POLITECNICO DI MILANO

Lecco Campus
ENGINEERING FACULTY IV

Design and Development of an X-ray proof Operation Theater with Innovative Materials

Submitted to-
Mechanical Engineering Department

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TO WHOM IT MAY CONCERN

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Abstract

In medical X-ray imaging applications, the radiation consists of primary and secondary radiation. Primary radiation, also called the useful beam, is the radiation emitted directly from the X-ray tube that is used for patient imaging. A primary barrier is a wall, ceiling, floor or other structure that will intercept radiation emitted directly from the X-ray tube. Its function is to attenuate the useful beam to appropriate shielding design goals. Secondary radiation consists of X-rays scattered from the patient and other objects such as the imaging hardware and leakage radiation from the protective housing of the X-ray tube. A secondary barrier is a wall, ceiling, floor or other structure that will intercept and attenuate leakage and scattered radiations to the appropriate shielding design goal. Traditionally, it has been used concrete or gypsum wallboard as well as lead protected. For X-ray room and Operation Theater we are now heading for modern design of new technologies using aluminum honeycomb wall panels with PVC or HPL layers. Hereafter it will be considered a complete design of an X-ray proof Operation Theater for a hospital area. The wall panels are engineered to be equipped with coplanar clock, chronometer, gas plugs, and electric plugs, air grid set for ventilation, monitor and pc cabinet, surgery cabinets. The ceiling of the room will be made of air tight tiles complete with supporting structure and including filter tiles and IP65 lighting system. The floor will be of PVC conductive in the operating theatre and patient preparation room.

This co-planar wall system offers an easy to be cleaned surface and, thanks to the flash to wall solutions, guarantees a perfect aseptic surface and a complete air tight solution: the supporting structures are equipped with air tight gaskets and the panels are sealed from the front with silicon in matching color. In addition, the false ceiling system consists of a metal substructure for suspension and powder coated aluminum tiles integrated with lights, all sealed in the same way of the wall with double protection. Tiles and light frames are designed expressly in aluminum not to interfere with the X-ray devices and are different for operating theatres and other medical rooms (or corridors).

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Chapter-1: Project overview and general study to design a shielding room

1.1 Company Introduction

Edilsoffitti Group

The company, established in 1990, is the first-born of the Edilsoffitti Group.

Quality, experience, great skill, elegance and extremely fast realization distinguish Edilsoffitti in civil interior furnishing and personalized contracts, which aim at an extremely high level of technology, livability and functionality. Theatres, conference halls, hotels, offices and interiors furnishing designs for every civil and industrial application, created ad hoc following the professional, architectural and aesthetic requirements of the client. The mission of Edilsoffitti is to obtain the highest level of client satisfaction, offering planning, realization and a “turnkey” service is that is customized and made to measure for all the requirements of the client.

Edilsoffitti is the best solution on the civil and industrial market for realizing creative and professional projects with the desired standards. The Edilsoffitti Group project holds the fundamental attributes for a success that is completely Italian, but designed for internationality. The rationality of the company organization, the professionalism of the design and executive staff, state of art assemblies, quality material, execution speed, engineering precision, refinement and artisan worth guarantee the uniqueness of the Group and the attainment of important targets. The unquestionable success obtained by the Group is confirmed in its logo: four circles that represent the Edilsoffitti Group companies and become the guarantee of a 360^0 service, which begins from the original ideas of the client and finishes in impeccable, accurate, functional and elegant realization, which convinces and persuades even the sharpest and most technically demanding eye.

Edilsoffitti Engineering

Architecture, engineering, technique, precision and professionalism are the special characteristics of Edilsoffitti Engineering: Planning becomes the protagonist, giving shape to the ideas and requests of the client.

Edilsoffitti Engineering is the true name of accuracy, functionality, quality and precision taken to excellence. The engineering company, which is the part of the Edilsoffitti Group, designs civil, naval, industrial and medical-health interior furnishing of extremely high level, guaranteeing the uniqueness and customization of solutions that distinguish the group in all sectors it works with. Optimization of the planning times and methods, together with a company vision that always strives to satisfy the client’s requests, even the most demanding ones, guarantee very high quality and professional planning that is recognized in every corner of the world.

Edilsoffitti Engineering, which has experienced a fast growth over the last few years, is a solution that offers reliability and quality for anyone who wants excellent planning, based on a solid technical background and built around clients and their needs.

CRK

A rational and well-structured company organization, the use of the top of the range materials, the passion and taste for technical and aesthetic detail have obtained great international success for the naval branch of Edilsoffitti, which becomes a concrete reality with CRK.

The world's most prestigious and recognized shipping companies have chosen and still choose CRK for the rationality of its customized solutions, which embrace of the naval sector. Starting from the engineering-architectural planning, to the fitting- out of interior furnishing and very prestigious finishing, up to complete naval refitting, CRK's distinctive mark is a blend of refinement, quality organization, speed and innovation. Designs and complex problems become dreams come true and livable spaces where you can enjoy yourself and spend your free time relaxing.

The precise, accurate and concrete work by CRK makes cruise liners, ferries and yachts the best place to realize excellence and satisfaction at an international level. CRK creates unique and contemporary architectural objects that live through time, blending technique and refined aesthetic taste.

