exposure is close collimation of the primary beam in order to avoid irradiating organs unnecessarily. The parent is reassured and agrees to the examination proceeding without the use of patient contact shielding. A play specialist works with the operator and parent and helps calm the child who manages to sit still in the required position for the chest X-ray.

The risk of patient contact shielding moving and obscuring the lung bases should be balanced against the risk of a repeat exposure and the anticipated benefit from reducing dose from scattered radiation.

### Scenario 2

A pregnant 25 year old female attends from the emergency department for a CT pulmonary angiogram. There is a high clinical suspicion of pulmonary embolism. The patient is very unwell and is also distressed about the safety of her unborn child during the scan. She is insisting on the use of patient contact shielding for her abdomen and pelvis. There is a local procedure for pregnant patients undergoing CT which necessitates a consultant referrer to consultant practitioner referral pathway and recommends patient shielding is not used. The examination is justified with instructions for additional optimisation by using a reduced scan length. The radiographer explains the benefits and risks of the scan to the patient including the local policy not to use patient shielding. The patient is not convinced as she is aware that radiation can cause cancer. Consequently the patient becomes more distressed despite the efforts of the radiographer and the emergency department staff to reassure her. The radiographer discusses the benefits and risks with the referrer and the practitioner.

There are three options:

1. Not perform the scan - assess whether the risk of using the patient contact shielding (including the risk of having to repeat the scan) outweighs the benefit of the scan.
2. Delay the scan until the patient can be convinced to proceed without patient shielding - assess the risk as above.
3. Perform the scan using the patient contact shielding - the benefit to the patient and the unborn child of reaching a diagnosis and commencing appropriate treatment outweighs any risk to the unborn child of a potential repeat exposure due to obscured anatomy caused by the shielding.

The decision is made to perform the scan using the patient contact shielding. The patient must be able to tolerate the weight of the shielding for the duration of the scan. The risk of a repeat exposure if the patient or shielding moves should be clearly explained. The reasoned decision is documented by the operator. The dose is recorded in the patient record according to the local procedure.

Important notes to consider:

- Special consideration should be given to referral pathways for pregnant patients undergoing CT. This should take into account the stage of pregnancy.
- Alternative means of reaching a diagnosis should have been excluded.
- CT protocols must be optimised and advice sought from the MPE to ensure exposures are as low as reasonably practicable.
- Operators must be adequately trained to ensure they have the knowledge, skills, competence and confidence to appropriately influence the benefit/risk discussion. They should not acquiesce to the patient's early request for shielding unless the benefit of not following professional body guidance can be clearly demonstrated.
- Operators must be adequately trained with the knowledge, skills and competence to optimise exposures. In the case of CT this means adapting scan technique where appropriate (for example shortening the length of the scan where justified) and understanding when it is appropriate to use contact shielding as a final optimisation measure.
- The patient has a right to express what matters to them. The operator and practitioner should consider whether reducing anxiety is likely to contribute to improved tolerance or compliance with the scan instructions. Benefit should always outweigh risk.
- Employer's procedures for the use of patient shielding (where appropriate) should include the type of shielding and its use (see chapter 5).
- In all cases, the patient must be provided with adequate information relating to the benefits and risks of the exposure and the measures taken to reduce patient and fetal dose before the exposure takes place.

Several factors may influence the decision to use contact shielding. As previously stated it should be based on scientific evidence. In addition to this its use may be determined by the clinical indications for the examination, practitioner and operator training, and professional judgement. Within this context, both what matters to the patient and professional body

guidance should be considered. Careful attention should be given to the documentation of any practice outside normal recommended procedures.

### **5.3 Consent**

The patient must give permission before they receive any type of medical treatment, test or examination.<sup>6</sup> This includes the placement of patient contact shielding. In the rare circumstances when patient contact shielding is justified, the patient must be fully informed and provided with adequate information regarding the benefits and risks of using the contact shielding to enable them to make a choice. Operators should be familiar with the legislation and professional body guidance associated with capacity and consent matters.<sup>7</sup>

### **5.4 Patient Complaints and Duty of Candour**

Patient complaints should be thoroughly investigated. Where appropriate, an incident or error arising from the improper use of patient contact shielding should be investigated to determine the root cause and contributory factors. Analysis and feedback, focussed on learning from errors rather than ascribing blame, should form part of the local governance assurance framework.

The NHS has a contractual obligation under the Health and Social Care Act 2008 (Regulated Activities) Regulations 2014: Regulation 20, to be open with patients when things go wrong with their healthcare. This is termed the “Duty of Candour” and is integral to the development of an open and honest culture that provides patients with information about their healthcare. The implementation of “Duty of Candour” varies across the devolved nations. Staff should refer to the regulations and guidance for the country they are working in. The enforcing authorities in England,<sup>8</sup> Scotland<sup>9</sup> and Wales<sup>10</sup> have published guidance and information for providers of healthcare.

### **5.5 Summary**

Written procedures based on statutory regulations, available guidance and scientific evidence help to ensure more consistent operator practice. This is supported by education at pre-registration level, local training and Continuous Professional Development (CPD) programmes. Patients must receive adequate information, time and opportunity to discuss and consent to the examination, including the decision to include or omit patient contact shielding, prior to the exposure. Those who query inconsistent practice should be supported to do so and signposted to further information including local policies and procedures and associated evidence. Employers should support operators to make decisions in the best interests of the individual patient.

Scenario	Recommendation	Comments
<p>Patient requests patient contact shielding</p>	<p>Operators have the skills, knowledge and competence to explain the presence or absence of patient contact shielding. They should be confident to influence the discussion in the best interests of the patient.</p> <p>Where it is recommended for use, ensure operators are skilled in its application to prevent the need for repeat exposures.</p> <p>In other exceptional circumstances where the patient has made a request for shielding outside local policies, the operator should try to understand why and then explain the benefits and risks involved. Operators should discuss individual challenging situations with the practitioner and referrer to determine what is best for the patient.</p>	<p>Adequate training should be evidenced in operator training records and reflected in CPD.</p> <p>Ensure written procedures explicitly list these examinations and that operators know where to find them. Ideally it will be an electronic record with appropriate version control.</p> <p>In these cases the psychological benefit to the patient may be considered. Use only for those scenarios where the risk of not using it outweighs the benefit.</p>

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## Chapter 6 Clinical service requirements for patient contact shielding

### 6.1 Overview

For all exposures involving ionising radiation, there must be sufficient net benefit to outweigh the risk posed from the effects of the radiation. The presence or absence of patient contact shielding should form part of the benefit and risk analysis for each individual exposure.

Due to innovation in technology and dose reduction strategies the use of patient contact shielding will rarely increase the benefit to the patient. In some cases, where the shielding is not used correctly, it may increase the exposure to the patient or produce suboptimal image quality.<sup>1</sup> In specific situations where it has been agreed it is appropriate to use patient contact shielding, justification for its use should be documented.

The use of patient contact shielding should never be used as the primary method of reducing patient dose and is generally not recommended for the majority of imaging exposures.

### 6.2 Priorities in imaging

The principal objective of a medical exposure involving ionising radiation is to provide an image of sufficient diagnostic quality to answer the clinical question or to guide an interventional procedure while keeping doses as low as reasonably practicable. This is achieved through justification, optimisation and good radiographic technique.

Technical advances in medical imaging equipment and protocol optimisation have resulted in significant dose reductions.<sup>2</sup> Evidence-based radiographic practice is more likely to have a greater impact on radiation dose reduction than the use of patient contact shielding. It is important, therefore, that IR(ME)R operators work in collaboration with IR(ME)R practitioners and medical physics experts (MPE) to focus on reducing overall dose by employing appropriate techniques such as accurate collimation, and the selection of optimised exposure factors and protocols. Operators and practitioners must ensure that diagnostic exposures are kept as low as reasonably practicable, consistent with the intended purpose.

There should be a procedure agreed, through the local governance process, to describe when and how to use patient contact shielding.

The procedure should include:

- Training and appropriate use of patient contact shielding (inclusion criteria and contraindications)
- Purchase, storage and maintenance of patient contact shielding
- Patient communication (including how to respond to challenging scenarios)
- Process for when repeat exposures are required due to misplacement of shielding

### 6.3 Training

Operators must be adequately trained and have the underpinning knowledge, education, skills and assessment of competence to know when and how to use patient contact shielding. Training should take into account professional body guidance and local agreements. Practice should be informed by research and should be regularly reviewed through audit. Local agreements should reflect this and any revisions to policies and procedures be communicated to operators and practitioners in a timely manner.

There should be clearly documented and communicated local inclusion criteria that detail the type of examination and patient demographic where the use of patient contact shielding may be used.

In those specific situations where patient contact shielding is justified, any device used for shielding the patient from radiation must be correctly applied. A poorly placed shield may partially or completely obscure relevant anatomy and/or pathology.

Patient contact shielding in the primary beam may also introduce visual perception artefacts to the observer, such as the Mach effect.<sup>3</sup> Improper placement of patient contact shielding when using an Automatic Exposure Control (AEC) system may cause the exposure to the patient to be increased or reduce the quality of the image.

Obscuring anatomy or degradation of image quality may result in the need for a repeat exposure. Images seen to have patient contact shielding that obscures relevant anatomical features should be saved and evaluated by the operator. This should preferably be done prior to the repeat exposure to confirm the requirement for additional information.

Radiation errors caused by poor practice should be recorded as an unintended exposure in line with local incident reporting procedures.

Operators should refer to local procedures or seek advice from their MPE in non-standard or challenging situations.

Training should include but is not limited to:

- Selection and purchase of patient contact shielding (including appropriate standards or certification) – shielding should be appropriate for the intended purpose and there should be a range of sizes available for babies, children and adults.
- Storage of patient contact shielding – manufacturer’s instructions must be followed to minimise damage.
- Maintenance – in line with local infection control procedures (fit for purpose and responsibility to remove when damaged).
- Quality assurance checks – how and when checks should be completed and recorded
- Knowledge of policies and procedures relating to the use of patient contact shielding – in particular, to babies, children and young adults.<sup>4</sup>
- Appropriate radiographic technique – when and how to use patient contact shielding.
- Communication skills (see chapter 5.2).

#### **6.4 Continuing Professional Development (CPD)**

Registered health care professionals have a responsibility to meet the CPD and lifelong learning standards of their regulatory or professional body.<sup>5,6,7,8</sup> It is also a requirement of IR(ME)R, that employers must take steps to ensure that every practitioner or operator engaged to carry out exposures undertake CPD. There should be a process in place to ensure training in the correct positioning of patient contact shielding is completed, recorded in the individuals training file and updated when new techniques are introduced.

While radiography has progressed significantly in the last few decades, the practice of using patient contact shielding on patients has remained almost entirely unchanged. Operators should regard the function of patient contact shielding to be the final element in a comprehensive and individualised dose reduction strategy and not a primary dose reduction technique. Operators must keep up to date with current techniques and technologies to ensure doses are justified, optimised and kept as low as reasonably practicable.

#### **6.5 Procurement, storage and maintenance of patient contact shields**

The decision to purchase patient contact shielding devices should be made after consultation with the MPE to ensure appropriate selection is made. Each device should be used, stored and cleaned in line with manufacturers’ guidelines and local infection control policies. It should be fit for its intended purpose and any damage reported to the appropriate person. Improper storage can result in a reduction in the effectiveness of the shielding. Deterioration of outer surface of contact shielding material may also cause the production of lead dust which can lead to low level lead exposure in both children and adults.<sup>9</sup>



Examinations should not be performed using inappropriate substitute materials. Products with a UK product safety mark can be assured of compliance with basic health and safety requirements.<sup>10</sup>

## 6.6 Applying patient contact shielding

Some practical issues to consider where shielding has been justified:

- Possible discomfort experienced by the patient (due to position or weight).
- Possibility of the shielding moving during an examination (due to patient age/capacity/medical condition).
- Manual handling challenges for staff.
- Infection control – compliance with organisational and local procedures.

