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Planning of Radiological Departments

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PLANNING OF RADIOLOGICAL DEPARTMENTS

The planning of both Diagnostic and Therapuetical Radiological Departments is a complex process and requires many different aspects to be taken into consideration. Radiaton protection is of prime importance and should be considered at the start of the planning process since it will influence layout of rooms and construction. Unfortunately in many cases it is considered as a specialist aspect after much of the fundamental work has been done. This can lead to expensive modifications, or even inappropriate facilities, both of which can be avoided if some of the basic principles are incorporated in the planning process at an early stage.

The main requirements can be considered under three headings:

Layout
Construction
Special Features

A. Layout Requirements for X-Ray Rooms

1. Location of Departments

Diagnostic x-ray services are vital to virtually all clinical specialities and must be accessible to both in-patient and out-patients as well as convenient for Accident & Emergency cases. The following is an extract from a policy design document for x-ray departments in the UK.

> "The Department should be easily accessible for the Out-Patient Department, particularly the Fracture Clinic, the A & E Department, which it should adjoin, all the Wards, the Operating Theatres, the Intensive Therapy Unit and the Children's Department.
>
> Particular aspects of siting merit attention. The A & E Department should be adjacent to the Radiodiagnostic Department since the emergency medical care for severely injured patients may have to continue within the radiodiagnostic rooms. Rooms allocated to A & E use should be capable of separate operation at night thus enabling the rest of the Department to be physically shut off to prevent unauthorised access".

The department must therefore be centrally situated within a hospital with good access and communications. However, because of the radiation hazards rooms housing diagnostic x-ray units should be located away from areas of high occupancy and general traffic.

Particular attention should be given to departments that have not got purpose built accommodation when rooms that were never designed as x-ray rooms are modified to accommodate x-ray equipment. Often the location of these rooms is far from ideal and can lead to problems.

Therapy departments because of their specialist nature and higher radiation dose rates should not be centrally located. Separate buildings are often provided or the basements of buildings are used to accommodate the treatment machines as different construction techniques are required compared with normal.

2. Room Size

An ideal diagnostic x-ray room should be not less than 24 sq.m., eg 6 m x 4 m. This allows sufficient space to permit installation and servicing of equipment with safety and good working practices and procedures to be undertaken. Rooms should be large enough to avoid unnecessary exposure to any person in the room.

Smaller rooms limit the layout of equipment in the room and restrict access. This can lead to less than ideal radiation protection requirements and problems when other equipment, eg emergency trolleys, need to be used.

3. Arrangement of Rooms

The arrangement of rooms within a department obviously depends upon the size of the department, its workload and the space available. However irrespective of the number of x-ray rooms, the dark room, offices and waiting rooms ideally should be located such that no x-ray beam can be directed at them. Otherwise maximum care must be taken to ensure that sufficient protection is provided to persons in adjacent areas. The number of doors for entry to any x-ray room should be kept to a minimum and the room should not constitute a throughway from one place to another except in emergencies.

Again, corridors should be wide enough to allow easy access of equipment and patients.

Plans a, b & c serve to illustrate this point.

4. Controlled and Supervised Areas

The concept of controlled and supervised areas was introduced in ICRP 26 published in 1977.

A controlled area is any area in which the instantaneous dose rate (averaged over 1 minute) exceeds 7.5 µSv/hour and where doses of ionising radiation are likely to exceed 3/10's of the maximum limit for adult employees (currently 50 mSv) ie 15 mSv per annum.

A supervised area is one in which a dose could be received which exceeds 1/10 of the maximum limit, ie 5 mSv, and the instantaneous dose rate exceeds 2.5 µSv/hour.

Areas should be physically demarcated or where this is not possible clearly delineated. Entry into a controlled area should be restricted either to classified personnel or under a written system of work which ensures the individual's dose is not likely to exceed 3/10 of the dose limit.

