

# Radiation Safety Training Module: Diagnostic Radiology

## Planning of Diagnostic X-ray Installations

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Radiological Safety Division  
Atomic Energy Regulatory Board

# Contents

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- Expected questions to know after studying this lecture
- Introduction
- Types of Radiation
- Shielding
- Various Modalities of Diagnostic X-ray Equipment
- General Principles of Planning of X-ray Installations
- Codal Requirements for Room Layout Plan of X-ray
- Installation
- General Recommendations for Layout Planning
- Reference Data on shielding of X-ray Installation Room
- Summary
- Expected Questions
- References and sources for additional information

## Expected questions to know after studying this lecture

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- What is the purpose of layout planning of X-ray Installation?
- What is Half value Thickness of shielding material?
- What is Tenth Value Thickness of shielding material?
- What do you mean by workload of an X-ray installation?
- Understanding the concepts of Use factor and Occupancy factor.
- AERB Dose limits of worker and members of public.

# INTRODUCTION

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- Radiation safety is important in diagnostic radiology, not only because of regulatory requirements but also because of radiation workers, members of public and patient safety considerations.
- In Radiation Protection, the guiding philosophy is ALARA (as low as reasonably achievable).
- In Diagnostic Radiology, the main source of occupational exposure is scattered radiation from the patient – particularly in fluoroscopically guided procedures.

# OBJECTIVES

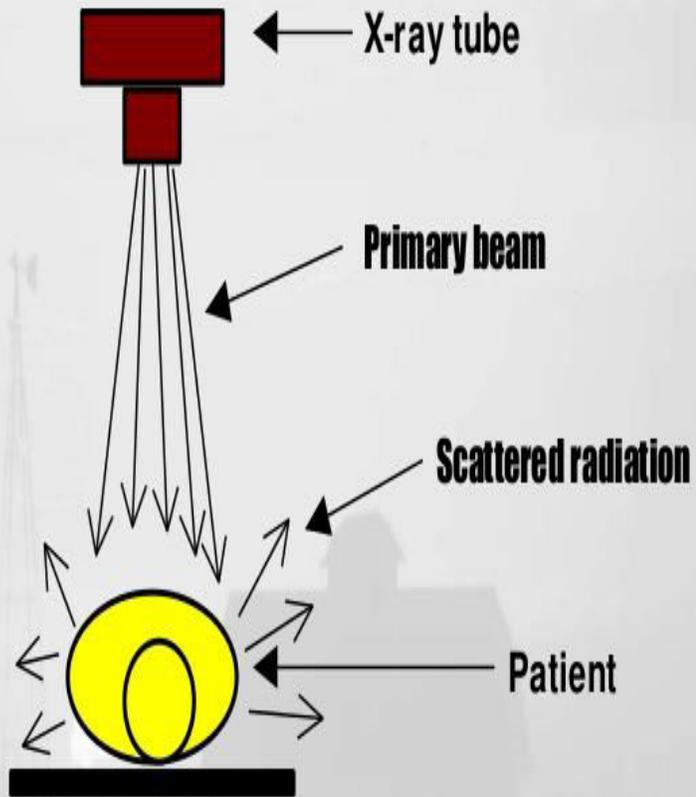
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The Objective of radiation shielding in diagnostic x-ray facilities is to protect

- Workers of X- ray department
- Members of the Public
- Persons working adjacent to or near the X-ray facility

**The purpose of layout planning of medical X-ray facility is to ensure that radiation exposure to radiation workers and members of the public does not exceed the dose limits prescribed by competent authority( i.e. Chairman, AERB).**

# Types of Radiation



**Primary Radiation:** Primary radiation (also called as useful beam) is the radiation emitted directly from the x-ray tube that is used for patient imaging.

**Primary Barrier:** It is a wall, ceiling, floor or other structures that will intercept radiation emitted directly from the x-ray tube.

**Secondary Radiation:** Secondary radiation consists of x-rays scattered from the patient and other objects such as imaging hardware and leakage radiation from the protective housing of the x-ray tube.

**Secondary Barrier:** A secondary barrier is a wall, ceiling, floor or other structures that will intercept and attenuate leakage and scattered radiation emitted from patient and other objects.

## SHIELDING

- Shielding in diagnostic radiology is used to **reduce exposure to radiation workers and the members of general public**. The decision to utilize shielding, its type and thickness are functions of photon energy and intensity of ionizing radiation.
- As the thickness of the shielding material is interposed between X-ray beam and the point of interest (e.g. location of technologist) increases, the exposure rate decreases exponentially.
- If  $I_0$  (R/Min) is the intensity of radiation beam at a point without shielding and  $I$  (R/Min) is the intensity when a thickness ( $t$ ) of a shielding material is interposed between the source and the point .
  - $I = I_0 e^{-\mu t}$
- where  $\mu$  is called the linear attenuation coefficient and represents the fraction of x-ray energy removed from the incident beam by unit thickness of the shielding material.