With paediatric patients it may be more difficult to ensure that the contact shielding remains out of the primary beam, due to patient size and risk of movement. A locally agreed standard for the use of shielding in children should reflect best practice and should take into account the responsibilities of operators.<sup>11</sup>

Careful consideration should be given to the benefits and risks of attempting to use patient contact shielding on a confused or uncooperative patient. Reference should be made to consent procedures.

Occasionally, physical location of the organs requiring protection may be challenging. To illustrate this, Figure 6.1 demonstrates the variation in practice and challenges associated with accurately identifying the position of the ovaries when placing gonad shielding.<sup>4</sup>



*Figure 6.1 Schematic diagram of pelvis with positions of 128 ovaries plotted, located using ultrasound.<sup>4</sup>*

In the rare circumstance where the use of patient contact shielding is justified, written procedures should reflect equality and diversity and meet the needs of local populations. This may include the use of shielding for patients, for example, who may find it difficult to cooperate. Careful consideration should be given to the location of reproductive organs in

transgender and gender non-conforming individuals. Where required, there should be a suitable range of devices available to meet the age and size requirements of the individual. Some providers may include a size guide for reference.

Regular assessment of practice and review of local policies and procedures are recommended.

### **6.7 Leadership**

Leadership plays an important role in setting a standard for the appropriate use of patient contact shielding in diagnostic imaging. Continuing education and the consistent application of local procedures will encourage a culture of good practice. Regular monitoring of compliance and reflective feedback, including learning from errors and near misses, are key to good governance and to the continuing professional development of the operator. A multidisciplinary team approach with support from senior staff and MPEs will encourage a culture of evolution and evidence-based learning. The formation of multidisciplinary radiation protection champions<sup>12</sup> within Image Optimisation Teams (IOT)<sup>13</sup> should support, drive and provide training in all areas of radiation protection including patient contact shielding.

### **6.8 Continuous Quality Improvement (CQI)**

Audit is a quality improvement process that can be used to measure organisational compliance against local policies and procedures. Reject analysis is an important quality assurance tool that helps to evaluate areas of practice that can be improved. By examining the underlying causes for rejected images, which may include the misplacement of patient contact shielding, it is possible to identify technical and training issues<sup>14</sup> and can help increase departmental performance, reduce radiation burden, and decrease waiting times.<sup>15</sup>

Images that have been rejected due to a misplaced patient contact shielding device should be recorded and form part of the clinical audit process for education and service improvement.

Further information and advice on reject analysis is available.<sup>16,17</sup>

### **6.9 Repeat exposures**

The local reject analysis programme should include inappropriate or inaccurate use of patient contact shielding as an option. The local procedure should outline the process for the review of repeat exposures.

Prior to a repeat exposure being carried out the operator should confirm the requirements for additional information based on the clinical question being asked. It may be possible to limit the field of view for the repeat image to the obscured or missing anatomy.

## 6.10 Summary

The use of patient contact shielding is not generally recommended for diagnostic radiology applications.

It is expected there may be a few specific situations and exceptions where patient contact shielding is justified. In these cases, it should be a local multidisciplinary decision with these exceptions listed in the local procedure which will include:

- Exceptions
- Use of patient contact shielding for the exceptions listed
- Radiation protection training for patient contact shielding
- Patient communication
- Selection, care and QA of the patient contact shielding
- Who to contact for advice/support
- Consent

Scenario	Recommendation	Comments
Diagnostic radiology applications	Not recommended	No radiation protective shielding should be routinely applied

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## Chapter 7 Shielding in general radiography

The use of patient contact shielding **is not recommended** for general radiography for the majority of imaging situations (see section 7.7). Where patient contact shielding is being considered, the guidance in these chapters should be taken into account.

### 7.1 Organs at risk

In general radiography the anatomy imaged and the organs in or near to the primary beam are highly variable, being dependant on the pathology of interest and the operator's technique (e.g. positioning and collimation). When undertaking exposures, the operator will need to consider which organs are to be included in the primary beam or will be close by, and how the anatomy of interest can be imaged while excluding as much of the surrounding anatomy as possible.

### 7.2 The anatomy and concept behind shield application

There are a number of organs that could potentially have patient contact shielding applied. These are generally organs near to the surface of the body and have previously been considered easily locatable. Reports from the International Commission on Radiological Protection<sup>1,2</sup> suggested that consideration should be given to the breast, gonads and thyroid where these organs lie within 5 cm of the primary beam. However, patient contact shielding applied to these organs has the potential to obscure the anatomy of interest, especially when placed within the primary beam, which effectively rules out its potential use. This also applies to other organs which can have similar or greater radiosensitivity than those listed in the ICRP publications<sup>1,2</sup> (such as the colon during projections of the abdomen). However, there is little literature published regarding potential benefit or detriment of patient contact shielding for these other organs.

The radiosensitivity previously attributed to the gonads has been reduced over time as more evidence has come to light (see chapter 3). The historically higher radiosensitivity attributed to the gonads is the likely reason for the acceptance into common practice of applying patient contact shielding (e.g. in the form of gonad shields). It may be possible to exclude the male gonads from the primary beam using collimation. The accurate positioning of gonad shields on female patients is compromised by a large variation in gonad location,<sup>4,5,6,7</sup> resulting in the ovaries often not being shielded. This is particularly prevalent in small children. Where such shielding is incorrectly placed there may be a resulting loss of diagnostic information with the potential requirement for repeated imaging, or an increase in dose where placed over an AEC device.<sup>3,4,5</sup>

The thyroid may be included in or close to the primary beam for some projections (for example radiography of anatomy including the chest, cervical spine, skull, or shoulder).

Shielding of the thyroid may be possible with the use of a thyroid shield, however in cases where the thyroid lies in the primary beam (for example applying a thyroid shield when imaging the cervical spine) the anatomy of interest may also be obscured.

Protection of the breast tissue may be possible (e.g. with a scoliosis shawl) in anterior-posterior (AP) examinations of the spine. However, ICRP 121<sup>1</sup> recommends the use of posterior-anterior (PA) positioning for spinal examinations, particularly in pubescent girls where the developing breast tissue is considered to be more radiation sensitive. In PA examinations the body will provide attenuation of the X-ray beam, protecting the breast tissue, with collimation restricting the area exposed to radiation. Patient contact shielding to the exit side of the patient would provide negligible protection for the patient and can lead to repeat imaging due to obscuring anatomy or increase dose by interfering with the operation of an AEC device.

In general, with good collimation and using PA positioning for skull, spinal and chest X-rays, patient contact shielding is likely to have a negligible effect and, in many instances, may obscure diagnostic information or lead to an overall increase in patient dose.

### 7.3 In-beam protection (primary beam)

There are risks from the application of in-beam protection. These include:

- Shielding may impinge on the detector forming part of the Automatic Exposure Control (AEC) mechanism. Should the patient contact shielding obscure the AEC in any way, the result may be significantly increased dose relative to not using the patient contact shielding. Patient contact shielding **MUST NOT** be used where there is a chance that this may occur.
- Patient contact shielding may obscure anatomy of interest. This would necessitate repeat imaging which in turn leads to an increased radiation dose.

As described in chapter 4.1.1, general radiography equipment is usually equipped with adjustable collimation allowing a rectangular radiation field to be defined, along with a light beam diaphragm that illuminates the radiation field on the patient. Using anatomic landmarks, the operator (e.g. radiographer) is able to adjust the size of the primary beam to an area of interest. Good collimation (as close to the anatomy of interest as possible) is of key importance to reducing patient dose. Careful collimation restricts the area of the patient irradiated to that necessary which can reduce or prevent the inclusion of sensitive organs present in the primary beam and in turn reduce the radiation dose to the patient. It also reduces secondary radiation which can lead to improvements in image quality. A move to digital imaging has led to the introduction of digital cropping (also known as a dark mask). It should be noted that this is not the same as collimating the primary beam.

## 7.4 Outside beam protection

Shielding of organs at risk more than 5 cm from the primary beam is likely to have a negligible effect on the radiation dose received.<sup>1</sup> In the case of the male gonads (where excluded from the primary beam using collimation), it may be possible to accurately place the patient contact shield given that the gonads can often be observed (in the case of small children this is likely to be considerably more difficult), however the considerations in chapter 4 (patient consent) should be taken into account.

## 7.5 Influence of shielding on equipment function and image quality

Should a patient contact shielding device obscure an active AEC device, there is the likely risk that this will significantly increase the radiation dose to the patient. Care should be taken where patient contact shielding is used to ensure that it does not encroach in any way on the AEC system. If there is a risk of this happening then patient contact shielding must not be used.

## 7.6 Special patient groups

### 7.6.1 Pregnant patients

The Health Protection Agency (HPA, now referred to as Public Health England), Society and College of Radiographers (SCoR) and the Royal College of Radiologists (RCR)<sup>8</sup> have published guidance regarding the protection of pregnant patients during diagnostic ionising radiation exposures. The application of shielding to pregnant patients is considered with regard to increased dose to the fetus. ICRP report 34<sup>2</sup> also makes recommendations regarding diagnostic radiology exposures during pregnancy. In summary, these publications recommend:

- Radiography of areas remote from the fetus may be carried out at any point during pregnancy with no additional patient contact shielding, provided that accurate collimation is used and that the equipment itself is adequately shielded. Guidance indicates that 'remote from the fetus' refers to any examination outside the area between the diaphragm and knees.<sup>8</sup> In the UK, all appropriately CE marked equipment (see discussion in chapter 5) should fall within the category of adequately shielded. The Medical Physics Expert (MPE) should be able to advise if clarification is required.
- Where the pelvis may be included in the primary beam, consideration should be given to the use of alternative non-ionising techniques such as MRI or ultrasound. If ionising radiation must be used then a thorough assessment should be carried out to ensure that exposure to the fetus is justified.<sup>8</sup> ICRP report 34<sup>2</sup> recommends that if the exposure is justified then consideration should be given to the techniques used to ensure dose to the fetus is kept as low as reasonably practicable, e.g.

minimisation of the number of views taken, strict collimation and partial shielding of the fetus. However, care must be taken to ensure that the images remain of suitable diagnostic quality.

The ICRP recommendations do not necessarily consider the psychological effect of an exposure to ionising radiation on an expectant mother. It has been documented that pregnant patients undergoing diagnostic radiology examinations may request patient contact shielding despite undergoing an examination outside the pelvic region and not usually requiring extra protection.<sup>9</sup> In these cases whether or not to provide extra shielding, usually in the form of lead/lead equivalent material draped over the abdomen, is in accordance with written procedures and at the discretion of the radiographer. Of course, in such cases accurate collimation must be used and the shielding must not encroach on the AEC system.

### 7.6.2 Paediatrics

When imaging children, the shielding considerations are the same as those for imaging adults regarding the eye lens, thyroid and breast. However, there is some discussion regarding the use of patient contact gonad shielding in pelvic examinations for female paediatric patients due to the unpredictable positioning of the ovaries. Positioning of traditional shielding may not cover the gonads and may obscure diagnostic information, inadvertently increasing dose to the gonads due to repeated exposures.

## 7.7 Recommendations for local practice

*Table 7.1: Recommendations for patient shielding in diagnostic radiology*

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 recommended	Recommended where thyroid is less than 5 cm from the primary beam, projection is AP and will not obscure anatomy of interest or interfere with AEC device



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 due to obscuring diagnostic information or to interfere with AEC function.
Patient contact shielding for protection of eye lens	Not recommended	Use PA skull positioning, no recommendations for shielding.
Pregnant patients	Not recommended	Not required for examinations outside the pelvic region (diaphragm to knee). For examinations within pelvic region, consider non-ionising imaging alternatives. If ionising radiation must be used carry out a thorough justification and risk assessment process.