However ICRP 60 published in 1990 reconsiders the whole issue of controlled and supervised areas. The Commission no longer believes this a useful division and recommends management defines areas where controls are needed. A controlled area would become one if the routine monitoring is not sufficient to predict with confidence the doses to individual workers. If environmental monitoring is sufficient but doses may exceed the dose limit for members of the public then it should be a supervised area.

B. Construction

The walls, ceiling, floors and doors of an x-ray department must provide sufficient shielding to ensure that doses received by staff and members of the public are kept within the annual dose equivalent limits, currently 50 mSv and 1 mSv respectively.

However ICRP 60 recommends that the dose limit for employees be reduced to 20 mSv/annum to be averaged over a period of 5 years with no more than 50 mSv in a single year. The figures for the public remain unchanged.

By far the most useful material for radiation protection purposes in modern building design is concrete either ready mixed or as blocks. For diagnostic facilities thicknesses vary between 10 and 30 cm, whilst for therapy rooms thicknesses of between 1 and 2.5 m are common. If space is at a premium these thicknesses can be reduced by using high density concrete made out of barium or iron ore aggregates but this is very much more expensive.

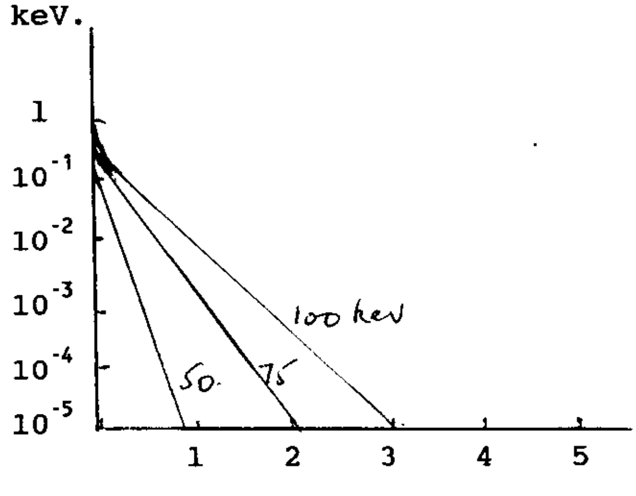
Brick is less dense than concrete (1.4 to 1.8 compared with 2.2 g/cm^3) and therefore greater thicknesses are required to provide the same protection although the use of special plaster containing barium - barylite - increases the protection.

Frequently in radiation protection the level of protection afforded by a barrier is expressed in terms of lead equivalence. This is the thickness of lead which provides the same level of protection as the barrier concerned. Obviously the lead equivalence varies with the energy of the radiation as shown in the table

Protection equivalent to 1 mm of lead

	Brick	Concrete	Barium Concrete
keV	1.6 g/cm	2.2 g/cm	3.2 g/cm
50	155	109	10.2
75	122	86	6.4
100	114	76	5.1
150	122	86	10.2
250	98	74	15.2
^{60}Co (2 MeV)		5.6	
^{226}Ra		6.6	

In diagnostic departments complete protection is afforded by small thicknesses of lead as can be seen from the charts of transmission of x-rays of different energies through lead. 1 mm of lead reduces the intensity of a beam of 75 keV photons to one thousandth of its original value, whilst 1.5 mm is required for the same effect at 100 keV.



As a result lead is still used extensively in diagnostic departments for shielding because it can be incorporated easily into doors and screens without adding to their dimensions greatly. It is also used on walls in the form of lead-plywood panels especially when an existing room is being modified to take an x-ray set.

The windows within screens and cubicles in diagnostic departments are made of lead glass. This can be obtained with varying density and refracture index, typically 5 g/cm and 1.8 respectively.

	Lead Equivalent of Lead Glass density 5 - 5.2 g/cm R.I. 1.8	
Lead Glass thickness mm	**100 keV**	**200 keV**
5.0	1.5	
6.5	2.0	1.5
8.0	2.5	2.0
9.5	3.0	2.5

Calculation of Thicknesses of Protective Barriers

In order to calculate the thickness of a particular barrier it is necessary to know

a) the energy of the radiation
b) the total output from the set
c) the use of the set
d) the occupancy of the adjacent area.