KOSS Medical Equipment

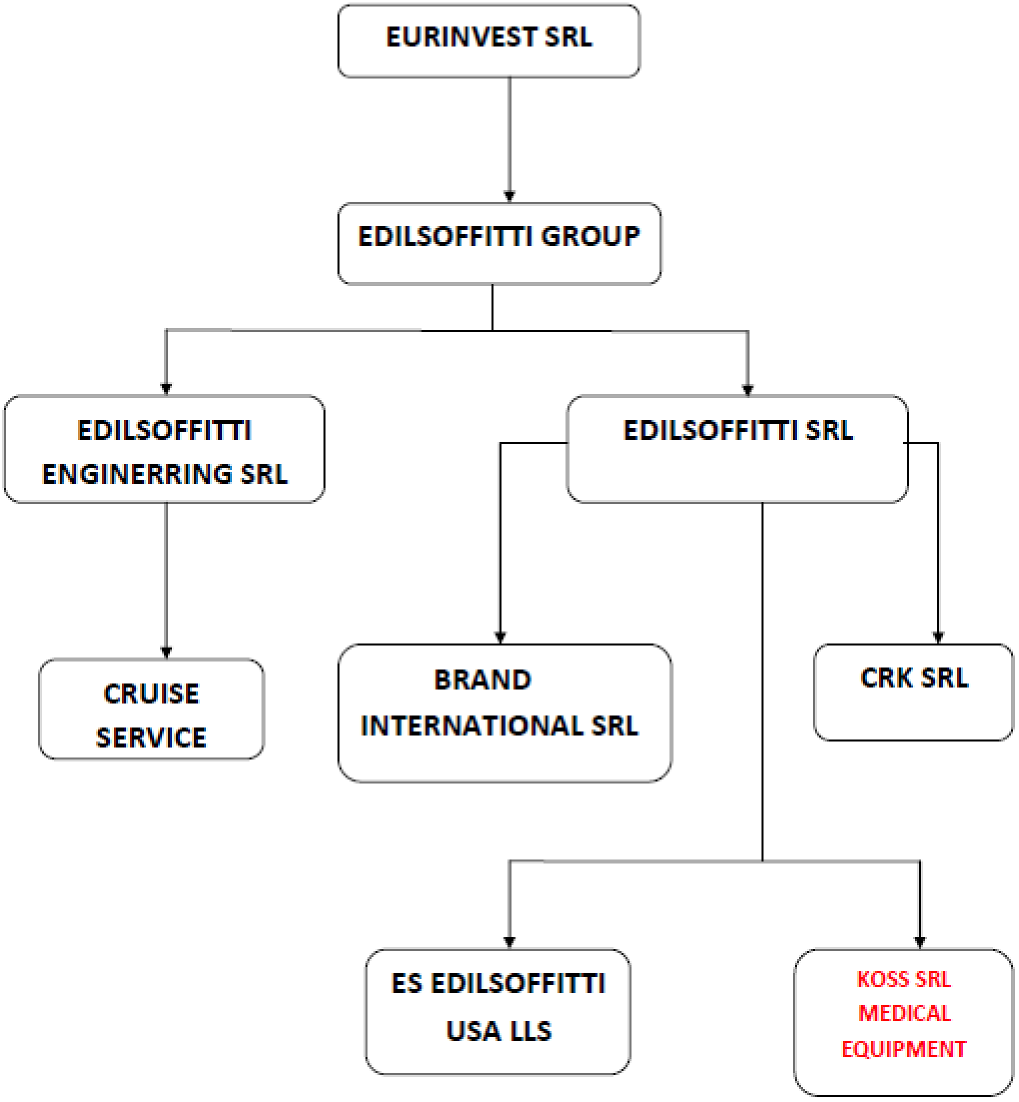
Koss is Edilsoffitti Group's latest challenge. This spin-off company, which is centered on the medical-health sector, realizes operating blocks, clinical and hospital spaces and clean rooms of extremely high level, using the technical-engineering ability that carries the Group's signature.

Koss' solution respects the extremely high technological and quality standards demanded by the medical sector, counting on the precision, technology and functionality already mastered by the Edilsoffitti Group. The group's knowhow and experience in managing large-scale complex designs efficiently and reliably allows Koss' to work with quality, speed and precision levels that are extraordinary in comparison to those of traditional competitors in the medical-health sector.

Of fundamental importance is the accent placed by Koss on the use of unique materials, which guarantee excellence, safety and reliability for sector professionals.

Koss' technical staff made up architects, engineers and medical consultants, guarantees careful planning that can satisfy sector professionals completely: space functionality, attention to details, fast action and flexibility.

This is the summary chart of Edilsoffitti Group and activities:



1.2 Project Overview

This research dedicated to the medical facilities (clinics, hospitals, as well as laboratories, clean rooms, etc.) and it is able to offer customized turnkey solutions for operating blocks through a complete management of the different stages of the process: feasibility study, design, quality survey, construction and installation, after-sales service. The central and distinctive element in our philosophy is the human being, whether patient or physician, and the well-being in the biomedical environment. The materials normally used for the cladding in the operating theatres are: Corian, HPL, PVC, stainless steel. For other rooms or corridors, which do not require special aseptic features or where reasons budget compel architectural solutions, wall panels can be engineered in a simpler way (for ex. by using thick laminates panels) or foreseeing plaster board walls covered with PVC layer.

Fig 1.1: Decorated Operation Theater

The wall system also includes all the technical elements for completion which can be placed flush with wall and located inside the wall and the ceiling hollow spaces. This co-planar system offers an easy to clean surface (no corners, no reliefs, and no slots) and guarantees a perfect aseptic surface. This false ceiling system consists of a metal substructure for suspension and painted stainless steel panels integrated with lights. In the operating theatres the ceilings, always in coplanar position and sealed, are equipped with air tight systems and filters. Lights are different for operating theatres and other medical rooms (or corridors).

Activity list

Fig 1.2: Decorated Operation Theater

WALL

- Complete wall supporting structure and insulation panels;
- Wall partitions (glass, fabrics, HPL and others)
- Cladded wall system (in different solutions: Corian, PVC, HPL or else),

Including a wide range of accessories such as:

- Special wall panel equipped with coplanar clock and chronometer, gas plugs, electric plugs;
- Special wall panel equipped with coplanar control panel (switches);
- Special wall panel equipped with coplanar air grids set for ventilation;
- Special wall panel equipped with coplanar monitor and PC case holder;
- Special wall panel equipped with coplanar diaphanoscope;
- Special wall panel equipped with cabinets, coplanar glass doors, push to open or handle opening;
- Special wall panel equipped with window;
- Special leaded wall panel, for operating theaters with X-ray sources.

FLOOR

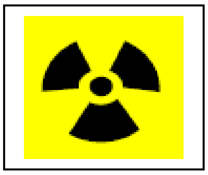
- Complete PVC conductive floor;
- Complete PVC dissipative floor;
- Complete cove floor-wall.

CEILLING

- Complete ceiling supporting structure;
- Ceiling panels / planks;
- Air-tight ceiling panels, filter panels;
- Integrated coplanar ceiling lights (also in air tight panels)
- Soffits or bulkheads;
- Edge profile connecting ceiling - wall;
- Filters.

MEDICAL ACCESSORIES

- Scrubs (metal or Corian) complete with electronic taps and dispensers;
- Technical cabinet, equipped with clock, diaphanoscope, gas plugs, electric plugs;
- Technical cabinet, equipped with control panels (switches);
- Doors, air tight doors, leaded doors, sliding doors with automatic movement;
- Crash rails.



1.3 General concept to design a room

Introduction and Recommendations

Purpose and Scope

The purpose of radiation shielding is to limit radiation exposures to employees and members of the public to an acceptable level. This Report presents recommendations and technical information related to the design and installation of structural shielding for facilities that use x rays for medical imaging. It includes a discussion of the various factors to be considered in the selection of appropriate shielding materials and in the calculation of barrier thicknesses. It is mainly intended for those individuals who specialize in radiation protection; however, this Report also will be of interest to architects, hospital administrators, and related professionals concerned with the planning of new facilities that use X-rays for medical imaging. Terms and symbols used in the Report are defined in the Glossary. Recommendations throughout this Report are expressed in terms of shall and should where:

- shall indicates a recommendation that is necessary to meet the currently accepted standards of radiation protection; and
- should indicates an advisory recommendation that is to apply when practicable or practical.