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## Chapter 8 Shielding in diagnostic and interventional Fluoroscopy

The use of patient contact shielding **is not recommended** for fluoroscopy for the majority of imaging situations (see section 8.5). Where patient contact shielding is being considered the guidance in these chapters should be considered.

### 8.1 Organs at risk

In fluoroscopy procedures the anatomy imaged and the organs in or near to the primary beam are highly variable, being dependent on the pathology of interest and the operator's technique (e.g. positioning and collimation). When undertaking exposures, the operator will need to consider which organs are to be included in the primary beam or will be close by and how the anatomy of interest can be imaged while excluding as much of the surrounding anatomy as possible.

### 8.2 The anatomy and concept behind shield application

Fluoroscopy equipment is the collective name for dynamic X-ray imaging systems used for real-time imaging for diagnosis and image-guidance of therapeutic procedures. There are two main types of imaging mode supported by dynamic imaging systems:

- 'Fluoroscopy' – where a sequence of low dose images are generated and displayed in real time for 'live' visualisation during a clinical procedure; and
- 'Acquisition' – in which higher dose images are stored automatically during the sequence and can be reviewed during or after the procedure.

Patient doses from dynamic imaging are amongst the highest radiation doses found in modern medical practice.<sup>1</sup> Fluoroscopy dominates most procedures in terms of time, whereas in terms of dose, acquisition can account for over half of the total accumulated patient dose.<sup>2,3</sup>

Due to modern applications of fluoroscopic imaging there are a number of radio-sensitive tissues that may be included in the image. In particular, mobile systems and modern static equipment tend to have the tube and detector mounted on a C-arm, which is capable of a wide range of rotational movements permitting various cranial/caudal and oblique projections. Attention should be given to angle the beam away from radiosensitive areas and collimating these areas out of the field if possible<sup>4</sup>. The equipment (positioning, geometry, field of view) is also extremely versatile and care must be taken to minimise radiation exposure of patients and staff.

Patient contact shielding may be used for protection of the patient's radio-sensitive organs, such as the breast, eyes and thyroid, provided it does not interfere with the equipment

function (see section 8.3). However, scattered radiation arising and propagating inside the patient's body constitutes the main source of radiation dose to organs and this internal scatter can only be managed by good technique.<sup>5</sup>

### **8.3 Influence of shielding on equipment function**

For the vast majority of fluoroscopy procedures, modern equipment will operate in a mode whereby tube voltage, tube current and X-ray pulse rate and duration are determined by an active automatic dose rate control (ADRC) system. This control mechanism is designed to maintain the radiation dose to the image detector irrespective of patient size and attenuation. Therefore any interference with its operation, such as introducing highly attenuating material into the primary beam, could cause it to increase the exposure factors and consequently significantly affect patient dose. This could include patient contact shielding and also lightweight disposable lead-free drapes or pads intended to reduce scattered radiation levels to the operator.<sup>6</sup> Great vigilance would be required to prevent this from happening since the interference can occur accidentally as the equipment (including patient) is moved during the dynamic imaging procedure. Repositioning of the shield can be inconvenient, particularly in technically challenging procedures and could potentially add to the overall procedure time and dose to the patient.<sup>7</sup>

Applying protection to organs lying close to the X-ray field is therefore not recommended to reduce patient dose. The contribution to organ doses lying further afield is unlikely to be significant compared with internal scatter and could also inhibit the movement of the equipment when performing oblique views.

### **8.4 Special patient groups**

#### *8.4.1 Pregnant patients*

The Health Protection Agency (HPA, now known as Public Health England), Society and College of Radiographers (SCoR) and the Royal College of Radiologists (RCR) have published guidance regarding the protection of pregnant patients during diagnostic ionising radiation exposures.<sup>8</sup> The application of shielding to pregnant patients is considered with regard to increased dose to the fetus. ICRP report 34<sup>9</sup> also makes recommendations regarding diagnostic radiology exposures during pregnancy. In summary, these publications recommend:

- Fluoroscopic imaging of areas remote from the fetus may be carried out at any point during pregnancy with no additional patient contact shielding, provided that accurate collimation is used and that the equipment itself is adequately shielded. Guidance indicates that 'remote from the fetus' refers to any examination outside the area between the diaphragm and knees.<sup>8</sup> In the UK, all appropriately CE marked

equipment (see discussion in chapter 6) should fall within the category of adequately shielded. The MPE should be able to advise if clarification is required.

- Where the pelvis may be included in the primary beam, consideration should be given to the use of alternative non-ionising techniques such as MRI or ultrasound. If ionising radiation must be used then a thorough assessment should be carried out to ensure that exposure to the fetus is justified. ICRP report 121<sup>4</sup> recommends that if the exposure is justified then consideration should be given to the techniques used to ensure dose to the fetus is kept as low as reasonably practicable e.g. pulsed fluoroscopy, minimizing the number of views taken, strict collimation and angulation of the beam away from the fetus.

The ICRP recommendations do not necessarily consider the psychological effect of an exposure to ionising radiation on an expectant mother. It has been documented that pregnant patients undergoing diagnostic radiology examinations may request patient contact shielding despite undergoing an examination outside the pelvic region and not usually requiring extra protection.<sup>10</sup> In these cases whether or not to provide extra shielding, usually in the form of lead/lead equivalent material draped over the abdomen, is in accordance with written procedures and at the discretion of the operator. In such cases accurate collimation must be used and the shielding must not encroach on the AEC system.

#### 8.4.2 Paediatrics

When imaging children, the shielding considerations are the same as those for imaging adults regarding the eye lens, thyroid and breast. However, there is some discussion regarding the use of patient contact gonad shielding in pelvic examinations for female paediatric patients due to the unpredictable positioning of the ovaries. Positioning of traditional shielding may not cover the gonads and may obscure diagnostic information, inadvertently increasing dose to the gonads due to repeated exposures.

### 8.5 Recommendations for local practice

Scenario	Recommendation	Comments
Patient contact shielding during fluoroscopy procedures	Not recommended	No radiation protective shielding should be routinely applied to patients undergoing a fluoroscopic examination. Great care should also be taken if protective material, intended to reduce staff radiation dose, is applied to patients.

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## Chapter 9 Shielding in CT

The use of patient contact shielding **is not recommended** for CT for the majority of imaging situations (see section 9.7). Where patient contact shielding is being considered, the guidance in these chapters should be taken into account.

### 9.1 Computed Tomography and Organs at Risk (OAR)

Computed Tomography (CT) is a long established medical imaging modality utilising relatively high doses of ionising radiation to diagnose and monitor disease.<sup>1</sup> In 2018-19, CT represented approximately 13% of the total imaging activity undertaken on NHS patients in England compared to 52% for projection radiography (X-rays).<sup>2</sup> Despite its relatively small proportion in terms of examination numbers, CT contributes almost 70% of the collective dose for all imaging procedures.<sup>3</sup> In the UK, CT doses from typical examinations were observed to rise marginally between dose surveys conducted in 2003 and 2011.<sup>4,5</sup>

Like other radio-diagnostic examinations, any reduction in organ dose to the ICRP specified radiosensitive tissues (see chapter 3) will reduce the risk of cancer induction later in life within these organs.

Superficial radiosensitive organs of interest that are subject to relatively high doses in CT include the lens of the eye, breast and thyroid. The eye lens is of interest, not for cancer induction, but for the potential for cataract formation (see 3.1.3). Some CT scanners permit axial scans with tilted gantry (of the order of 10-15 degrees) to reduce orbital lens dose by a factor of 2 without introducing posterior fossa artefacts.<sup>10</sup> Some current models of multi-slice scanners do not allow for a tilted gantry, and while helical scanning with multi-planar reconstruction avoids artefacts, the accompanying helical overscan along the z-axis may thus include the eye, resulting in increased dose to the lens.

Superficial radiosensitive organs that lie on or close to the surface of the patient lend themselves to the potential use of in-plane patient shields. For example, for a CT scan of the chest, over 40% of the contribution to cancer risk arises from the absorbed dose to the female breast.<sup>11</sup> In-plane contact shielding therefore has the potential to reduce the radiation risk from the exposure. The benefits and limitations from the use of such shielding must be carefully considered.

Typical doses to the organs of interest and associated risk, are given in table 9.1.

Table 9.1 – Magnitude of organ doses and the lifetime attributable risk (LAR) of cancer incidence from CT examinations

Organ	Effects	Examination	Typical doses	LAR % unless stated otherwise	Reference
Lens (eye)	Posterior Subcapsular and cortical opacities. Cataracts	Adult CT Brain Perfusion Stroke/tumour assessment	81-348 mGy per study	NA	(12)
		CT scan of the middle ear. Cholesteatoma (paediatric study)	50-60 mGy/scan		(9)
			Cumulative mean 256 mGy Cumulative max 970 mGy		
Breast	Cancer	CT Thorax	5-10 mGy		(13)
			10.6 mGy		(14)
		CTCA Prospective gating	2-15 mGy	0.01-0.06 (20 year old female)	(15)
		CTCA Retrospective gating	Up to 100 mGy	0.43 (20 year old female)	
Thyroid	Cancer	CT Neck	29-80 mGy	0.06% (20 year old female)	LAR inferred from mean dose of 55 mGy in (16)
Gonads					
Testes	Cancer	CT Abdomen & Pelvis	1.4 mGy	NA* (0.007 From Beir VII phase 2)	(14)
Ovary			13 mGy		(14)
Gonads					
Testes	Hereditary effects	CT Abdomen & Pelvis	1.4 mGy	7 in 1 million	(14)
Ovary			13 mGy	62 in 1 million	(14)

\*Note there is no currently accepted risk coefficient for radiation induced testicular cancer.

### 9.1.1 Dose index parameters in CT

In the context of this guidance and consideration of patient shielding in CT, it is worth introducing some of the standard framework for CT dosimetry. It is a requirement of the Ionising Radiations (Medical Exposure) Regulations 2017<sup>17</sup> that all CT operators and practitioners receive appropriate training to understand the interplay between CT parameters, image quality and radiation dose.

The volume weighted CT Dose index ( $CTDI_{vol}$ ) and Dose-Length-Product (DLP)<sup>18</sup> are generally displayed prior to and following, a CT exposure. It is important to recognise that these dosimetry terms relate to a calculated dose index for exposure incident on defined phantoms and are not intended to accurately reflect individual patient dosimetry.

Nonetheless, with the current absence of widely adopted patient specific dosimetry methods, the  $CTDI_{vol}$  and DLP are used to represent and audit patient doses in CT. The International Electrotechnical Commission (IEC) defined reference phantoms used to determine the  $CTDI_{vol}$  (and therefore DLP) are either 32 cm or 16 cm in diameter and these are broadly intended to simulate the body or head respectively.

The AAPM have provided conversion factors<sup>19,20,21</sup> to correct, if desired, the scanner reported dosimetry metrics to better match individual patient habitus. In doing so, the so called “size specific dose estimate” (SSDE) can be obtained. This can be useful especially when correcting the scanner reported  $CTDI_{vol}$  and DLP for paediatric exposures.<sup>22</sup>

## 9.2 The anatomy and concept behind shield application

### 9.2.1 Dose distribution in CT image plane

Ahead of any discussion regarding the potential merit and limitation of patient shielding in CT it is first necessary to review how the dose distribution in CT differs to projection radiography.

In projection radiography, the fall-off in absorbed dose along the projection path is approximately exponential. In CT however, the effect of the beam continuously rotating around the patient gives, in essence, a summation effect of the dose from thousands of angular X-ray projections. (Figure 9.2a, 9.3a).

The resultant dose distribution from a CT scan is dependent on the diameter and shape of the patient or phantom, as well as the beam shaping filter used (commonly known as the bow tie filter). CT scanners are calibrated so that the effect of the beam shaping filter is characterised, and accounted for, in the reconstruction process. CT scanners assume that the patient is positioned centrally and significant deviation from this assumption will adversely affect both the dose<sup>23</sup> and noise distribution<sup>24</sup> (Figure 9.2).