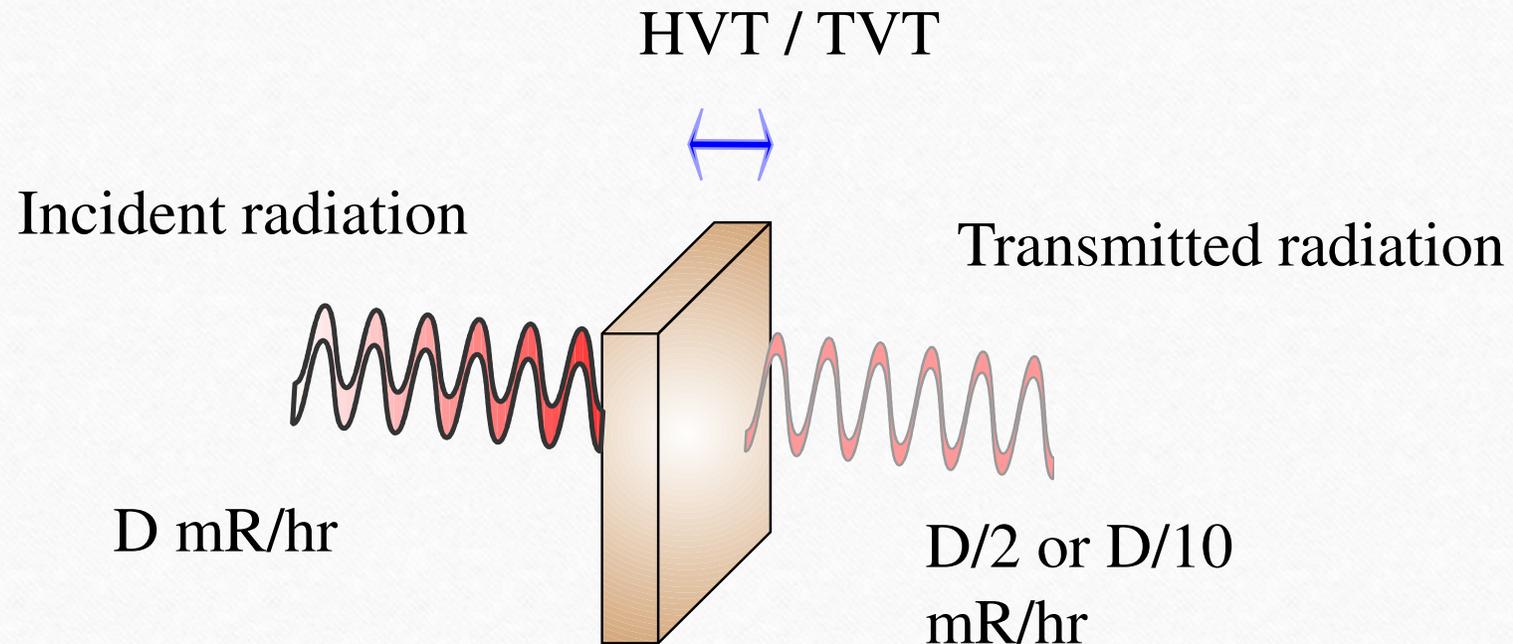
$$I/I_0 = e^{-\mu t}$$

$$I_0/I = e^{\mu t}$$

$$\log_e (I_0/I) = \mu t$$

## SHIELDING...

Thickness of protective shielding is necessary to reduce the exposure rate from any x-ray machine to the desired permissible level.



## SHIELDING...

**HALF-VALUE THICKNESS (HVT)** : Thickness of a specified material which, when introduced into the path of a given beam of radiation, reduces its initial intensity to one half.

$$I_0/I = 2 = e^{-\mu t_{1/2}}$$

$$\log_e 2 = 0.693 = \mu t_{1/2}$$

$$\mu = 0.693/t_{1/2}$$

**TENTH-VALUE THICKNESS (TVT)** : Thickness of a specified material which, when introduced into the path of a given beam of radiation, reduces its initial intensity to one tenth.

$$I_0/I = 10 = e^{-\mu t_{1/10}}$$

$$\log_e 10 = 2.303 = \mu t_{1/10}$$

$$\mu = 2.303/t_{1/10}$$

## SHIELDING...

Peak Voltage (kV)	Lead (mm) HVL	Concrete (cm) HVL
50	0.06	0.43
100	0.27	1.6
125	0.28	2.0