Quantities and Units

The recommended quantity for shielding design calculations for X-rays is air kerma (K), defined as the sum of the initial kinetic energies of all the charged particles liberated by uncharged particles per unit mass of air, and measured at a point in air. The unit of air kerma is joule per kilogram ($J\ kg^{-1}$), with the special name gray (Gy). However, many radiation survey instruments in the United States are currently designed and calibrated to measure the quantity exposure, using the previous special name roentgen (R). Exposure also can be expressed in the unit of coulomb per kilogram ($C\ kg^{-1}$), referring to the amount of charge produced in air when all of the charged particles created by photons in the target mass of air are completely stopped in air. For the direct measurement of radiation protection quantities discussed in this Report, the result from an instrument calibrated for exposure (in roentgens) may be divided by 114 to obtain K (in gray). For instruments calibrated in roentgens and used to measure transmission factors for barriers around facilities that use X-rays for medical imaging, no conversion is necessary because a transmission factor is the ratio of the same quantities. The recommended radiation protection quantity for the limitation of exposure to people from sources of ionizing radiation is effective dose (E), defined as the sum of the weighted equivalent doses to specific organs or tissues [i.e., each equivalent dose is weighted by the corresponding tissue weighting factor for the organ or tissue (W_T)]. The value of W_T for a particular organ or tissue represents the fraction of detriment (i.e., from cancer and hereditary effects) attributed to that organ or tissue when the whole body is irradiated uniformly. The equivalent dose to a specific organ or tissue (H_T) is obtained by weighting the mean absorbed dose in a tissue or organ (D_T) by a radiation weighting factor (W_R) to allow for the relative biological effectiveness of the ionizing radiation or radiations of interest.

Controlled and Uncontrolled Areas

A controlled area is a limited access area in which the occupational exposure of personnel to radiation is under the supervision of an individual in charge of radiation protection. This implies that access, occupancy and working conditions are controlled for radiation protection purposes. In facilities that use X-rays for medical imaging, these areas are usually in the immediate areas where x-ray equipment is used, such as X-ray procedure rooms and X-ray control booths or other areas that require control of access, occupancy and working conditions for radiation protection purposes. The workers in these areas are primarily radiologists and radiographers who are specifically trained in the use of ionizing radiation and whose radiation exposure is usually individually monitored. Uncontrolled areas for radiation protection purposes are all other areas in the hospital or clinic and the surrounding environments.

Shielding Design Goals for Medical X-Ray Imaging Facilities and Effective Dose

Shielding design goals (P) are levels of air kerma used in the design calculations and evaluation of barriers constructed for the protection of employees and members of the public. There are different shielding design goals for controlled and uncontrolled areas. The relationship of E to incident K is complex, and depends on the attenuation of the x rays in the body in penetrating to the radiosensitive organs and hence on the X-ray energy spectrum, and also on the posture of the exposed individual with respect to the source. Rotational exposure should be assumed, since it is probable that an individual is moving about and would not be exposed from one direction only. It is not practical to base shielding design directly on E, since E cannot be measured directly. Therefore, for the purposes of this Report, the shielding design goals are stated in terms of K (in milligray) at the point of nearest occupancy beyond the barrier. For example, as discussed in Section 4, the distance of closest approach to an X-ray room wall can be assumed conservatively (on the safe side) to be not <0.3 m. Shielding design goals (P) are practical values, for a single medical X-ray imaging source or set of sources, that are evaluated at a reference point beyond a protective barrier. When used in conjunction with the conservatively safe assumptions recommended in this Report, the shielding design goals will ensure that the respective annual values for E recommended in this Report for controlled and uncontrolled areas are not exceeded. Shielding design goals are expressed as weekly values since the workload for a medical x-ray imaging source has traditionally utilized a weekly format.

Controlled Areas

The employees who work in controlled areas (i.e., radiation workers) have significant potential for exposure to radiation in the course of their assignments or are directly responsible for or involved with the use and control of radiation. They generally have training in radiation management and are subject to routine personal monitoring. NCRP recommends an annual limit for E for these individuals of 50 mSv y–1 with the cumulative E not to exceed the product of 10 mSv and the radiation worker’s age in years (exclusive of medical and natural background radiation

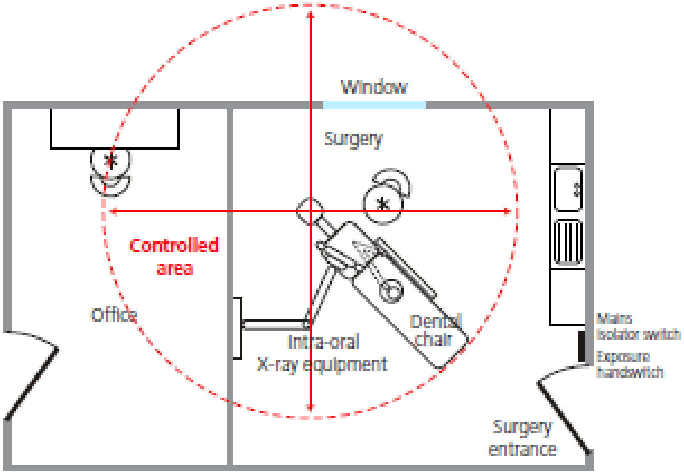


Fig 1.3: Control area in room

Recommendation for controlled areas—
Shielding design goal (P) (in air kerma): 0.1 mGy week–1 (5 mGy y–1)

Uncontrolled Areas

Uncontrolled areas are those occupied by individuals such as patients, visitors to the facility, and employees who do not work routinely with or around radiation sources. Areas adjacent to but not parts of the x-ray facility are also uncontrolled areas. Based on ICRP (1991) and NCRP (1993) recommendations for the annual limit of effective dose to a member of the general public, shielding designs shall limit exposure of all individuals in uncontrolled areas to an effective dose that does not exceed 1mSv y–1. After a review of the application of the guidance in NCRP (1993) to medical radiation facilities, NCRP has concluded that a suitable source control for shielding individuals in uncontrolled areas in or near medical radiation facilities is an effective dose of 1mSv in any year. This recommendation can be achieved for the medical radiation facilities with a weekly shielding design goal of 0.02 mGy air kerma (i.e., an annual air-kerma value of 1 mGy) for uncontrolled areas.
Recommendation for uncontrolled areas—
Shielding design goal (P) (in air kerma): 0.02 mGy week–1 (1 mGy y–1)

Shielding Design Assumptions

A medical x-ray imaging facility that utilizes the P values given above would produce E values lower than the recommendations for E in this Report for controlled and uncontrolled areas. This is the result of the conservatively safe nature of the shielding design methodology recommended in this Report. Several examples of this conservatism, and the relative impact of each, are given below:

- The significant attenuation of the primary beam by the patient is neglected. The patient attenuates the primary beam by a factor of 10 to 100.
- The calculations of recommended barrier thickness always assume perpendicular incidence of the radiation. If not assumed, the effect would vary in magnitude, but would always be a reduction in the transmission through the barrier for X-rays that have non perpendicular incidence.