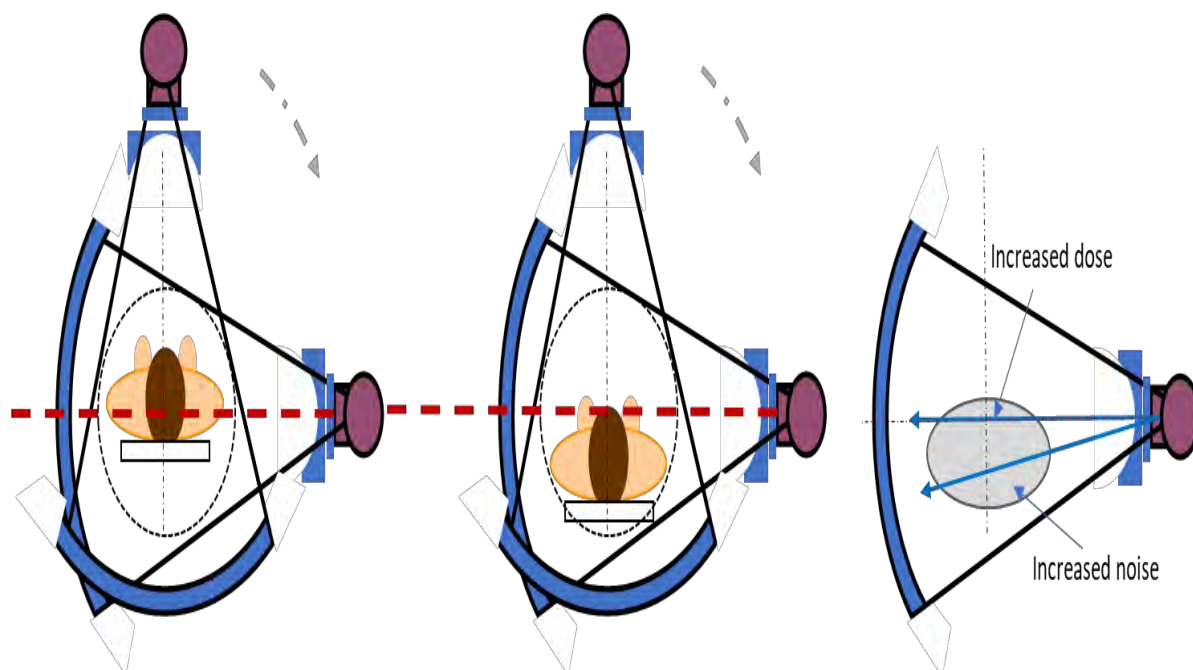


Figure 9.2a) patient centred b) patient off-centre c) schematic demonstrating x-ray paths for higher dose and noise (courtesy ImPACT, S. Edyvean).

The beam shaping filter is inherent in the design of the scanner and has a greater thickness of filter at the edges of the prescribed scan field of view. Modern scanners may have up to four filters which are automatically selected, generally according to the scan field of view, in order to optimise the dose distribution across the patient.

For a head sized cylinder, such as the 16 cm CTDI head equivalent phantom, a relatively uniform distribution is usually found. Theoretically for a smaller size phantom the periphery dose may be lower than the centre. However, for the larger, body equivalent, 32 cm phantom, absorbed doses are higher at the periphery of the phantom; roughly by a factor of two (Figure 9.3a,b).

The exact dose distribution for individual patients will vary markedly from that in the standard IEC reference phantoms used by the scanner when calculating  $CTDI_{vol}$  (Figure 9.3c). This has to be established by measurement or calculation, both of which can present challenges.<sup>26</sup>

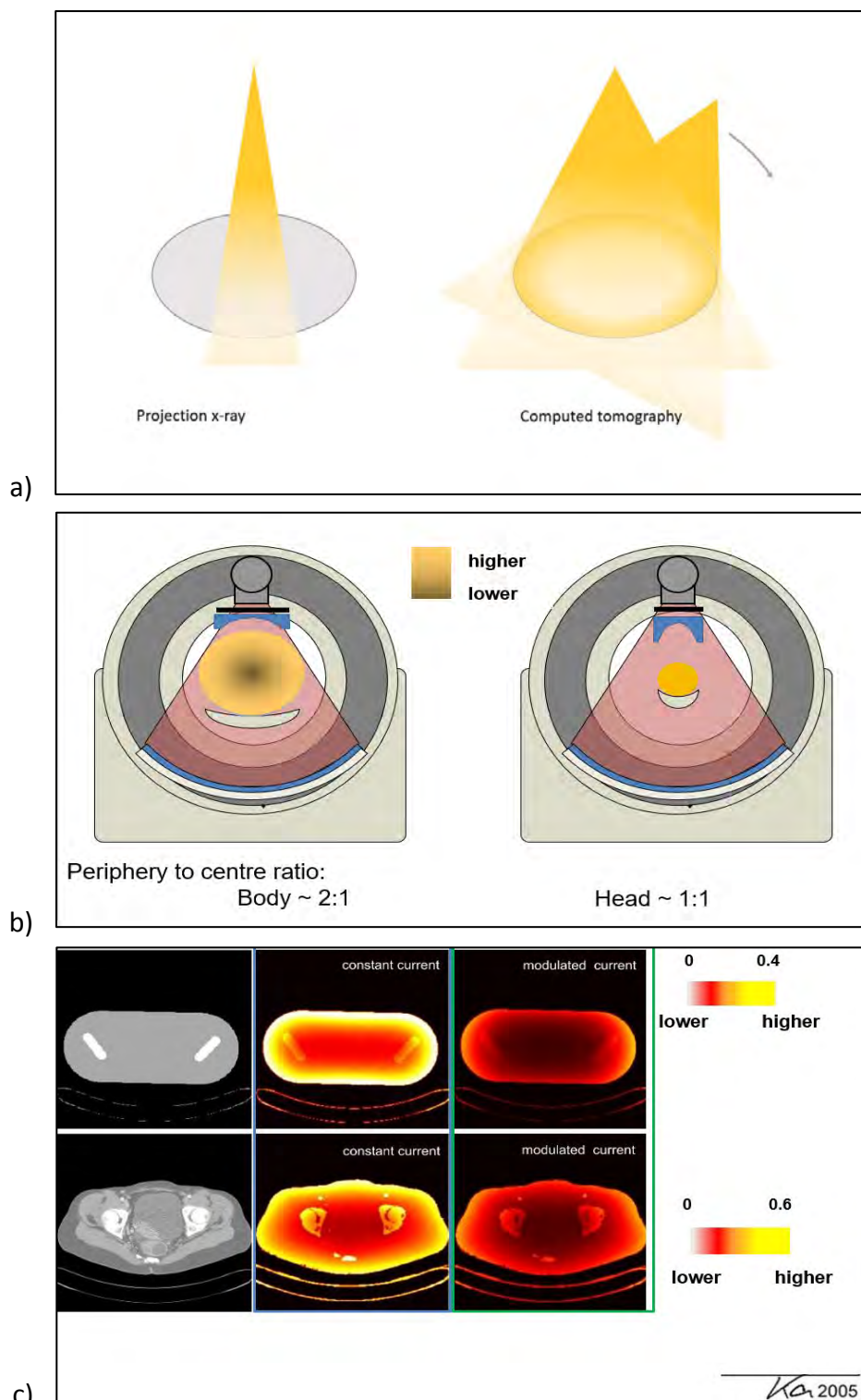


Figure 9.3

a) schematic view of dose distribution between projection radiography and X-ray CT (courtesy S. Edyvean)

b) schematic view of dose distribution of a body sized cylinder relative to a head size. (courtesy ImPACT)

c) simulated illustration of the dose distribution over the cross section of a patient – with and without tube current modulation (Kalender<sup>25</sup>).

When assessing the possible dose reduction offered by contact shielding, one approach is to measure potential dose savings within anthropomorphic reference phantoms (Figure 9.4). Monte Carlo calculations can also be undertaken on these phantoms. Even so, it must be recognised the anthropomorphic model will still deviate significantly from real life. The clinical situation brings in risk, and accuracy, factors that relate to variations in body size and shape, and patient movement after or during set-up. Patient specific dosimetry calculated using the CT image itself is possible, but is unlikely to be readily utilised in the near future.<sup>27</sup>

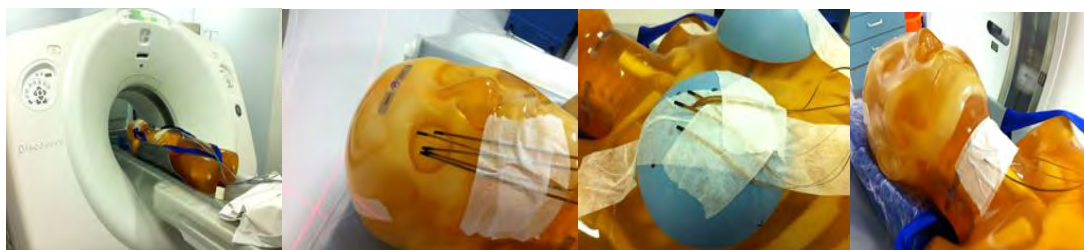


Figure 9.4 – Examples of use of anthropomorphic phantom to assess organ dose in CT (courtesy Rob Loader).

### 9.2.2 The use of shields in CT

More discussion on the use of shields in CT is given in the in-plane and out-of-plane sections of this chapter. A short summary is included within this section.

It is widely recognised that the optimisation of any CT scan acquisition should be the first step before any shielding is considered. This is where the most significant gains in dose saving (and therefore reduction of risk) can be made, without many of the risks and limitations associated with the use of patient shielding in CT.

The use of shields in CT for in-beam and out of beam shielding has extensive coverage in the literature.<sup>28-43</sup> They have been used in particular for thyroid, breast, eye and abdomen (fetus). Examples are shown in Figure 9.5. Their use may seem attractive, bearing in mind the ICRP 2007 recommendations of increased weighting factors for breast tissue in the calculation of effective dose, as well as growing evidence to suggest a reduced threshold for cataract induction culminating in a lower dose limit for exposed workers<sup>7,8</sup>. However, as discussed in this chapter, the potential for image quality detriment and error must be considered.

When used for in-beam protection, such as for eyes and breast, the shield is either placed directly on the anatomy, or with an air gap produced by using air filled foam separators in order to reduce image artefacts from the high atomic number of the shield material.<sup>28</sup>

Outside beam shielding has primarily been explored for shielding of the fetus in chest CT examinations where pulmonary embolism is suspected in pregnancy and for protecting the thyroid.

Materials that have been used in the literature are either lead (whether specific products, or lead aprons), barium, bismuth, or other specialised construction.<sup>13, 28–34</sup>



Figure 9.5 Examples of bismuth patient protection shields for breast and thyroid (courtesy Robert Loader)

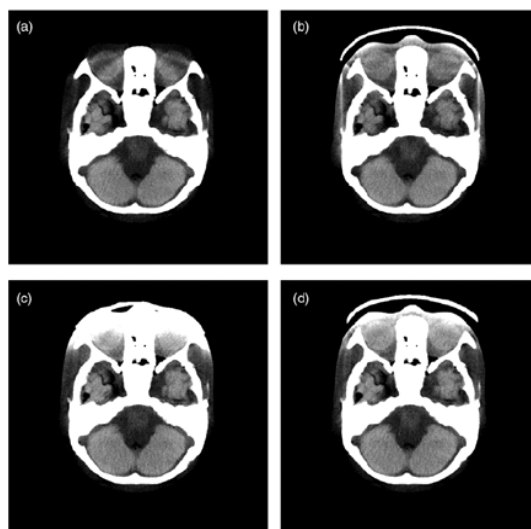
### 9.3 In-beam protection (primary beam)

#### 9.3.1 In-beam physical shields

In terms of image quality, the introduction of attenuation shields (e.g. bismuth) within the primary X-ray fan/cone beam of a CT scanner can result in false calibration assumptions and consequently give rise to associated beam hardening and streak artefacts, particularly where the shield is placed directly on the patient without stand-off material (see example in Figure 9.6).