Clearly it would be inappropriate to provide high degree of protection if, for instance, there is little chance of there being anyone the other side of the barrier or of the primary beam ever pointing in that particular direction.

To reduce the number of possibilities three conditions are often assumed for use and three for occupancy, these being

Full use U = 1

Floors, ceilings and walls routinely exposed to primary beam.

Partial use U = 0.25

Doors and walls not routinely exposed to primary beam and floors of dental installations.

Occasional use U = 0.07

Ceilings not routinely exposed to primary beam.

Full occupancy T = 1

Control areas, waiting areas, rest rooms and living quarters.

Partial occupancy T = 0.25

Corridors, utility rooms, elevators.

Occasional occupancy T = 0.07

Patient toilets, stairways.

Typical Calculation for a Linear Accelerator Room

Energy of radiation is 6 mV
Output of linac at 1 m 240 Sv/hour
Beam on time per day 2 hours
Fraction of time in particular direction 0.2
Occupancy of outside area U = 1

Barrier required to allow the outside area 5 m away to be unsupervised.

Output from Linac at 1 m = 240 Sv/hour

Therefore Dose Rate at 5 m $= \frac{240}{5^2} = 9.6$ Sv/hour

In any day (8 hours) Linac on for 2 hours

Therefore Total Dose = 2 x 9.6 = 19.2 Sv

But only spends 20% of time in particular direction

Therefore Total Dose in direction = 19.2 x 0.2
= 3.84 Sv

For unsupervised areas Dose Rate < 2.5 µSv/hour

Therefore in 8 hour period Dose < 20 µSv

Therefore barrier to reduce Dose from 3.84 Sv to <20 µSv ie Reduction of $\frac{2 \times 10^{-5}}{3.85} \sim 5 \times 10^{-6}$

From transmission curves of 6 mV in concrete this requires 190 cm concrete.

For diagnostic departments the following tables are useful, produced by the WHO in 1975. These give the necessary thickness of barrier required to provide an unsupervised or public area outside the x-ray room (ie less than 2.5 μSv/hour or 100 μSv/week) assuming U = 1 and T = 1

A. Primary beam radiation not exceeding 150 mAmin/week

Tube Voltage	Distance from target	Barrier Thickness Lead mm	Concrete mm
100	2	1.8	150
	3	1.6	130
	5	1.2	100
125	2	2.1	170
	3	1.8	150
	5	1.3	110
150	2	2.2	190
	3	1.9	170
	5	1.4	130

B. Scattered radiation from Fluoroscopy 300 mAmin/week

Tube Voltage	Distance from target	Barrier Thickness Lead mm	Concrete mm
85	1	1.2	130
	2	1.0	105
	3	0.8	85
100	1	1.35	110
	2	1.05	90
	3	0.85	70
125	1	1.4	110
	2	1.1	90
	3	0.9	70

C. Special Features

1. Protective Screens

Radiographic rooms with sets working up to 125 keV have screens to protect staff operating the equipment. These are constructed of lead plywood with a large lead glass window. These are usually positioned outside the primary beam and allow visibility of the door to the room if anyone should enter as an exposure is about to be made.

Screens providing protection against scattered radiation have approximately 1 mm of lead or lead equivalence whilst those which could be irradiated by the primary beam have 2 mm.

For operating voltages higher than 125 keV a separate room must be provided for the control consul and staff must remain outside the examination room.

2. Warning Lights

Radiation warning signs are very important and one should be displayed on each door to discourage the entry of non essential persons. The doors should always be closed during exposure and an illuminated sign such as a red light automatically switched on and displayed in a prominent position outside to signify when the x-rays are on.

Warning lights should also be provided on all control panels. These are particularly important in rooms where there are more than one x-ray set and there is the possibility of making an exposure from the wrong tube.