Peak Voltage (kV)	Lead (mm) TVL	Concrete (cm) TVL
50	0.17	1.5
100	0.88	5.3
125	0.93	6.6

# Modalities of Diagnostic X-ray Equipment

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The following modalities of X-ray equipment are used in diagnostic radiology:

- Radiography (Fixed, Mobile, Portable)
- Interventional Radiology, C-Arm
- Computed Tomography
- Dental Radiography [ Dental (intra-oral), OPG, Dental CBCT]
- Mammography
- Bone Mineral Densitometer
- Any of the above x-ray equipment mounted on vehicles

# General Principles of Planning of X-ray Installations

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Three steps should be taken to ensure permissible level of radiation protection in X-ray facilities:

- A. Preparation of facility plan
- B. Consideration for room layout plan
- C. Determination of parameters governing shielding requirements.

# General Principles of Planning of X-ray Installations

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The amount of shielding required depends on a number of factors, including:

- Type of equipment
- Workload
- Type of radiation: e.g. useful beam, leakage, or scattered
- Distance from the radiation source or the scattering source to the occupied area
- Type of area: controlled or uncontrolled

# General Principles of Planning of X-ray Installations...

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## Workload in Diagnostic Radiology

- Workload is the X-ray unit output/week at well defined point.
- Workload is based on tube current and 'beam- on' time.
- It is the amount of time that the x-ray beam is producing radiation multiplied by the tube current, measured in **mA.min/week**.
- Workload is determined by the type of examination and corresponding exposure techniques (kV and mAs), average number of films per procedure, and average number of patients per week.

## Workload in Radiography (mA-min/week)

$$W = \text{No. of patients/day} * \text{No. of days/week} * \text{No. of films/patient} * \text{mAs/film} * 1\text{min}/60\text{sec}$$

## Workload in Computed Tomography (mA-min/week)

$$W = \text{No. of patients/day} * \text{No. of days/week} * \text{No. of slices/patient} * \text{mAs/slice} * 1\text{min}/60\text{sec}$$

## General Principles of Planning of X-ray Installations...Typical Workload of Diagnostic Radiology Facility

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Type of facility	Typical No. of patients (N)/week	Total Workload per Week (mA-min/week)
Cardiac Angiography	30	4800
Radiography & Fluoroscopy	500	400
Mammography	200	660
Computed Tomography	300 scans/week	20,000
Dental OPG/CBCT	50 scans/ week	150

# General Principles of Planning of X-ray Installations...

## USE FACTOR (U)

It indicates the fraction of time during the radiation under consideration is directed at a particular barrier.

Area (Primary Barrier)	Radiographic Installations (U)
Floor	1
Doors and Walls	1/4
Ceiling	1/4

U=1 is used for secondary protective barriers

## General Principles of Planning of X-ray Installations...

### OCCUPANCY FACTOR (T)

It indicates the fraction of time during a week that a single individual might spend in an adjacent area.

**It is a factor related to degree of occupancy of the area.**

Occupancy level	Type of area	Occupancy Factor (T)
Full	Work area such as offices, laboratories, wards, nurse's stations, living quarters, children's play areas	1
Partial	Corridor, rest rooms, unattended parking lots.	1/4
Occasional	Waiting rooms, toilets, stairways, elevators	1/16

## General Principles of Planning of X-ray Installations...

### DOSE LIMITS

Part of the Body	Occupational Worker	Apprentices and Trainees	Members of Public
Whole Body (Effective Dose)	20 mSv in a year averaged over five consecutive years  30 mSv in any year	6 mSv in a year	1 mSv in a year
Lens of Eye (Equivalent Dose)	150 mSv in a year	50 mSv in a year	15 mSv in a year
Skin (Equivalent Dose)	500 mSv in a year	150 mSv in a year	50 mSv in a year
Extremities (Equivalent Dose)	500 mSv in a year	150 mSv in a year	50 mSv in a year

➤ *Dose limits given for occupational Worker is applicable for female workers also. However, once pregnancy is declared the equivalent dose limit to embryo/foetus shall be 1 mSv for the remainder of the pregnancy.*

➤ *Apprentices and trainees between 16 and 18 years of age.*

# General Principles of Planning of X-ray Installations...

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Shielding design goals (P) are practical values, for a single x-ray equipment, that are evaluated at a reference point beyond a protective barrier.

**Controlled Areas:** Controlled areas are those where x-ray equipment is used, such as x-ray procedure rooms and x-ray control room.