The resultant increase in image noise and overall reduction in clinical image quality could in some cases be of higher detriment than the same examination at reduced exposure factors to match the dose saving achieved by the shield to the organs. Often, therefore, a reduction in  $CTDI_{vol}$  can achieve similar dose savings with a comparably small impact on image noise if parameters are carefully selected.

The use of in-beam physical patient shields poses particular issues when used in automatic exposure control (AEC) systems. This is addressed in section 9.5 (Influence of shielding on equipment function and image quality).



*Figure 9.6 Demonstrating typical artefacts from the use of eye shields, with and without stand-off material: a) without shield b) with barium shield c) with bismuth shield and no stand-off d) with bismuth shield and stand-off material. Reproduced with permission from Huggett et al.<sup>28</sup>*

On reviewing the literature on the use of in-plane patient protection many of the published papers demonstrate seemingly significant dose savings for a number of applications. However, this can be at the expense of image quality in terms of noise increase and artefacts.<sup>28</sup>

For example dose savings from the use of in-plane patient shields to reduce lens dose can achieve a lens dose saving of between 20-50%.<sup>12,28,32</sup>

Dose savings to the thyroid are reported as being between 25 and 40% for the use of thyroid shields during CT studies of the head and neck.<sup>32</sup> The American Thyroid Association published a policy statement on Thyroid shielding recommending the use of thyroid shielding where possible to protect the thyroid, noting the high sensitivity to radiation (especially in children). However, there is no discussion or expansion on the limitations of the use of such shielding, although much emphasis is placed on the importance of alternative optimisation strategies, referencing the Image Gently Campaign.<sup>35</sup>

Breast dose savings from the use of in-plane organ shields have been quoted in the literature of between 20 and 60%.<sup>32</sup> The actual dose saving to the breasts will vary with shape, size and position.<sup>13,36</sup>

The emergence of the use of organ shields for reducing breast dose in CT Coronary Angiography (CTCA) has coincided with the increased use of CT in the diagnosis and 'rule-out' for coronary artery disease where breast cancer risk to younger women from this technique is not insignificant. This is particularly the case if the scan is undertaken with

retrospectively ECG gated acquisitions;<sup>15,36,37</sup> fortunately with modern scanners this technique is much less frequently used. However, despite the benefit of dose reduction, the use of contact shields in CTCA has demonstrated adverse effects on image quality with varied increases in image noise and artefact in the location of the coronary arteries.<sup>36</sup> One study concluded that the use of bismuth breast shielding had no observed effect on the effects on DNA double strand breaks (implying no radiation damage) yet contributed significantly to an increase in noise and a decline in image quality.<sup>38</sup>

The American Association of Physicists in Medicine (AAPM)<sup>39,40</sup> has released a series of updated position statements concerning the use of patient shields, advising against their use in CT in favour of alternative optimisation strategies. The AAPM noted a number of significant disadvantages:

- The unpredictable and potentially undesirable levels of dose and image quality when used in conjunction with AEC systems (e.g. tube current modulation).
- Degradation of image quality and accuracy by introducing streak and beam hardening artefacts.
- Wasted radiation exposure (associated with the requirement in CT to collect projection data over at least 180°).

The latest position statement<sup>40</sup> strongly recommends fetal and gonad shielding should be discontinued as routine practice, providing negligible or no benefit with the potential to negatively affect the efficiency of the exam.

While the position statement was focused on the use of bismuth products, the learning themes can be applied to other materials offering organ dose saving (e.g. barium).

The complex relationships between CT parameters, diagnostic requirements and risk are best explored and optimised by a multidisciplinary team that should include operators, practitioners, application specialists and medical physics experts (see 5.7).

### *9.3.2 In-beam virtual shields (e.g. organ based tube current modulation)*

In the evolution of CT technology and with an eye on reduction of unnecessary dose to radio-sensitive superficial organs such as the breasts and thyroid, CT scanner manufacturers have incorporated organ based tube current modulation (Figure 9.7). These are often not available for novel applications (e.g. CTCA due to the necessity for the exposure initiation to compliment the cardiac gating cycle).

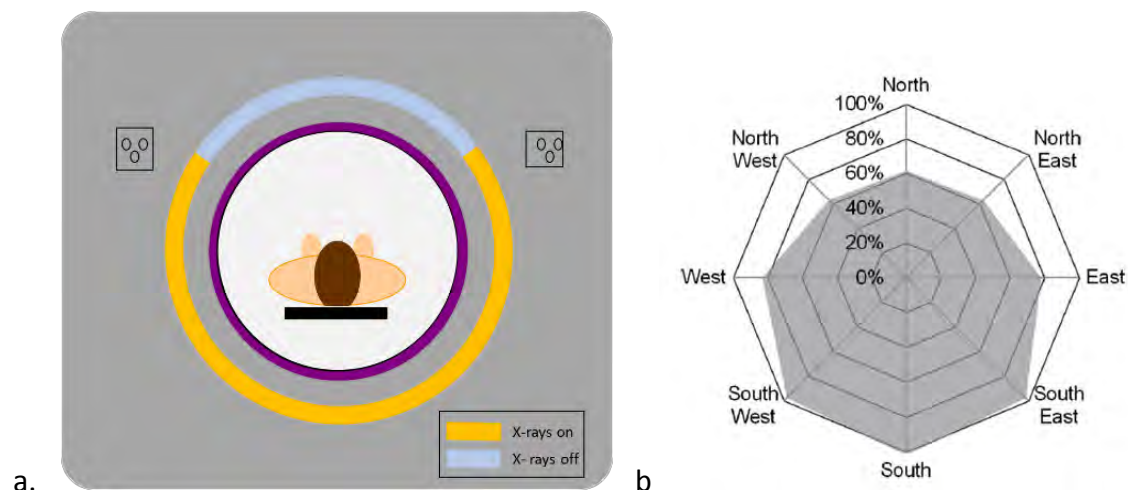


Figure 9.7 a) Schematic of the organ dose modulation. Tube current is reduced substantially, or to zero, in the anterior part of the patient and increased in the back of the patient (courtesy S. Edyvean) b) Dose with Organ Dose Modulation enabled as a percentage of dose without ODM enabled. Reproduced from Dixon et al 2016.<sup>41</sup>

In this mode, the tube current is either switched off or reduced over the arc of the rotation covering the radiosensitive organ. As most radiosensitive organs predominantly lie in an anterior location relative to the patient centre, a small net dose saving may be realised in this region. However, depending on the design of the scanner, the tube current may automatically increase during the rest of the rotation, thus giving higher doses to the remaining regions. If tube current is not increased on opposite tube locations to account for the lower tube current over the (normally anterior) arc then image noise will be higher when using such organ-based tube current modulation.<sup>41,42</sup>

Actual organ dose saving will depend on the shape, size and location of the organ in relation to the angular shadow offered by the rotational tube modulation. Another factor to consider, particularly with breast imaging, is to establish whether the breasts do fall within the reduced dose region, or whether they are included in an increased tube current region.

While a detailed review of this technology falls outside the scope of this document, it would be worth considering the use of such technology in favour of in-plane patient shields as beam hardening artefacts are avoided.<sup>41-44</sup> Careful thought must be applied to the overall benefits of the use of the virtual shield when compared to other optimisation strategies (for example the use of gantry tilt). If higher noise levels are accepted clinically with the use of either physical shielding or virtual shields, then the original protocol should be reviewed to determine the dose saving possible at this new level of image noise, thereby eliminating the need for shield use.

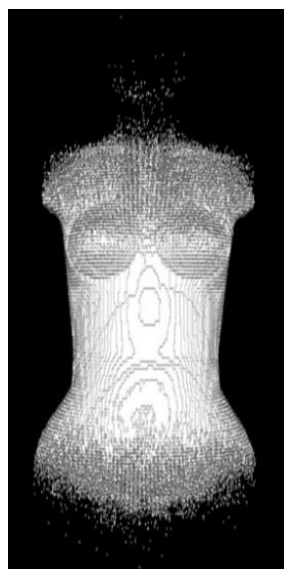
Prior to enabling organ-based tube-current modulation it is recommended to make a local scientific evaluation and literature review enabling advantages and limitations to be

conveyed to the IR(ME)R practitioner and/or operator. The advice of the Medical Physics Expert (MPE) should also be sought, as in all situations, when considering the introduction of new applications and technology.

#### 9.4 Outside beam protection

The scattered radiation extends some considerable distance from the primary beam (Figure 9.8), although the scatter dose is orders of magnitude lower than the primary beam<sup>33,45</sup> (at the level of microgray).

It can be tempting to protect the patient from these low levels of dose by applying outside beam protection – however, one consideration is that that the use of protection would have no effect on a large proportion of the scattered radiation, since most of the scattered radiation arises from scatter from within the body<sup>33,46</sup> (see also section 9.6.1.2 and Figures 9.11, 9.12).



*Figure 9.8 3D rendered view of the total absorbed dose volume in MSCT as an example of scatter coverage from just a single axial rotation centered in a body region, using 4 cm wide beam collimation (GE VCT model), 120 kV tube voltage and adult female anthropomorphic phantom model. The phantom model is CIRS ATOM Adult Female (Model 702-D) with small breasts (Model 702-BR-190). (Image Courtesy of Mika Kortensniemi, Calculated with ImpactMC program, STUK- Radiation Safety Authority & HUS Medical Imaging Center, Finland)*

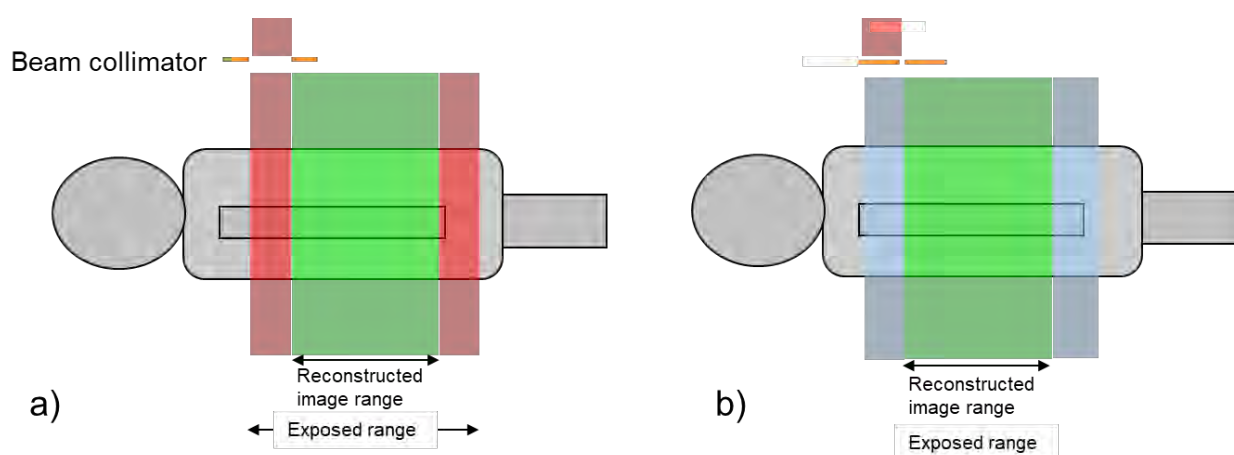
An additional consideration for the use of outside beam patient protection, compared to in-beam protection, might also be that there is no image quality detriment, such as beam hardening and photon starvation artefacts, provided the shield stays away from the primary



X-ray field. However, this is not as straightforward as it may seem, especially with helical beam scanning.