• The shielding design calculation often ignores the presence of materials (e.g., lead fluoroscopy curtains, personnel wearing lead aprons, ceiling mounted shields, equipment cabinets, etc.) in the path of the radiation other than the specified shielding material. If the additional materials were included, the effects would vary in magnitude, but the net effect would be a reduction in transmission due to the additional materials.

• The leakage radiation from X-ray equipment is assumed to be at the maximum value allowed by the federal standard for the leakage radiation technique factors for the x-ray device (i.e., 0.876 mGy h–1 air kerma) (100 mR h–1 exposure). In clinical practice, leakage radiation is much less than this value, 3 since Food and Drug Administration (FDA, 2003a) leakage technique factors are not typically employed for examination of patients. If the maximum value were not assumed, the effect would be a reduction in leakage radiation and its contribution to secondary radiation.

• The field size and phantom used for scattered radiation calculations yield conservatively high values of scattered radiation. If a more likely field size and phantom were used, the contribution to scattered radiation would be reduced by a factor of approximately four.

• The recommended occupancy factors for uncontrolled areas are conservatively high. For example, very few people spend 100 percent of their time in their office. If more likely occupancy factors were used, the effect would vary in magnitude, but would always result in a reduction in the amount of exposure received by an individual located in an uncontrolled area.

• Lead shielding is fabricated in sheets of specific standard thicknesses. If shielding calculations require a value greater than a standard thickness, the next available greater standard thickness will typically be specified. This added thickness provides an increased measure of protection. The effect of using the next greater standard thickness in place of the actual barrier thickness would vary in magnitude, but would always result in a significant reduction in transmission through the barrier.

• The minimum distance to the occupied area from a shielded wall is assumed to be 0.3 m. This is typically a conservatively safe estimate for most walls and especially for doors. If a value >0.3 m were assumed, the effect would vary, but radiation levels decrease rapidly with increasing distance.

1.4 Fundamentals of Shielding for Medical X-Ray Imaging Facilities

Basic Principles

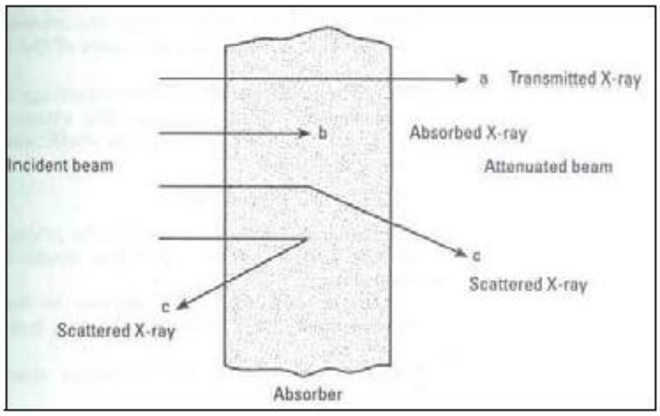


Fig 1.4: X-ray scattering

In medical X-ray imaging applications, the radiation consists of primary and secondary radiation. Primary radiation, also called the useful beam, is radiation emitted directly from the

X-ray tube that is used for patient imaging. A primary barrier is a wall, ceiling, floor or other structure that will intercept radiation emitted directly from the x-ray tube. Its function is to attenuate the useful beam to appropriate shielding design goals. Secondary radiation consists of X-rays scattered from the patient and other objects such as the imaging hardware and leakage radiation from the protective housing of the X-ray tube. A secondary barrier is a wall, ceiling, floor or other structure that will intercept and attenuate leakage and scattered radiations to the appropriate shielding design goal. Figure 1.5 illustrates primary, scattered, leakage and transmitted radiation in a typical radiographic room. Primary and secondary radiation exposure to individuals depends primarily on the following factors:

- The amount of radiation produced by the source
- The distance between the exposed person and the source of the radiation
- The amount of time that an individual spends in the irradiated area
- The amount of protective shielding between the individual and the radiation source

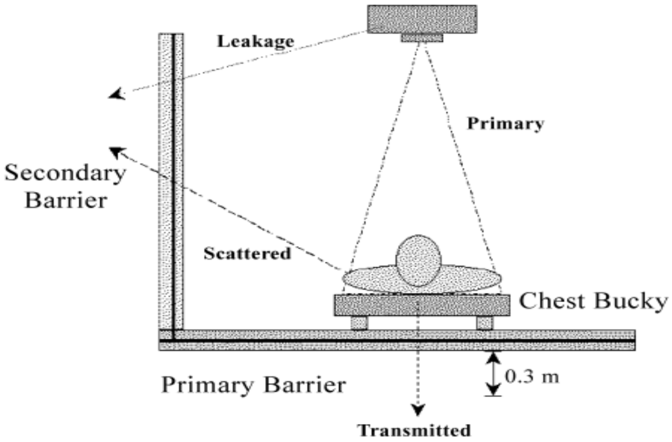


Fig 1.5. Figure illustrating primary, scattered, leakage and transmitted radiation in a radiographic room with the patient positioned upright against the chest Bucky. The minimum distance to the occupied area from a shielded wall is assumed to be 0.3 m.

The exposure rate from the source varies approximately as the inverse square of the distance from the source. To assess the distance from the source when a barrier is in place, it is usually assumed that the individual to be protected is at least 0.3 m beyond the walls bounding the source. The exposure time of an individual involves both the time that the radiation beam is on and the fraction of the beam-on time during which a person is in the radiation field. Exposure through a barrier in any given time interval depends on the integrated tube current in that interval [workload in mill ampere-minutes (mA min)], the volume of the scattering source, the leakage of radiation through the X-ray tube housing, and the energy spectrum of the X-ray source. In most applications covered by this Report, protective shielding is required.

Types of Medical X-Ray Imaging Facilities

Radiographic Installations

A general purpose radiographic system produces brief radiation exposures with applied electrical potentials on the x-ray tube (operating potential) in the range from 50 to 150 kVp (kilovolt peak) that are normally made with the X-ray beam directed down towards the patient, the radiographic table and, ultimately, the floor. However, the x-ray tube can usually be rotated, so that it is possible for the X-ray beam to be directed to other barriers. Barriers that may be directly irradiated are considered to be primary barriers. Many general purpose radiographic rooms include the capability for chest radiographs where the beam is directed to a vertical cassette assembly, often referred to as a “chest Bucky” or “wall Bucky.” Additional shielding may be specified for installation directly behind this unit.

Provision shall be made for the operator to observe and communicate with the patient on the table or at the vertical cassette assembly. The operator of a radiographic unit shall remain in a protected area (control booth) or behind a fixed shield that will intercept the incident radiation. The control booth should not be used as a primary barrier. The exposure switch shall be positioned such that the radiographer cannot make an exposure with his or her body outside of the shielded area. This is generally accomplished if the x-ray exposure switch is at least 1 m from the edge of the control booth. The control booth shall consist of a permanent structure at least 2.1 m high and should contain unobstructed floor space sufficient to allow safe operation of the equipment. The booth shall be positioned so that no attenuated primary or attenuated single-scattered radiation will reach the operator’s position in the booth. There shall not be an unprotected direct line of sight from the patient or X-ray tube to the x-ray machine operator or to loaded film cassettes placed behind a control booth wall.