Recommended weekly shielding design goal (P) at control areas is **40 mR/week (20 mSv in a year)**.

The workers in these areas are primarily radiologists/related medical practitioners and x-ray technologists who are trained in the use of ionizing radiation and whose radiation exposure is individually monitored.

**Uncontrolled Areas:** Uncontrolled areas are those occupied by individuals such as visitors to the facility and employees who do not work routinely with or around radiation sources. Areas adjacent to but not part of the x-ray facility is called uncontrolled areas.

Recommended Weekly shielding design goal (P) at uncontrolled areas is **2 mR/week (1 mSv in a year)**.

## Codal Requirements for Room Layout of X-ray Equipment

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- The room housing an X-ray equipment shall have an appropriate area to facilitate easy movement of staff and proper patient positioning.
- Appropriate structural shielding shall be provided for walls, doors, ceiling and floor of the room housing the X-ray equipment so that radiation exposures received by workers and the members of the public are kept to the minimum and shall not exceed their respective dose limits.
- The control console of computed tomography equipment shall be installed in a separate room located outside but adjoining to computed tomography room and provided with appropriate shielding, direct viewing and oral communication facilities between the operator and the patient.
- Interventional Radiology equipment room shall have an adjoining control room with appropriate facilities for shielding, direct viewing and oral communication facilities between the operator and the patient.

## Codal Requirements for Room Layout of X-ray Equipment...

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- In case of room housing radiography equipment, chest stand shall be located in X-ray room such that no significant stray radiation reaches at control console/entrance door/ areas of full time occupancy such that the dose limits to radiation worker and members of public are not exceeded.
- **Mobile X-ray equipment, when used as fixed X-ray equipment, shall comply with all the requirements of those of fixed X-ray installation.**
- Movement of mobile X-ray equipment shall be restricted within the institution for which it is registered.
- A permanent radiation warning symbol and instructions for pregnant/likely to be pregnant women shall be posted on the entrance door of the X-ray installation, illustrating that the equipment emits X-radiation when energized.
- X-ray equipment installed in a mobile vehicle, shall be provided with an appropriate shielding enclosure to ensure adequate built-in protection for persons likely to be present in and around the vehicle. Shielding shall be provided around the equipment from all the sides up to height of 2 m from external ground surface.

## General Recommendations for Planning

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- Room should have preferably one entrance door and window if present, should be above 2 m from the finished floor level outside the x-ray room.
- The protective screen (mobile protective barrier) should be at least 2 m high in height and of sufficient width to allow at least two persons stand behind the screen during exposure.
- The mobile protective barrier should have a viewing window with size 45 cm x 45 cm and centered 1.5 m above the finished floor.
- Floor-to-floor height (the vertical distance from the top of one floor to the top of the next floor) will range from 3 to 5 m. A conventional ceiling height of 2.4 m should be adequate for Dental and DEXA rooms.
- The x-ray room should not be a throughway to another room.
- **The operator's console area should be located such that the operator has a clear panoramic view of the patient and radiation is scattered twice before entering the protective area.**

*A pragmatic approach to radiation shielding should be considered; it may be more prudent and possibly more cost effective to specify a consistent level of shielding in all boundaries in the room rather than specifying different levels of shielding in each boundary.*

## REFERENCE DATA OF SHIELDING OF X-RAY INSTALLATION ROOM

### Radiography and Fluoroscopy unit....

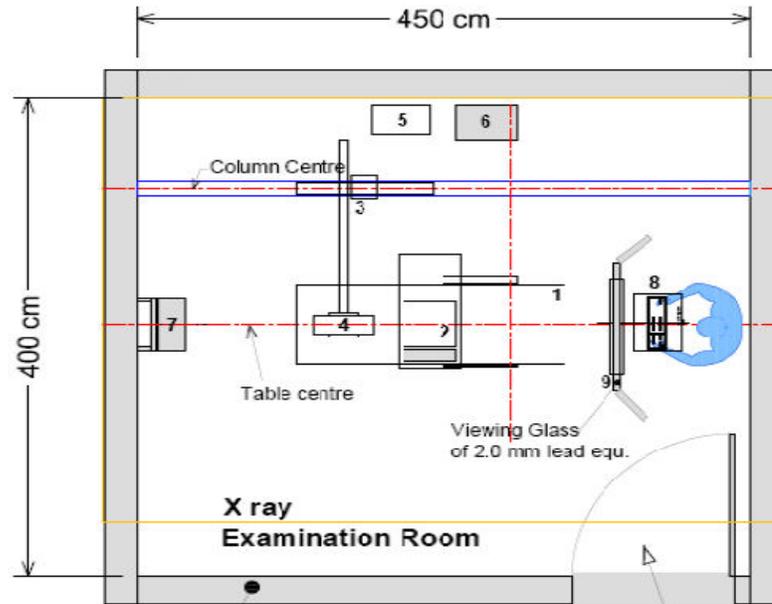
Shielding Material	Distance from centre of patient Table		
	1.5m	2.0m	Primary wall of dedicated chest x-ray installation at 2 m
Brick(cm)	23	20	20
Concrete (cm)	15	12	12
Steel(cm)	2.3	2.0	2.0
Lead(cm)	0.17	0.15	0.15
**Any other material	2.0TVT	1.8TVT	1.8TVT