Helical scanning has a requirement to ‘overscan’ beyond the first and last image position in order to provide enough data to interpolate for those images. This may be more than one rotation, and, factoring in the beam width (which can be up to 160 mm extending along the patient axis), even a small amount of ‘overscan’ can extend a considerable non-intuitive distance beyond the image volume. The placing of out of beam protection beyond the irradiated volume is therefore not a simple, error free, task.

Some CT systems incorporate adaptive collimation to limit the contribution to patient dose from the z-axis overscan (Figure 9.9). Even so, this is still not a straightforward scenario, and there is potential for outside beam patient protection to be added in a position where image artefacts can be caused.



*Figure 9.9 Schematic illustration of dynamic, or adaptive, helical collimation a) Fixed collimator width for whole of helical scan. b) Adaptive or dynamic beam collimation. Collimator opens until fully open over reconstruction range, and then closes again at end of helical scan. (Courtesy S. Edyvean)*

For both in-beam and outside beam contact shielding, the radiation science, in terms of levels of radiation dose and radiosensitivity of organs and the social and psychological factors, must be considered.

For outside beam protection, therefore, three important factors must be considered when looking at the science behind this practice. Firstly, the level of scattered radiation dose is small compared to the primary beam. Secondly, most of the scatter occurs within the patient and therefore adding surface protection has minimal overall benefit. Thirdly, there is a risk the shield may slip into the planned image volume and adversely affect the image or AEC performance.

## 9.5 Influence of shielding on equipment function and image quality

Throughout this chapter, we have identified how image artefacts can arise from photon starvation and beam hardening effects from the use of in-plane shielding. Out-of-plane shields could potentially slip into the scan plane or clip the overscan region and adversely affect the reconstruction of the peripheral scan volume. If shields are not secured appropriately and then slip during the scan, this will induce a variety of artefacts in the image, most likely requiring a repeat scan at additional radiation risk to the patient.

One significant limitation of the use of shielding in CT that must be considered is the effect on dose and image quality if used in conjunction with the Automatic Exposure Control (AEC). CT technology uses data from the localiser series to derive the scan mA table and in some cases the peak tube voltage (kVp). Authors have reported the relative merits and limitations of positioning the shield prior to, or following, the AEC set up.<sup>31</sup> An illustration of how the use of in-plane contact shielding can influence the mA table of a CT scanner is reproduced in figure 9.10. The 2019 position statement from the AAPM summarises these limitations well and uses them with other rationale to promote alternatives to shielding in CT when possible.<sup>40</sup>

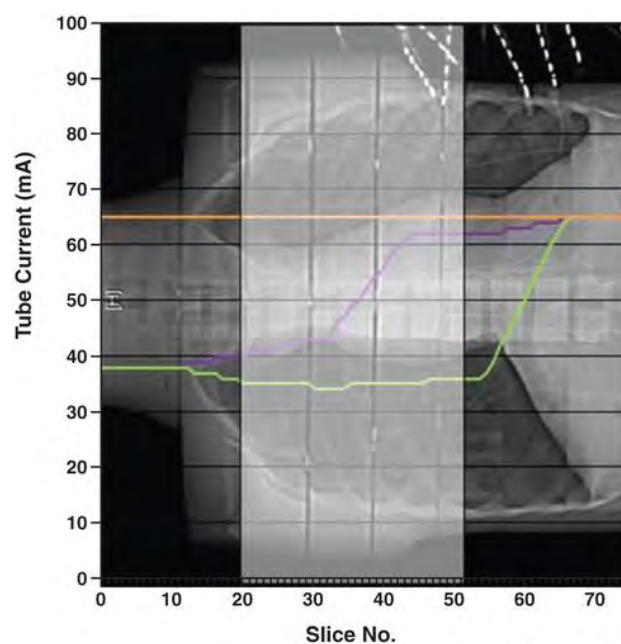


Figure 9.10.<sup>31</sup> The effect on tube current by placing the patient shield before or after the AEC set up. This is for a paediatric anthropomorphic phantom, however the principle applies for adults also. Tube current generated at each slice level for each scanning regime: z-axis Auto mA (GE Healthcare) tube current modulation, shield present in scout image (purple); z-axis Auto mA tube current modulation, shield placed after scout image was obtained (green); fixed tube current (65 mA) scanning (orange). Slice thickness was 5 mm. White rectangle indicates location of shield.

## 9.6 Special patient groups

### 9.6.1 Pregnant individuals and individuals of childbearing potential

The shielding of the fetus when a pregnant patient undergoes a CT examination of the chest (for example for suspected pulmonary embolism) is a special case of outside beam protection. The scientific points for consideration are exactly the same. However any discussions around this may require more sensitive handling.

UK legislation<sup>17</sup> requirement is for justification and optimisation of the use of ionising radiation in all radiological imaging procedures, paying particular attention to pregnant individuals, and individuals of childbearing potential. As such the use of CT scanning during pregnancy should be strictly limited to those occasions when it is deemed to be entirely necessary, and steps should be taken to limit the radiation dose so long as the quality of the generated images is consistent with the intended purpose of the examination.

Outside beam shielding, has been advocated in CT for protection of the fetus of pregnant patients undergoing head, neck, chest or extremity CT scans.<sup>33,34,47</sup> This is in particular where chest CT imaging is undertaken for suspected pulmonary embolism.

However a recent literature review article, 2018,<sup>47</sup> of the use of out-of-plane high Z-shielding for fetal dose reduction in CT strongly advocates that there are many optimisation strategies available and that the current status of CT technology, with correct use of AEC and iterative reconstruction, allows for significant dose reductions: 'dose sparing by high Z garments, albeit coming 'free of charge', is only to be expected if no other relevant technical or clinical parameter might be optimised and if no garment is ever placed in the primary field of view, including the over-ranging in CT imaging'.<sup>47</sup>

#### 9.6.1.1 Practice

There is a widespread difference in practice as to the use of abdominal shielding in pregnant individuals undergoing CT. A survey published by Iball *et al* in 2010<sup>34</sup> revealed that the use of lead shielding in this situation was about 72% in the UK. It was also found to vary significantly worldwide. The highest usage was in North America (95%) and the lowest usage in Europe (46%). The key benefit from this survey is that it highlighted the discrepancy in use at the time.

Chest CT imaging of a pregnant patient may occur very infrequently at any individual hospital or NHS Trust/Board. The above survey, in 2009, found that 94% of all UK survey respondents said they perform 10 or fewer scans on pregnant patients per year.<sup>34</sup>

A disadvantage to using shielding is the discomfort experienced by the patient and the manual handling issues for the staff. The same survey also reported that a quarter of all

respondents said that patients complained about the weight of the shielding and approximately 20% of all respondents (operators) said that they experienced occupationally related back pain.

#### 9.6.1.2 Doses and dose reduction

The scatter radiation comprises three components: internal, external and where patient protection is used – internally reflected back or secondary internal scatter as illustrated in figure 9.11. In terms of the overall scattered radiation dose, the contribution to the fetus from internal scatter is about 70%, external scatter about 30%, and minimal from secondary internal scatter.<sup>47</sup>

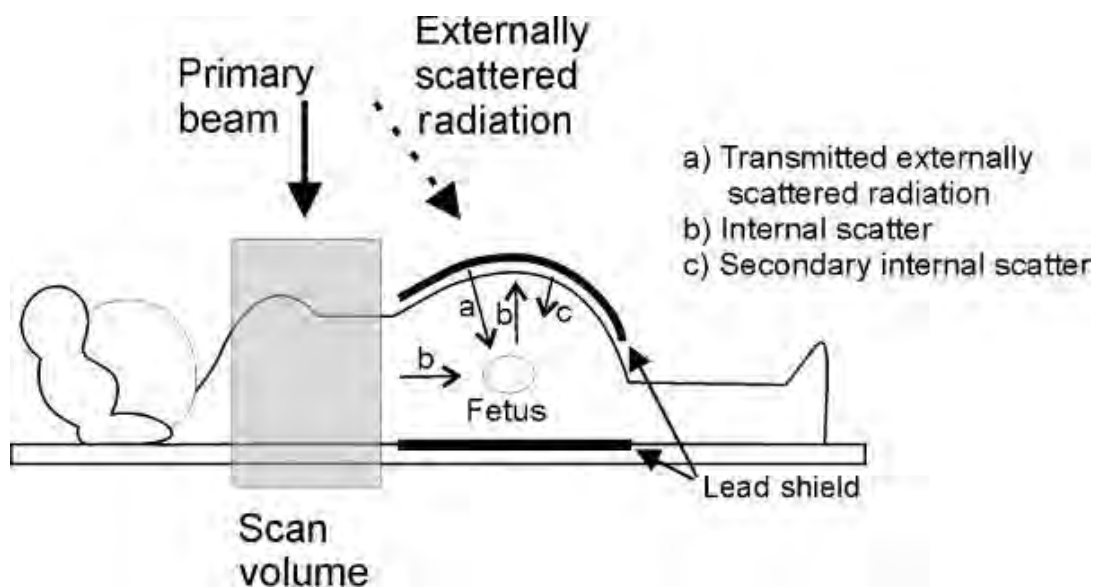


Figure 9.11 Schematic showing the three sources of scattered photons that contribute to the fetal dose from a chest CT scan. (Reproduced from Iball, Kennedy and Brettle 2008.<sup>46</sup>)

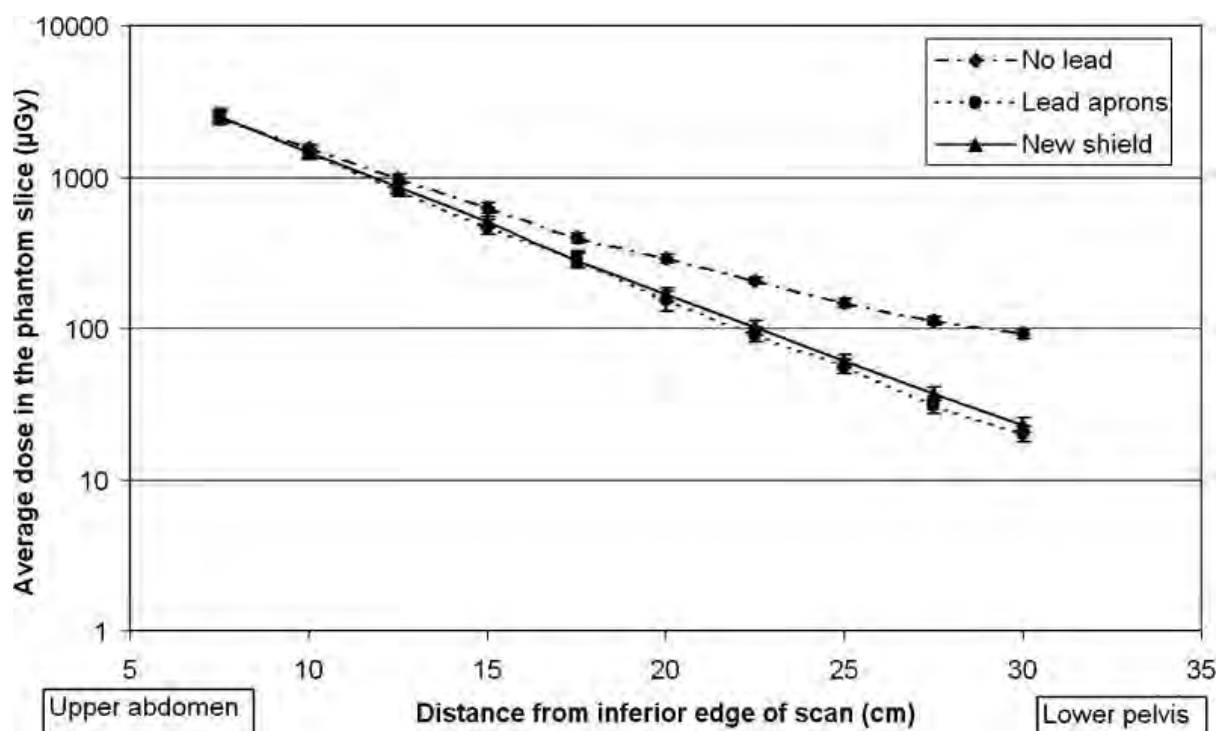


Figure 9.12 Average dose per scan for each section within the abdomen and pelvis of a (non-pregnant) RANDO phantom for three sets of CT chest scans that were performed. Error bars represent two standard errors about the mean for each section. The dose values in microgray are presented on a log scale. (Reproduced from Iball and Brettle 2011.<sup>33</sup>)

In Figure 9.12 this reduction in estimated fetal dose from scattered radiation with the use of out-of-plane shields is demonstrated as a function of distance from the inferior edge of a chest CT scan,<sup>33</sup> where patient protection is placed at a fixed position of 6.25 cm from the inferior edge of the scan. The authors used an anthropomorphic (non-pregnant) phantom scanned with a routine chest CT examination with a CTDI<sub>vol</sub> of 11 mGy. Doses to the uterine region were investigated: unshielded and shielded. Two methods of shielding were investigated; a new material wrapped around the phantom, and lead aprons positioned both anteriorly and posteriorly. Their work shows a maximum dose reduction of 35% with the new material and 42% with the use of lead aprons. This saving would be decreased further if only the anterior were protected, as is common practice. With no protection, the scatter dose at this position (30 cm from the inferior edge of the scan) is 100 microgray (Figure 9.12). Similarly, the study by Grunig *et al*,<sup>48</sup> gives Equivalent dose to the fetus of an average of 110 (range 3.7–380) microsievert.