The control booth shall have a window or viewing device that allows the operator to view the patient during all x-ray exposures performed in the room. The operator must be able to view the wall Bucky and x-ray table, as well as patients confined to stretchers. When an observation window is used, the window and frame shall provide the necessary attenuation required to reduce the air kerma to the shielding design goal. The window(s) should be at least 45 × 45 cm and centered 1.5 m above the finished floor. A typical design for a control booth is illustrated in Figure 1.6.

Fluoroscopic Installations

Fluoroscopic imaging systems are usually operated at potentials ranging from 60 to 120 kVp. A primary barrier is incorporated into the fluoroscopic image receptor. Therefore, a protective design for a room containing only a fluoroscopic unit need consider only secondary protective barriers against leakage and scattered radiations.

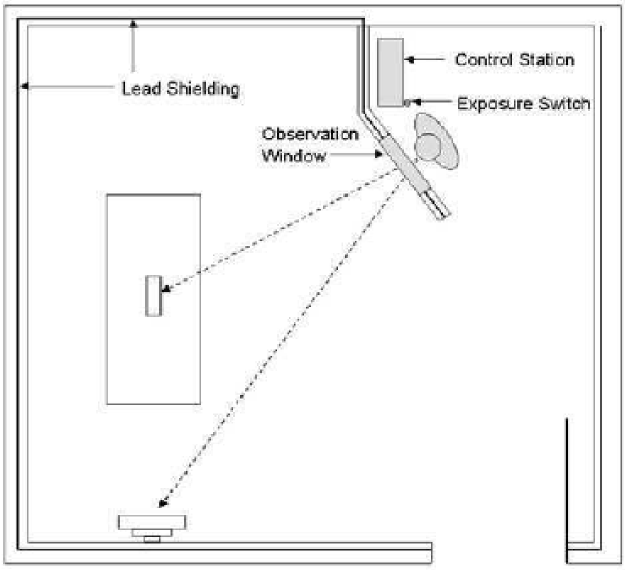


Fig. 1.6 Typical design for a control booth in a radiographic x-ray room surrounded by occupied areas. Dashed lines indicate the required radiographer’s line of sight to the x-ray table and wall bucky. The exposure switch is positioned at least 1 m from the edge of the control booth, as discussed in Section 2.2.1.

However, the qualified expert may wish to provide fluoroscopic rooms with primary barriers so that the function of the room can be changed at a later date without the need to add additional shielding. Most modern fluoroscopic X-ray imaging systems also include a radiographic tube. The shielding requirements for such a room are based on the combined workload of both units.

Interventional Facilities

Interventional facilities include cardiovascular imaging (cardiac catheterization) rooms, as well as peripheral angiography and neuroangiography suites. These facilities, which w X-ill be referred to as cardiac angiography and peripheral angiography, may contain multiple x-ray tubes, each of which needs to be evaluated independently. Barriers shall be designed so that the total air kerma from all tubes does not exceed the shielding design goal. The types of studies performed in these facilities often require long fluoroscopy times, as well as cine and digital radiography. Consequently, workloads in interventional imaging rooms generally are high and tube orientation may change with each of the studies performed. The shielded control area should be large enough to accommodate associated equipment and several persons.

Dedicated Chest Installations

In a dedicated chest radiographic room, the x-ray beam is directed to a chest image-receptor assembly on a particular wall. All other walls in the room are secondary barriers. Chest techniques generally require operating potentials >100 kVp. For the wall at which the primary beam is directed, a significant portion that is not directly behind the chest unit may be considered a secondary barrier. However, the segment of the wall directly behind and around the chest Bucky is a primary barrier and may require additional shielding.

1.5 Shielding Design Elements

Interior Walls

Local building and fire codes, as well as state health-care licensing agencies, specify requirements for wall assemblies that meet Underwriters Laboratories, Inc. standards for life safety. Unshielded walls in contemporary health-care facilities are normally constructed of metal studs and one or more layers of 5/8 inch thick drywall (gypsum wallboard) per side. The corridor side of walls may contain two layers of gypsum wallboard. Several types of shielding materials are available for walls.

Sheet Lead. Sheet lead has traditionally been the material of choice for shielding medical imaging x-ray room walls. Figure 1.7 shows the thicknesses of sheet lead (in millimeters and inches) and their nominal weights (in lb foot–2) found to be commercially available from a survey of several major suppliers in the United States. All of these thicknesses may not be available in every area. Figure 2.3 also presents the relative cost per sheet (on average) for each thickness compared to the cost per sheet for the 0.79 mm thickness. Note that the weight in pounds per square foot is equal to the nominal thickness in inches multiplied by 64. For example,1/16 inch lead is equivalent to 4 lb foot-2. For typical shielding applications, a lead sheet is glued to a sheet of gypsum wallboard and installed lead inward with nails or screws on wooden or metal studs. X-ray images of wall segments show that insertion of the nails or screws does not result in significant radiation leaks.

Gypsum Wallboard. Gypsum wallboard (sheetrock) is commonly used for wall construction in medical facilities. As Glaze et al. (1979) pointed out, the gypsum in each sheet is sandwiched between a total of 1 mm of paper. A nominal 5/8 inch sheet of “Type X” gypsum wallboard has a minimum gypsum thickness of approximately 14 mm. Although gypsum wallboard provides relatively little attenuation at higher beam energies, it provides significant attenuation of the low-energy x rays used in mammography. As mentioned earlier, gypsum wallboard typically contains voids and no uniform areas and therefore one should be conservatively safe when specifying this material for shielding.

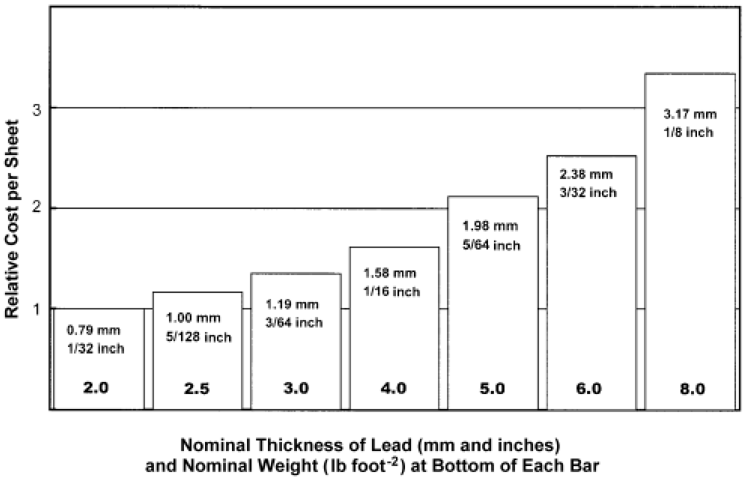


Fig. 1.7 Thicknesses of sheet lead commercially available in a recent survey of several suppliers in the United States. The height of each bar is the relative cost per sheet compared to the 0.79 mm thickness. All the thicknesses given may not be available in every area of the United States.