**Floor(if installation is not on ground floor) and ceiling thickness of 6-8 inch concrete is adequate.**

\*\* Note: Lead free shielding material have been developed by CSIR. These materials may also be used as radiation protection in medical diagnostic x-ray installation

## Model layout of Radiography unit

## Model Layout - X-ray Installation



### Legend:

1. Examination Table
2. Spot Film Device
3. Column Stand
4. X-ray Tube Head
- 5, 6. Unit Electronics
7. Chest Stand
8. Control Unit
9. MPB with lead glass viewing window of 1.7 mm lead equivalence

All dimensions are in cm  
Scale 1:50

All walls of the Examination Room are 23cm.(9")thk.made of bricks.

Single leaf door lined with 2.0 mm lead.

Model Name:  
Manufacturer:  
Type Approval No.

Signature of applicant:

Name of the Institution:

Stamp of the Institution:

## REFERENCE DATA OF SHIELDING OF X-RAY INSTALLATION ROOM

### Interventional Radiology (Cardiac Angiography) Facility:

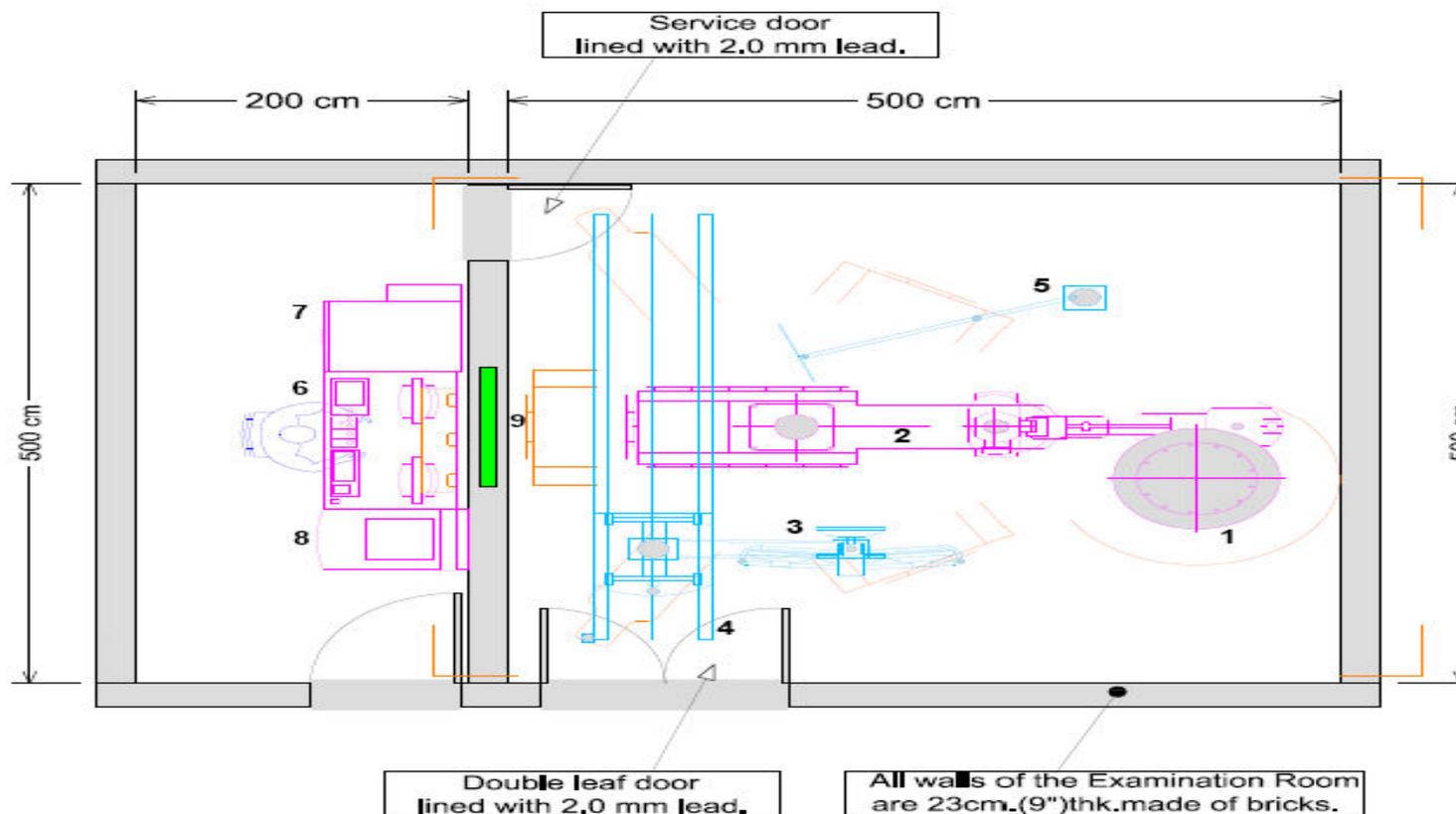
A primary barrier is incorporated into the fluoroscopic image receptor. Therefore, a protective design for a room, housing cardiac angiography unit needs only secondary protective barriers against leakage and scattered radiations.