These levels of scatter doses and percentage reduction are also presented by Ryckx *et al* who undertook a review of publications on abdominal shielding in chest CT of the pregnant patient, published in 2018.<sup>47</sup> From the 11 publications reviewed, uterus doses ranged between 60 and 660 µGy per examination, and relative dose reductions to the uterus due to high-Z garments were between 20% and 56%.

It is important to note that calculations undertaken by the authors of the review showed that reducing the scan length by one to three centimetres could potentially reduce uterus dose up to 24% for chest imaging and even 47% for upper abdominal imaging. These dose reductions were in the order of those achieved by high-Z garments.

Their conclusion was that efforts should be concentrated on positioning the patient correctly in the gantry and optimising protocol parameters, rather than using high-Z garments for out-of-plane uterus shielding.

### 9.6.2 Paediatrics

Previous discussions surrounding the use of in-plane and out-of-plane shielding also apply to paediatric CT exposures. However, it is worth highlighting the additional considerations for paediatrics.

The increased risk due to the age of the paediatric patient (see 3.3.1) has led some authors to consider the potential advantages of using in and out-of-plane patient shields to reduce organ doses to the breasts, thyroid and eyes (lens) of children.<sup>31</sup>

The Royal College of Radiologists recognises the use of in-plane shielding as “controversial”<sup>49</sup> and reiterates the significant limitations previously described; ending their discussion with the reference to the AAPM position statement.<sup>39</sup> Optimisation efforts are better focused using appropriate AEC modulation or careful selection of protocol for patient weight/BMI/age. The “Image Gently” alliance has published a great deal of work concerning the optimisation of paediatric protocols since 2006.<sup>35,50</sup> The AAPM Alliance for Quality Computed Tomography have issued paediatric protocols<sup>51</sup> and in the UK the Institute of Physics and Engineering in Medicine (IPEM) are currently undertaking work on optimisation in paediatric CT (private communication, Worrall M, 2019).

The use of out-of-beam beam shielding for paediatric patients is likely to present more difficulties than for adults, to ensure any contact shield remains away from the scanned volume, due to the small patient size and increased risk of patient movement (see 5.6).

A recent study, with a chest CT scan of a paediatric size anthropomorphic phantom, investigated extent of radiation dose reduction due to the position of the lead apron beyond the edge of the scan volume.<sup>52</sup> With increased distance of the placement of the lead apron, there was a diminished level of scatter dose reduction. This was extremely small compared with the overall dose from the examination (0.2% for the lead apron placed 10cm from the scan volume). Even when placed in close proximity to the scan volume (1 cm distance from the inferior edge) the percentage dose reduction was only 0.7% of the primary dose in the image volume. The conclusion of this study was that the small dose reduction gained from the use of lead shielding over the abdomen and pelvis during chest CT examination of

paediatric patients is not likely to outweigh the associated potential risks of artefacts and infection.

## 9.7 Recommendations for local practice

The key recommendation in this chapter is that, in CT, all optimisation approaches should be considered and applied in the first instance; and **the use of patient shielding in CT is not generally advised.**

There is considerable literature demonstrating dose reduction with the use of patient contact shielding, many of which are on phantom studies; however there is a stronger argument against the use of patient protection which is also supported in recent statements and review articles.<sup>32,46</sup> The prime reasons against the use of patient protection are; for in-beam protection, the effects on image quality and interference with automatic exposure control settings; and, for out-of-beam, the potential for artefacts from misplaced protection. Considerations for reassurance of the patient or carer, suggest that the use of patient protection may either reassure, or frighten; and therefore strong, informed, guidance from the radiology professionals is required, while bearing in mind the perspective of each patient.

If the IR(ME)R practitioner believes there is a strong argument to justify the use of physical patient shielding in CT (in-beam or otherwise), the protocol should be carefully optimised in collaboration with the operator, the medical physics expert and applications specialist. Ahead of any clinical exposure it is strongly recommended that the diagnostic value of the CT study is assessed having considered the impact on image quality. Operators will need to be appropriately trained regarding positioning, sequence of positioning (considering the use of AEC) and the implications of an inappropriately positioned shield, or one that slips ahead of or during the scan. Operators should also be trained to be able to answer patient (or representative) questions relating to the use of the shield and the benefits and limitations.

It is highly likely that similar or even larger dose savings can be achieved by carefully considering alternative optimisation strategies that will not introduce significant artefact into the image. Aside from other justification and optimisation strategy that is likely to have similar (if not greater) impact on organ or fetal dose, the following questions should be asked prior to any consideration to use patient shields:

### 1. *Why am I considering the use of contact shielding in CT?*

While not generally advised, any use of contact shielding should be considered carefully by a multi-disciplinary team, and written into examination protocols ahead of use. Its selection simply to reassure the apprehensive patient should be discouraged as this promotes mixed messages and an exaggeration of radiation risk

to the patient and wider community. Instead efforts should concentrate on explaining the risks from the use of contact shields to the patient.

**2. What is the likelihood and consequence of the contact shielding interfering with the AEC?**

If optimised for the given procedure, the AEC is arguably the best tool to optimise the patient exposure for the intended diagnostic purpose. If the contact shield is scanned (either deliberately or inadvertently) during the CT localiser series then the patient exposure is likely to be significantly higher than intended, undoing any small intended benefit.

**3. What is the effect on image quality from the introduction of contact shielding?**

In-plane contact shielding leads to photon starvation and beam hardening artefacts in the CT image (especially where stand-off material is not employed between the patient–shield interface). Out-of-plane shielding aims to limit external scatter and extra focal radiation from the tube/collimator assembly to the patient. Any potential dose saving is a small fraction of the overall scattered dose (external and within the patient). There is a risk of out-of-plane shielding causing artefacts when placed too close to, or slipping into, the scanned volume.

The recommendations within this report for Computed Tomography are therefore:

Scenario	Recommendation	Comments
In-plane organ contact shielding (adult and children)	Not recommended Ensure optimisation by alternative means wherever practicable.	Adverse effects on image quality Unpredictable AEC performance - rendering it ineffective, or even resulting in higher dose
In-plane contact shields to protect the lens for patients where frequent follow up head CT likely	Not recommended Ensure optimisation by alternative means wherever practicable.	Often low dose protocols can achieve the required diagnostic outcome e.g. when assessing shunt patency or ventricle size. (If there is a strong basis for protection on an individual basis, an air gap should be considered.) If considering, a careful review of likely image quality in line with the diagnostic purpose needs to be performed.
Out-of-plane organ contact shielding (adult and	Not recommended	Actual dose savings will be low. Not possible to limit internal scatter. Highest savings when shield close to edge of



children)		scanning volume but more likely to interfere with AEC if close An adequate distance to rule out misplacement or movement of protection then renders the reduction in external scatter minimal.
Out-of-plane contact shielding to protect fetus in pregnancy	Not recommended	Actual dose savings will be low. Not possible to limit internal scatter. Highest savings when shield close to edge of scanning volume but more likely to interfere with AEC if close. An adequate distance to rule out misplacement or movement of protection then renders the reduction in external scatter minimal.
In-plane contact shielding of the Gonads	Not recommended	Little evidence, careful thought required to positioning. Testes are not listed as an ICRP radiosensitive organ (for cancer incidence) Adverse effects on image quality for pelvis examinations (especially if protecting the ovaries). Hereditary effects associated with typical dose range are likely to be negligible
Out-of-plane contact shielding of the Gonads	Not recommended	Little evidence Not possible to limit internal scatter (especially for ovaries) Testes are not listed as an ICRP radiosensitive organ (for cancer incidence) Hereditary effects associated with typical dose range are likely to be negligible

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## Chapter 10 Mammography

The use of patient contact shielding **is not recommended** for mammography (see section 10.4). Where patient contact shielding is being considered, the guidance in these chapters should be considered.

### 10.1 The anatomy and concept behind shield application

Only the imaged breast should be subject to the primary X-ray beam and receive an intentional radiation dose. Therefore in-beam patient protection is not applicable in mammography.

The radiation dose to all other organs at risk (e.g. the lens of the eye, thyroid and salivary glands, and bone marrow) is extremely low or negligible and is mainly due to X-rays that scatter in the breast tissue and enter the trunk through the breast, minimizing the benefit of using any form of patient contact shield.<sup>1,2</sup>

### 10.2 Influence of shielding on equipment function and image quality

Mammography machines are designed to ensure patient safety, incorporating internal radiation shielding which prevents stray radiation. In general, the use of additional shielding is unnecessary.

Due to the specific equipment geometry employed, applying protection to organs lying close to the X-ray field, such as the thyroid or eyes, may interfere with imaging or cause artefacts that would necessitate repeat imaging of the breast. The additional risk to the patient from repeat imaging would be much greater than the risk reduction due to the use of a protective shield. Any applied shielding may also interfere with the radiographer positioning the patient, where proper positioning is critical to obtaining a high quality mammogram. They could also inhibit the movement of the equipment when performing oblique views. Any repeat imaging may also increase the patient's discomfort and anxiety. Therefore, thyroid shields should never be used in mammography, since they are not useful and may be very problematic.<sup>3,4,5</sup> The use of other protective shielding during mammography, such as a leaded garment placed around the lower torso, is also not recommended.