Other Materials. Concrete block, clay brick, and tile may also be used to construct interior walls. Generally, manufacturing specifications for these products will be available and the construction standards established for their use will allow the qualified expert, in consultation with the architect, to determine their appropriateness as shielding materials. These materials may contain voids which will require special consideration during shielding design. If there are voids in the blocks or bricks that may compromise the shielding capabilities of the wall, then solid blocks or bricks may be used or the voids may be filled with grout, sand or mortar. The densities of commercial building materials can be found in Avallone and Baumeister (1996).

Exterior Building Walls

Exterior building walls of medical imaging X-ray rooms may be composed of stone, brick, stucco, concrete, wood, vinyl, synthetic stucco, or other material. The range of potential attenuating properties of these materials is very wide and the qualified expert should request specific exterior wall design specifications from the architect prior to determining the shielding requirements. Wall systems are generally determined during the design development phase with the construction details established during the construction document phase. The architect should review the plans with the qualified expert during the design development phase of construction for shielding requirements and opportunities for structural modifications.

Doors

Lead-Lined Doors. The door and frame must provide at least the attenuation required to reduce the air kerma to the shielding design goal. If lead is required, the inside of the door frame should be lined with a single lead sheet and worked into the contour of the frame to provide an effective overlap with the adjoining barrier8.

Wooden Doors. Wooden doors exhibit limited attenuation efficiency and not all wooden doors are constructed with equal integrity. Some “drop-in-core” models exhibit large gaps between the solid core and outer frame (stiles and rails). Likewise, the “lumber core door” provides very little shielding because the core consists of staggered wooden blocks that are edge glued. This type of core demonstrates numerous voids when radio graphed. Another type often classified as a wooden door is a mineral core door. The core of this door consists primarily of calcium silicate, which has attenuation properties similar to gypsum wallboard.

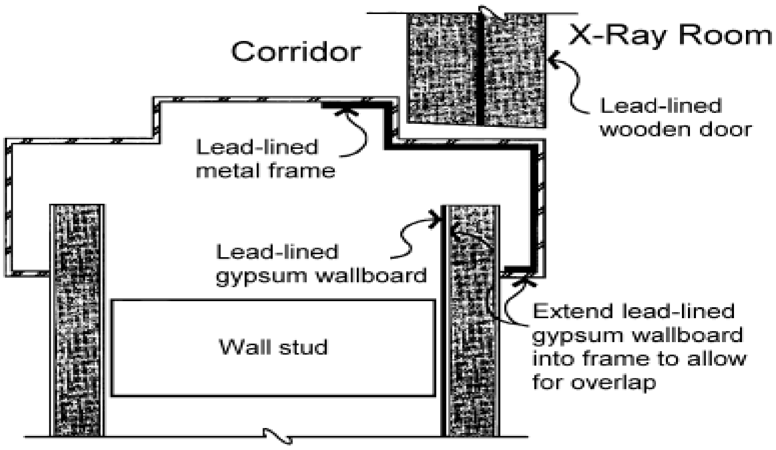


Fig. 1.8 Cross-sectional view of lead-lined door and frame illustrating the proper placement of lead shielding. When the thickness of the metal in the door frame is inadequate, the inside of the frame should be lined with a single lead sheet and worked into the contour of the frame to provide an effective overlap with the adjoining barrier.

Door Interlocks, Warning Lights, and Warning Signs. Door interlocks that interrupt x-ray production are not desirable since they may disrupt patient procedures and thus result in unnecessary repeat exa minations. An exception might be a control room door which represents an essential part of the control barrier protecting the operator. The qualified expert should consult local and state regulations with respect to interlocks, warning signs and warning lights.

Windows

There are various types of materials suitable for windows in medical X-ray imaging facilities. It is desirable that the window material be durable and maintains optical transparency over the life of the facility.

Lead Glass. Glass with a high lead content can be obtained in a variety of thicknesses. Lead glass is usually specified in terms of millimeter lead equivalence at a particular kVp.

Plate Glass. Ordinary plate glass may be used only where protection requirements are very low. Typically, two or more 1/4 inch (6.35 mm) thick glass sections are laminated together to form the view window. However, caution must be exercised when specifying thick, large-area plate glass windows because of weight considerations.

Lead Acrylic. This product is a lead-impregnated, transparent, acrylic sheet that may be obtained in various lead equivalencies, typically 0.5, 0.8, 1 and 1.5 mm lead equivalence. Lead acrylic is a relatively soft material which may scratch and can become clouded by some cleaning solvents.

Floors and Ceilings

Concrete is a basic construction material used in floor slabs. It may also be used for precast wall panels, walls, and roofs. Concrete is usually designed and specified as standard-weight or lightweight. The radiation attenuation effectiveness of a concrete barrier depends on its thickness, density and composition. Figure 1.9 illustrates typical floor slab construction used in most health-care facilities, namely metal-deck-supported concrete and slab. The concrete equivalence of the steel decking may be estimated from the attenuation data provided in this Report. The floor slab thickness can vary from as little as 4 cm to >20 cm.

Standard-Weight Concrete. Standard-weight (or normal weight) concrete is used for most foundations and main structural elements such as columns, beams and floor slabs. The average density of standard-weight concrete is 2.4 g cm^{-3} (147 lb foot^{-3}). Variations in concrete density may arise from differences in density of the components, from forming or tamping techniques used in the casting or from different proportions used in the mix.

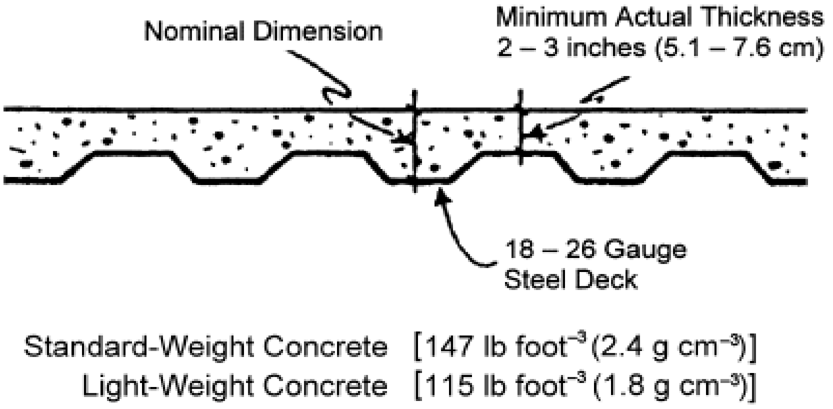


Fig. 1.9 Schematic of a typical concrete floor slab poured on a steel deck. The minimum thickness should be used in calculating the barrier thickness.