Shielding Material	Distance from centre of Patient Table			
	1.5m	2.0m	2.5m	3.0m
Brick(cm)	25	23	20	18
Concrete(cm)	18	15	12	11
Steel(cm)	2.5	2.0	1.5	1.3
Lead(cm)	0.2	0.18	0.16	0.15
**Any other material	2.35TVT	2.0TVT	1.95TVT	1.8TVT

**Floor(if installation is not on ground floor) and ceiling thickness of 6-8 inch concrete is adequate.**

\*\* Note: Lead free shielding material have been developed by CSIR. These materials may also be used as radiation protection in medical diagnostic x-ray installation.

# Model Layout of Interventional Radiology Installation



## Legend:

- 1. C-arm
- 2. Examination Table
- 5. Fixed Radiation Shield
- 6,7,8. Control Unit
- 9. Viewing glass window of 120cm x 100cm of 2.0 mm lead equivalence

Name of Institute:	
Complete Address of Institute:	
Make of X-ray Equipment:	
Model of X-ray Equipment:	
Signature of Head of Institute:	

## REFERENCE DATA OF SHIELDING OF X-RAY INSTALLATION ROOM

### Computed Tomography units:

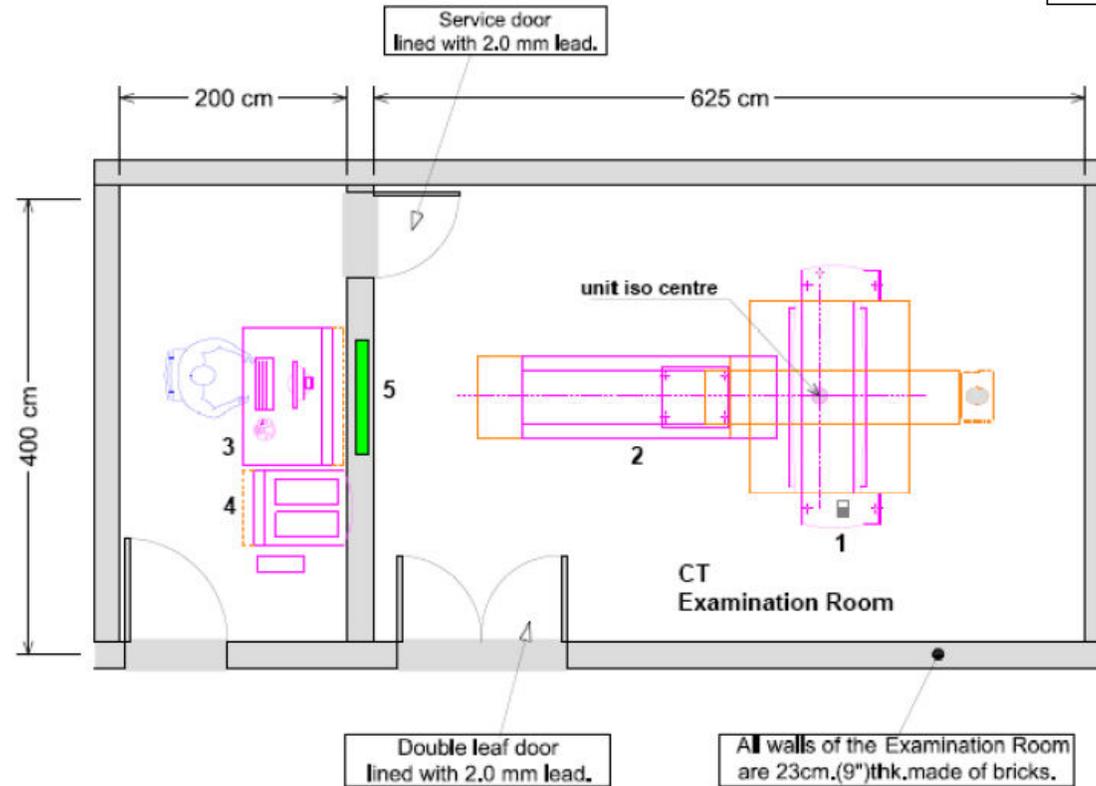
CT employs a collimated x-ray fan-beam that is intercepted by the patient and by the detector array. Consequently, only secondary radiation (primarily scattered radiation and some leakage radiation) is considered incident on protective barriers.