### 10.3 Special patient groups – pregnant patients

Most studies describe the uterus organ dose as “unmeasurable”. Thus the use of a shield to cover the abdomen of women undergoing mammography is neither necessary nor recommended. However, since patient contact shields covering the abdomen would not

generally interfere with the imaging, they may be given to a patient at their request, but not routinely as part of the imaging protocol.<sup>3</sup>

#### 10.4 Recommendations for local practice

Scenario	Recommendation	Comments
Patient contact shielding for mammography	Not recommended	No radiation protective shielding should be routinely applied to patients undergoing a mammographic examination

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## Chapter 11 Shielding in dental radiography

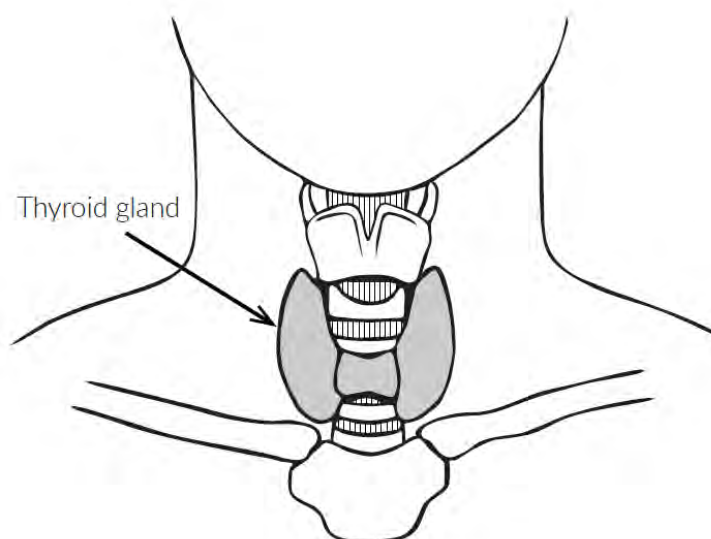
The use of patient contact shielding **is not recommended** for dental radiography for the majority of imaging situations (see section 11.7). Where patient contact shielding is being considered the guidance in these chapters should be taken into account.

### 11.1 Organs at risk

The organs at risk are those in or near the primary beam, these being the thyroid, lens of the eye, brain and salivary glands.<sup>1-5</sup> The abdomen of a pregnant patient could potentially be included in the primary beam for the vertical occlusal intraoral radiograph,<sup>3</sup> but is unlikely to be included for any of the other projections.

### 11.2 The anatomy and concept behind shield application

The thyroid surrounds the trachea, lying in the lower neck (see Figure 11.1) and in the case of dental radiography is the organ most sensitive to radiation that can be readily shielded<sup>3-7</sup> with an appropriately placed thyroid collar. The radio-sensitivity of the thyroid is considered to decrease as age increases<sup>4</sup> (see Figure 3.4).



*Figure 11.1 Illustration of thyroid gland location within the neck<sup>8</sup>*

Other organs such as the brain and salivary glands may be included in, or lie close to, the primary beam. It is likely that shielding of these organs would obscure diagnostic information. The eyes should lie outside the primary beam, but may receive a dose from secondary radiation due to their proximity to the anatomy of interest.



### 11.3 In-beam protection (primary beam)

There is a range of contradictory information regarding the shielding of organs at risk in dental radiology. The Dental Guidance Notes<sup>9</sup> and the European Guidelines<sup>4</sup> recommend that, for adult intra-oral radiography, in-beam shielding should not be necessary where equipment complies with the UK recommendations for cone length (focus to surface distance of 200 mm or more for equipment operating at 60 kV or greater<sup>9</sup>) and shape (rectangular collimation is recommended limiting the beam at the end of the collimator to no more than 40 by 50 mm, and ideally to no more than 35 by 45 mm<sup>7,9</sup>) and dimensions. However The American Thyroid Association<sup>2</sup> in their policy statement urges consideration of thyroid shielding for all dental radiographs and The American Dental Association Council<sup>3</sup> and NCRP report 177<sup>7</sup> recommends that thyroid collars shall be used where possible.

Rush *et al*<sup>10</sup> demonstrated that the paralleling technique can reduce dose by more than 65% and rectangular collimation can reduce doses by over 45% compared to a round collimator. A study by Hoogeveen *et al*<sup>11</sup> indicates that when rectangular collimation is used, thyroid shields only provide a significant dose saving for exposures of the upper anterior region.<sup>12</sup> An example of this is the vertical (vertex) occlusal projection, where a thyroid shield may reduce thyroid dose by up to approximately 36%.<sup>1</sup> It has been shown that the choice of exposure factors, technique and collimation will reduce doses as much, or more than the use of a thyroid shield.<sup>10–13</sup>

While the evidence for the use of a thyroid collar in intra-oral radiography is mixed, a focus on good technique including using rectangular collimation and beam aiming devices, paralleling technique and a suitable detector<sup>4,7,9,11,13,14</sup> will reduce doses significantly and any subsequent reduction from use of a thyroid shield will be negligible.

In panoramic, cephalometric and dental cone beam computed tomography (CBCT) imaging, the specification of the equipment should be taken into account when considering the need for a thyroid collar. Where there is limited collimator adjustment available it may not be possible to exclude unnecessary thyroid gland from the primary beam – however, careful attention to correct positioning should minimise this occurrence. Should a thyroid collar be used, there is potential for this to obscure the required anatomy, if the collar is positioned lower to avoid this then it is likely to render dose savings negligible.

For panoramic and cephalometric imaging, the use of a thyroid collar is therefore not recommended. In the case of CBCT, some studies have indicated that a thyroid shield may reduce the effective dose to the patient<sup>6,15,16,17</sup> in the region of approximately 10% to 46% for large fields of view for paediatric imaging. However, where the field of view may be suitably restricted and the thyroid not included in the primary beam then the effectiveness of a thyroid collar would be reduced. A recommendation of the Public Health England

(formerly the Health Protection Agency) guidance on the Safe Use of Dental Cone Beam CT<sup>16</sup> states: *“As the thyroid gland should not normally be in the primary X-ray beam during dental CBCT examinations conducted using suitable equipment the working party does not consider it necessary to recommend the routine use of thyroid shields. Where thyroid shielding is used it must be positioned so that it does not interfere with the primary beam since this could lead to significant artefacts rendering the image diagnostically unacceptable.”*

While it is generally considered that patient contact shielding should not be used, the limited information published for dental CBCT indicates that a dose reduction may still be achieved.<sup>6,14</sup> If shielding were to be used it is strongly recommended that an MPE is consulted first as there is the potential to introduce artefacts to the image should a thyroid collar enter the useful imaging volume.<sup>6</sup>

#### **11.4 Outside beam protection**

For shielding of the thyroid gland, the discussion in section 11.3 remains relevant due to the proximity of the thyroid gland to the primary beam. However the primary beam in dental radiology is highly collimated and radiation dose to areas other than that intended (including the gonads and the abdomen) is likely to be caused by internally scattered radiation which externally applied shielding is ineffective against.<sup>4,5</sup>

#### **11.5 Influence of shielding on equipment function and image quality**

Intra-oral units are not routinely equipped with AEC devices. As such the use of shielding is unlikely to have an effect on the function of these units.

Panoramic, cephalometric and dental CBCT units may be equipped with AEC. Should a thyroid shield stray into the primary beam it may result in an increase in the dose to the patient as the X-ray unit increases output to compensate for the high level of attenuation detected. If prospective (real time) AEC is utilised then a thyroid shield is NOT recommended. Where the AEC systems utilises a pre-scan to determine the necessary exposure factors a thyroid shield should NOT be worn during the pre-scan even where the decision has been taken to use a shield for the imaging portion of the examination.

#### **11.6 Special patient groups**

Pregnancy should not preclude dental radiology in the form of intra-oral, panoramic and cephalometric examinations.<sup>4,9</sup> However, dental radiology is often avoided for psychological reasons. In the case of intra-oral examinations, shielding of the abdomen should be considered for a view that may result in the primary beam being directed towards the abdomen. Use of the paralleling technique should generally avoid this. Efforts should

therefore be focussed on good practice (rectangular collimation and maintaining dose as low as reasonably practicable commensurate with obtaining an image of suitable quality). For CBCT the secondary radiation dose is highly variable depending on make and model and design. Shielding would therefore need to be considered for pregnant patients – however, the clinical indications for CBCT are limited and it may be more appropriate to postpone imaging until after pregnancy.

For paediatric patients, the thyroid gland is more sensitive than for adults (see Figure 3.4). As such a thyroid shield may provide some protection. However, in the first instance, the use of a rectangular collimator should be used and a focus placed on good technique.<sup>4</sup>

### 11.7 Recommendations for local practice

Scenario	Recommendation	Comments
All dental radiology, protection of brain, salivary gland and lens of the eye	Not recommended	Eyes should not be in the primary beam. Not possible to shield the other organs without obscuring required anatomy
Intraoral radiography	Not recommended	All European guidance regarding good practice should be followed. Use of rectangular collimation, beam aiming devices, film/detector speed and paralleling technique to be used first. Where inclusion of thyroid is unavoidable, use of patient contact shielding in consultation with MPE.
Panoramic and cephalometric radiography	Not recommended	Care should be taken with patient positioning and selection of appropriate exposure factors.  Thyroid collar must not be used with AEC without consultation with MPE
Dental CBCT	Not recommended with the exception of large FOV units, where there may be some benefit. In	Insufficient evidence for small field of view but effectiveness of a thyroid shield is likely to be low due to the exclusion of the thyroid from the primary beam and the reduction in

	which case it is recommended that the MPE is consulted	secondary radiation from tighter collimation. The use of a thyroid collar may lead to artefacts in the images. An MPE should be consulted where the use of a thyroid collar is to be considered, such as units with a large FOV.
Pregnant patients	Not recommended	For intraoral radiography, use of the parallel technique is recommended. If X-ray beam MUST be directed towards the abdomen then patient contact shielding (e.g. lead apron) covering the abdomen should be considered. May be considered for psychological purposes of reassurance as unlikely to be detrimental to the diagnostic quality of the images.

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## Chapter 12 Glossary

This document follows the UK legislation definitions<sup>1,2</sup> which are reproduced below and compared with definitions in the EC Basic Safety Standards Directive<sup>3</sup> (BSSD) and the IAEA Basic Safety Standards<sup>4</sup> (BSS). These terms are not job titles but refer to the role and responsibilities undertaken.

### **Operator**

“Operator” means any person who is entitled, in accordance with the employer’s procedures, to carry out practical aspects including those to whom practical aspects have been allocated, medical physics experts and, except where they do so under the direct supervision of a person who is adequately trained, persons participating in practical aspects as part of practical training;

In the EC BSSD this equates to: *individuals entitled to carry out practical aspects of medical radiological procedures.*

### **Practitioner**

It is important not to confuse the term IR(ME)R Practitioner with other uses of the term practitioner in the medical field. Under the UK legislation:

“Practitioner” means a registered health care professional who is entitled in accordance with the employer’s procedures to take responsibility for an individual exposure;

This is similar to the EC BSSD definition: *“practitioner” means a medical doctor, dentist or other health professional who is entitled to take clinical responsibility for an individual medical exposure in accordance with national requirements;*

This is assumed equivalent to the IAEA BSS ‘*radiological medical practitioner*’. Where a *radiological medical practitioner has assumed responsibility for protection and safety in the planning and delivery of the medical exposure ...*

### **Medical Physics Expert, MPE**

MPE means an individual or a group of individuals, having the knowledge, training and experience to act or give advice on matters relating to radiation physics applied to medical exposure, whose competence in this respect is recognised by the competent authority; which in the UK is the Secretary of State. This is identical to the EC BSSD definition.

This is assumed equivalent to the IAEA BSS ‘*Medical Physicist*’. Defined as a health professional with specialist education and training in the concepts and techniques of applying physics in medicine and competent to practise independently in one or more of the subfields (specialties) of medical physics. Where the competence of persons is normally

assessed by the State by having a formal mechanism for registration, accreditation or certification of medical physicists in the various specialties (e.g. diagnostic radiology, radiation therapy, nuclear medicine).

### **Referrer**

*“Referrer” means a registered health care professional who is entitled in accordance with the employer’s procedures to refer individuals for exposure to a practitioner.*

This is similar to the EC BSSD definition: *“Referrer” means a medical doctor, dentist or other health professional who is entitled to refer individuals for medical radiological procedures to a practitioner, in accordance with national requirements;*

This is assumed equivalent to the IAEA BSS ‘referring medical practitioner’.

### **Registered health care professional**

*“Registered health care professional” in the UK, means a person who is a member of a profession regulated by a body mentioned in section 25(3) of the National Health Service Reform and Health Care Professions Act 2002(a).*

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