Light-Weight Concrete. Light-weight concrete is often specified in floor slabs as a weight saving and fire protection measure. The air space pores reduce heat conduction, often allowing it to be classified as a primary fire barrier. Typically, light-weight concrete will have a density of 1.8 g cm–3 (115 lb foot–3) or about three quarters that for standard-weight concrete, depending on the aggregate used. “Honeycombing,” the creation of voids in the concrete, will affect its shielding properties. If the total design thickness of concrete is required to meet the shielding design goal, then testing for voids and a plan for corrective measures may be needed.

Floor Slab Construction. A typical concrete floor slab is a variable structure as shown in Figure 2.5, having been poured on a steel deck. Note that the minimum thickness of the concrete is less than the nominal dimension which is usually quoted. The minimum thickness should be used in calculating the barrier equivalence.

Floor-to-Floor Heights

Floor-to-floor height is the vertical distance from the top of one floor to the top of the next floor. The floor-to-floor height should provide adequate ceiling height for the use and servicing of imaging equipment. Although floor-to-floor height will range from 3 to 5 m, protective shielding need normally extend only to a height of 2.1 m above the floor, unless additional shielding is required in the ceiling directly above the x-ray room (over and above the inherent shielding of the ceiling slab). In this latter case, it may be necessary to extend the wall lead up to the ceiling shielding material. Darkroom walls may also require shielding that extends to the ceiling to protect film stored on shelves above the standard 2.1 m height.

Interstitial Space

Typical interstitial space is 1.5 to 2.4 m in height and contains structural support for maintenance or room for construction personnel to work above the ceiling. The floor of the interstitial space is much thinner than a typical concrete slab, it may be a steel deck without a concrete topping, a steel deck with gypsum topping, or a steel deck with a light-weight concrete deck. Interstitial space makes it possible for a person to work above or below an x-ray unit while the unit is in operation. The occupancy factor for this space is normally extremely low since access is usually restricted, but this should be determined on a case-by-case basis.

Shielding Design Considerations

Penetrations in Protective Barriers

Air conditioning ducts, electrical conduit, plumbing, and other infrastructure will penetrate shielded walls, floors and ceilings. The shielding of the x-ray room shall be constructed such that the protection is not impaired by these openings or by service boxes, etc., embedded in barriers. This can be accomplished by backing or baffling these penetrations with supplementary lead shielding. The supplementary thickness shall at least have shielding equivalent to the displaced material. The method used to replace the displaced shielding should be reviewed by the qualified expert to establish that the shielding of the completed installation will be adequate. Whenever possible, openings should be located in a secondary barrier where the required shielding is less. Other options designed by the qualified expert, such as shielding the other side of the wall that is opposite the penetrated area, may also be effective.

Joints

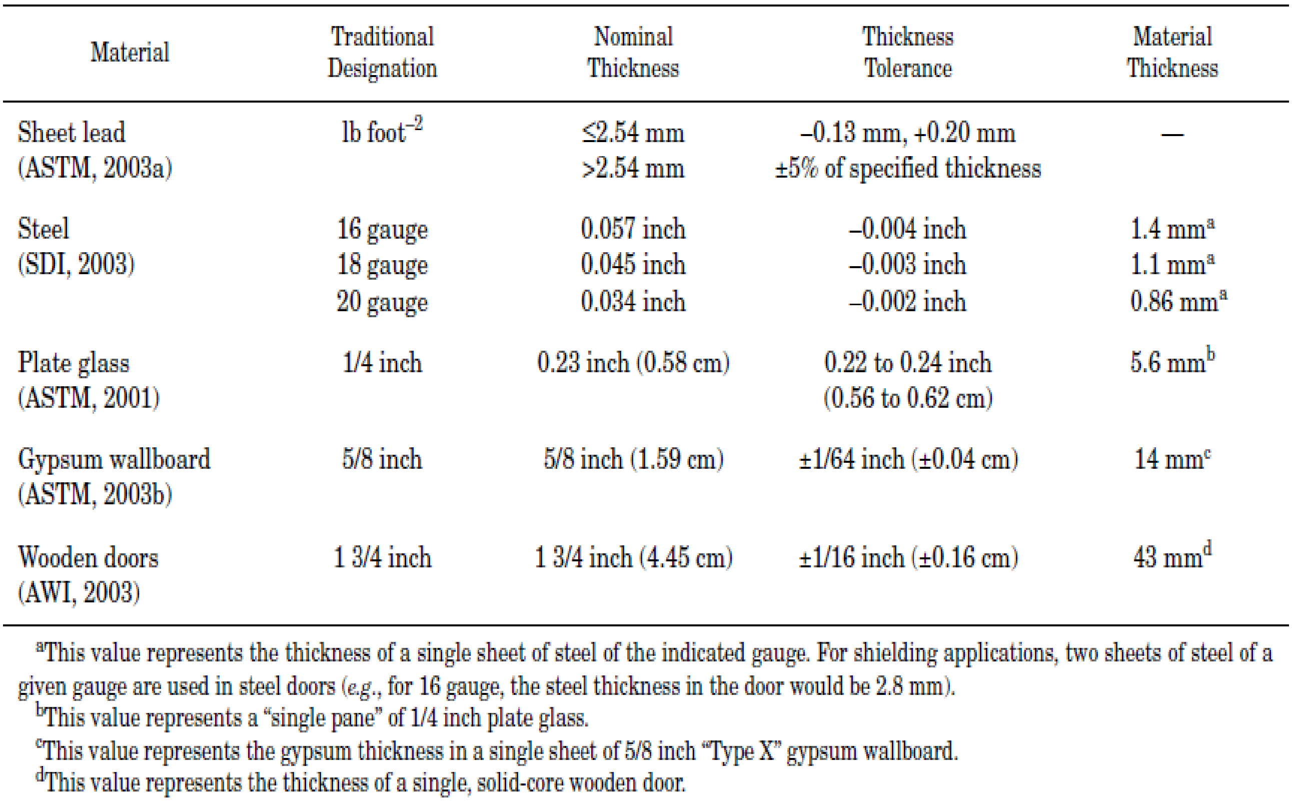
The joints between lead sheets should be constructed so that their surfaces are in contact and with an overlap of not <1 cm (lead shielding can be purchased with the lead sheet extending beyond the edge of the drywall to allow for adequate overlap). When brick or masonry construction is used as a barrier, the mortar should be evaluated, as well as the brick. Joints between different kinds of protective material, such as lead and concrete, should be constructed so that the overall protection of the barrier is not impaired.

Construction Standards

Generally, institutional construction is of a high quality and meets the most rigid standards in life safety design. However, construction does not take place in a controlled environment. Site conditions, weather, construction schedules, available materials, and qualifications of construction personnel may ultimately affect the integrity of the completed project. Shielding designs that require excessive precision in order to provide the required shielding may not be obtainable in the field. The qualified expert should work closely with the architect and the contractor in areas that require close attention to detail to ensure the appropriate shielding.