3. Protective Clothing

Any person not adequately protected by shielding of the screens must be provided with and must wear protective clothing. This will normally consist of suitable gloves and aprons having a minimum lead equivalence of 0.25 mm. Obviously this is not sufficient to give adequate protection against the primary beam but only from radiation transmitted through the patient and from scatter.

It is important that such clothing is examined visually at frequent intervals to make sure it has not been damaged and where necessary a radiographic examination should be carried out to determine the extent of any cracks or faults.

4. Local Rules

Typical examples of local rules for x-ray departments have been drawn up by the WHO 1975.

<u>Local Rules for X-Ray Room - Radiography Only</u>

1. **Before making an exposure close the doors of the x-ray room.**

2. **Do not direct the x-ray beam at the windows of the room or towards the control panel or darkroom wall.**

3. **During radiography all staff must stand behind the protected control panel and may observe the patient through the lead glass window.**

4. **Gonad shields must be used on patients whenever appropriate, and the field must be adjusted to the minimum size consistent with adequate clinical diagnosis.**

5. **When films or patients require support, use mechanical supports whenever possible.**

6. **No patient should wait or change in the x-ray room while another patient is being radiographed.**

7. **If anyone is ever required to support a patient or film during an exposure, he must:**

   (i) wear a protective apron and gloves and avoid the direct beam by standing to one side and away from the x-ray tube,

   (ii) record, in the notebook provided, his name, the date, the number of exposures, and the radiographic technique used.

Local Rules for X-Ray Room - Radiography and Fluoroscopy

1. Before making an exposure close the doors of the x-ray room.

2. Do not direct the x-ray beam at the windows of the room or towards the control panel or darkroom wall.

3. During radiography or fluoroscopy, all staff must either stand in the protective cubicle, observing through the lead glass window or wear protective aprons, keeping well away from the patient when not specifically required to come close. Protective gloves must be worn when handling the patient during fluoroscopy.

4. In conventional fluoroscopy the current must not exceed 4 mA at 100 kV. With image intensifiers the current should not exceed 1 mA at 100 kV. Examination time and field size should be kept to a minimum consistent with adequate clinical diagnosis.

5. Gonad shields must be used on patients whenever appropriate.

6. If films or patients require support, use mechanical supports whenever possible.

7. No patient should wait or change in the x-ray room while another patient is being radiographed.

8. If anyone is ever required to support a patient or film during an exposure, he must:

   (i) wear a protective apron and gloves and avoid the direct beam by standing to one side and away from the x-ray tube,

   (ii) record, in the notebook provided, his name, the date, the number of exposures, and the radiographic technique used.

Local Rules for Ward Mobile Radiography*

1. The direct beam must not irradiate any person other than the one being radiographed.

2. When the radiographic exposure is being made, staff must stand as far away from the patient as possible (at least 2 m) and wear protective aprons.

3. Gonad shields must be used on patients whenever appropriate, and the x-ray beam size should be restricted by diaphragms or a suitable rectangular cone so as not to irradiate more of the patient than is necessary for diagnosis.

4. If anyone is required to support a patient or film during an exposure, he must:

   (i) wear a protective apron and gloves and avoid the direct beam by standing to one side and away from the x-ray tube,

   (ii) record, in the notebook provided, his name, the date, the number of exposures, and the radiographic technique used.

*One most important local rule is that the person in charge of the area where the exposure is to be carried out must be informed.

Calculation of Barrier Thickness

Diagnostic Department

Radiography

80 kVp 100 FFD 75 FSD

Patient Dose ~ 100 μSv / mAs

Typical exposure 40 mAs

Dose ≃ 4000 μS − 4 mSv

For workload 150 mA min / week

No of Exposures $\simeq \frac{150 \times 60}{40} \sim 225$.

Total Dose = 4 × 225 = 900 mSv.

Assume wall at 2m

Dose at wall ~ $\frac{900}{2^2} = 225$ mSv

This must be reduced by barrier to less than 100 μSv

Barrier transmission $\leq \frac{100}{225 \times 10^3} \simeq 4 \times 10^{-4}$

From transmission of Pb at 80 kVp = 1.8mm.