Shielding Material	Distance from isocentre			
	1.5m	2.0m	2.5m	3.0 m
Brick(cm)	27	25	23	20
Concrete(cm)	18	15	13	12
Steel(cm)	2.7	2.5	2.0	1.8
Lead(cm)	0.21	0.18	0.15	0.14
**Any other material	3.0TVT	2.8TVT	2.6TVT	2.5TVT

**Floor(if installation is not on ground floor) and ceiling thickness of 6-8 inch concrete is adequate.**

\*\* Note: Lead free shielding material have been developed by CSIR. These materials may also be used as radiation protection in medical diagnostic x-ray installation

# Model Layout CT-Scan



## Legend:

1. CT gantry
2. Examination Table
3. Control Unit
4. Electronics
5. Viewing Glass 100 cm X 80 cm of 2.0 mm lead equivalence

All dimensions are in cm  
Scale 1:50

Model Name:

Manufacturer:

Signature of applicant:

Name of the Institution:

Stamp of the Institution:

## REFERENCE DATA OF SHIELDING OF X-RAY INSTALLATION ROOM

Bone Mineral Density Units: Dose rate at 1m is less than allowable dose limit for public hence no structural shielding is needed even with the smallest room.

### Dental CBCT/OPG:

The primary beam can be considered to be fully attenuated by the image detector and housing assembly and therefore the only significant contribution to occupational exposure is from scatter radiation.

Shielding Material	Distance from centre of Patient Table			
	0.5m	1.0m	1.5 m	2.0m
Brick (cm)	22	17	15	12
Concrete (cm)	15	11	9.5	8
Baryte Plaster (cm)	1.5	1.0	--	--
Lead (cm)	0.22	0.17	0.15	0.12
**Any other material	2.6 TVT	2 TVT	1.72 TVT	1.4TVT

\*Considered at this distance as the foot print of this equipment is small 100cm X 150cm. Floor (if installation is not on ground floor) and ceiling thickness of 6-8 inch concrete is adequate.

\*\* Note: Lead free shielding material have been developed by CSIR. These materials may also be used as radiation protection in medical diagnostic x-ray installation

## REFERENCE DATA OF SHIELDING OF X-RAY INSTALLATION ROOM

### Mammography:

In mammography, only secondary radiation needs to be considered for shielding calculation.

Shielding Material	Distance from centre of patient Table	
	1.0 m	1.5m
<b>Gypsum Wallboard (cm)</b>	1.5	1.0
<b>Plate Glass (cm)</b>	1.0	1.0
<b>Concrete (cm)</b>	1.0	1.0
<b>Brick (cm)</b>	1.5	1.0

- Standard gypsum wallboard construction is usually adequate to shield the walls of mammography facility (as per thickness )
- Solid core wooden door ( 5 cm thick) leading to corridors outside a mammography room provide adequate shielding.
- Standard wooden doors may not be sufficient if the shielded area has significant occupancy.
- Standard concrete construction provides adequate barriers above and below mammographic facilities.
- Lead lined walls and doors are usually not required.

**WARNING PLACARD INDICATED BELOW SHALL BE POSTED OUTSIDE X-RAY ROOM**

Type of equipment:  
Model Name:  
Licence No.



**X-RAY EXAMINATION IS GOING ON INSIDE, DO NOT ENTER**

**PLEASE WAIT FOR YOUR TURN**



**CAUTION**  
IF YOU ARE PREGNANT, OR THINK YOU MIGHT BE PREGNANT, TELL THE X-RAY TECHNOLOGIST BEFORE HAVING AN X-RAY COMPLETED

**DO NOT STAY INSIDE X-RAY ROOM, IF REQUIRED TO ASSIST THE PATIENT, INSIST FOR PROTECTIVE APRON!**

Similar display shall be prepared in local/regional language

Format of warning sign to be pasted outside medical diagnostic x-ray installation

**PASTE COPY OF AERB LICENCE HERE**

To be printed in appropriate size

# Summary

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- This presentation describes room design requirements and shielding recommendations for all modalities of diagnostic radiology equipment.
- It elaborates the technical factors governing the shielding thicknesses of different materials for various medical diagnostic X-ray installations.
- It will be helpful for the medical professionals associated with use of diagnostic X-ray equipment to understand room shielding requirements of various diagnostic X-ray modalities.

## Expected questions

1. What is the purpose of shielding of medical diagnostic x-ray installation?

Ans. The purpose of shielding of medical diagnostic X-ray installation is to ensure that radiation exposure to radiation workers and members of the public does not exceed the dose limits prescribed by competent authority( i.e. Chairman, AERB).

2. What are the different parameters which governed the barrier thickness in X-ray installation?

Ans. Type of equipment, workload, type of radiation and distance from the X-ray unit.

3. What equipment need proper room layout plan?

Ans. Except mobile equipment, all diagnostic X-ray equipment need proper room layout plan.

4. What is the AERB dose limit for occupational workers?

Ans. AERB dose limit for occupational exposure is 20 mSv in a year averaged over five consecutive years.

5. What is the dose limit for female workers?

Ans. Dose limits given for occupational worker is applicable for female workers also. However, once pregnancy is declared the equivalent dose limit to embryo/foetus shall be 1 mSv for the remainder of the pregnancy.

6. What is the AERB dose limit for members of public?

Ans. AERB dose limit for members of public is 1 mSv in a year.

7. What are the commonly used shielding material in medical x-ray installations?

Ans. Brick, Lead and Concrete are common shielding material used in x-ray installations.

8. How much radiation level will reduce if you add one HVT of particular material in between source and reference point?

Ans. Radiation level will be reduced by 50% if one HVT of particular material is added.

9. What are the points need to be considered for planning/construction an x-ray room.

Ans. Location of control console, patient entrance door, chest stand and location of opening window are considered for planning of X-ray installation.

10. Calculate Workload for radiography(fixed) installation considering 50 patients/day, 2 films used per patient and 40 mAs used per film and facility is operational 6 days per week?

Ans.  $W = 50 \text{ patients/day} * 6 \text{ days/week} * 2 \text{ films/patient} * 40 \text{ mAs/fim} * 1 \text{ min/60sec}$

$$W = 400 \text{ mA- min/week}$$

11. Calculate the workload of CT facility considering 60 patients/day, 20 slices/patient and 200 mAs/slice and 40 mAs used per slice and facility is operational 5 days per week?

Ans. .  $W = 60 \text{ patients/day} * 5 \text{ days/week} * 20 \text{ slices/patient} * 200 \text{ mAs/ slice} * 1 \text{ min/60sec}$

$$W = 20,000 \text{ mA- min/week}$$

## References and sources for additional information

1. AERB SAFETY CODE NO.AERB/RF-MED/SC-3 (Rev. 2), RADIATION SAFETY IN MANUFACTURE, SUPPLY AND USE OF MEDICAL DIAGNOSTIC X-RAY EQUIPMENT
2. Layout and Shielding Guidelines  
([http://www.aerb.gov.in/AERBPortal/pages/English/t/XRay/forms/layout\\_guidelines.pdf](http://www.aerb.gov.in/AERBPortal/pages/English/t/XRay/forms/layout_guidelines.pdf))
- 3.National Council on Radiation Protection and Measurements, Report 147, Structural Shielding Design for Medical X-Ray Imaging Facilities, NCRP, Bethesda, MD. 2004.
4. Radiation Shielding for Diagnostic radiology, 2<sup>nd</sup> Edition, Report of a BIR working party, D G Sutton et al, 2010.

## **List of presentations in the training Module**

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**Basics of Diagnostic X-ray Equipment**

**Biological effects of Radiations**

**Medical X-ray imaging techniques**

**Planning of Diagnostic X-ray facilities**

**Quality Assurance of X-ray equipment**

**Quality Assurance of Computed Tomography equipment**

**Radiation Protection in Diagnostic Radiology Practice**

**Causes, prevention and investigation of excessive exposures in diagnostic radiology**

**Regulatory Requirements for Diagnostic Radiology Practice**

**THANK YOU**