Dimensions and Tolerances

Design and construction professionals often discuss the dimension of system components in “nominal” terms or dimensions. For example, a “two-by-four” piece of wood is actually 1 1/2 × 3 ½ inches (3.8 × 8.9 cm), a “four-inch” brick is actually 3 5/8 inches thick (9.2 cm), and a nominal 20 cm thick concrete slab may actually be only 15 cm at its thinnest point. Likewise, construction tolerances allow for variations in design dimensions. The qualified expert should request actual material dimensions and material tolerances for the materials and systems used to create the shielding. The qualified expert needs to be aware that some dimensions may be to the center line of a wall, column, beam or slab. The nominal thicknesses, tolerances, and minimum allowed thickness of various shielding materials are shown in Table 1.1.



Material	Traditional Designation	Nominal Thickness	Thickness Tolerance	Material Thickness
Sheet lead (ASTM, 2003a)	lb foot^{-2}	≤2.54 mm >2.54 mm	–0.13 mm, +0.20 mm ±5% of specified thickness	—
Steel (SDI, 2003)	16 gauge 18 gauge 20 gauge	0.057 inch 0.045 inch 0.034 inch	–0.004 inch –0.003 inch –0.002 inch	1.4 mm[a] 1.1 mm[a] 0.86 mm[a]
Plate glass (ASTM, 2001)	1/4 inch	0.23 inch (0.58 cm)	0.22 to 0.24 inch (0.56 to 0.62 cm)	5.6 mm[b]
Gypsum wallboard (ASTM, 2003b)	5/8 inch	5/8 inch (1.59 cm)	±1/64 inch (±0.04 cm)	14 mm[c]
Wooden doors (AWI, 2003)	1 3/4 inch	1 3/4 inch (4.45 cm)	±1/16 inch (±0.16 cm)	43 mm[d]

[a] This value represents the thickness of a single sheet of steel of the indicated gauge. For shielding applications, two sheets of steel of a given gauge are used in steel doors (*e.g.*, for 16 gauge, the steel thickness in the door would be 2.8 mm).

[b] This value represents a “single pane” of 1/4 inch plate glass.

[c] This value represents the gypsum thickness in a single sheet of 5/8 inch “Type X” gypsum wallboard.

[d] This value represents the thickness of a single, solid-core wooden door.

TABLE 1.1—The nominal thicknesses and tolerances of various shielding materials used in walls, doors and windows (adapted from Archer et al., 1994).

Strategic Shielding Planning

Strategic shielding planning for a medical x-ray imaging department incorporates knowledge of basic planning, the ALARA principle, and shielding principles. The strategic planning concept involves the use of shielding options dictated by a knowledge of the sources of radiation in a facility, the occupancy and usage of adjacent areas, and whether specific walls, floors and ceilings are primary or secondary barriers. The qualified expert and architect need to be aware, for example, that the use of exterior walls and adjacent spaces, both horizontal and vertical, can often be cost-effective elements in the design of radiation shielding. As shown in Figure 1.10, a corridor can be used to separate offices and support rooms from the x-ray examination rooms rather than leaving these rooms adjacent to one another. This strategy will often reduce the amount of shielding required to meet the shielding design goal. The corridor is a low occupancy area and the occupied spaces (offices and lounges) are at least 2.5 m further from the source of x rays. The same strategy applies for spaces above and below (i.e., locating an x-ray room above or below a corridor or mechanical room rather than an occupied office is an effective strategy for reducing shielding requirements). Certain wall and door materials required for building and life safety codes may provide cost-effective alternatives to lead shielding. The effective and efficient use of shielding materials and the development of optimal design strategies require communication and cooperation among the architect, facility representative, and qualified expert (Roeck, 1994).

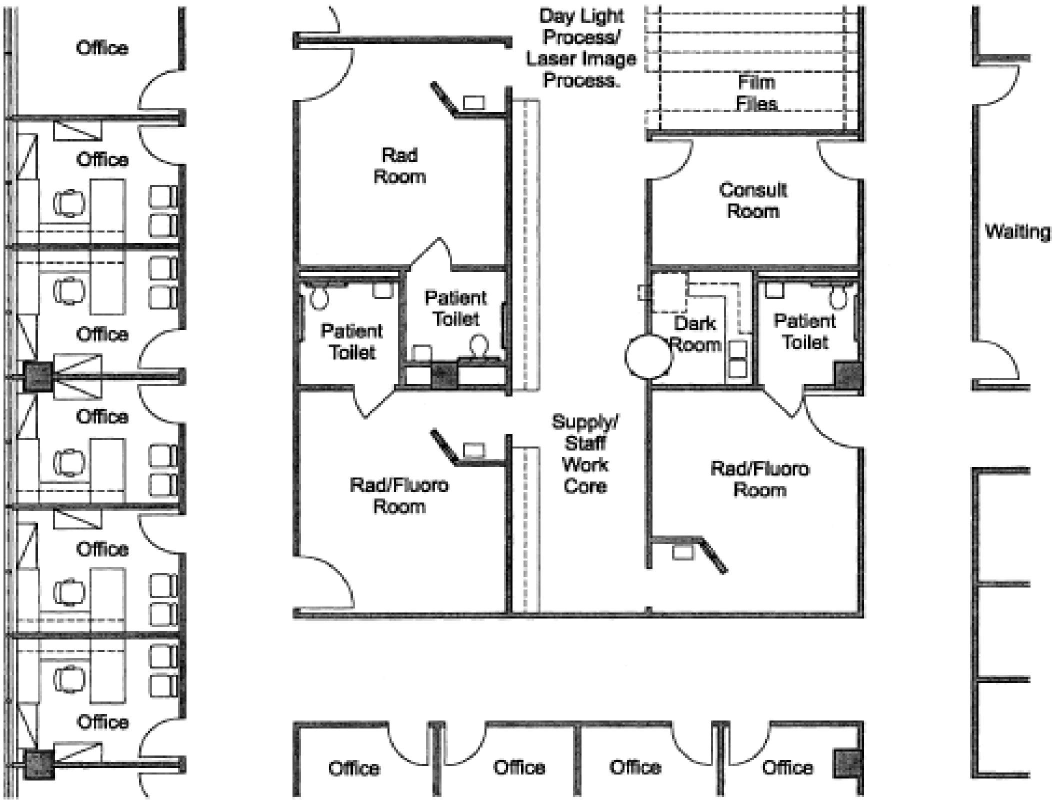


Fig. 1.10. Placing the corridor, as shown above, separating offices and support rooms from the x-ray examination rooms rather than having the rooms immediately adjacent will often reduce the amount of shielding required to meet the shielding design goal. The corridor is a low occupancy space and the occupied space (offices and lounges) are at least 2.5 m further from the source of x rays.

1.6 The Requirements of Medical X-Ray Imaging Shielding

Concepts and Terminology

Shielding Design Goals

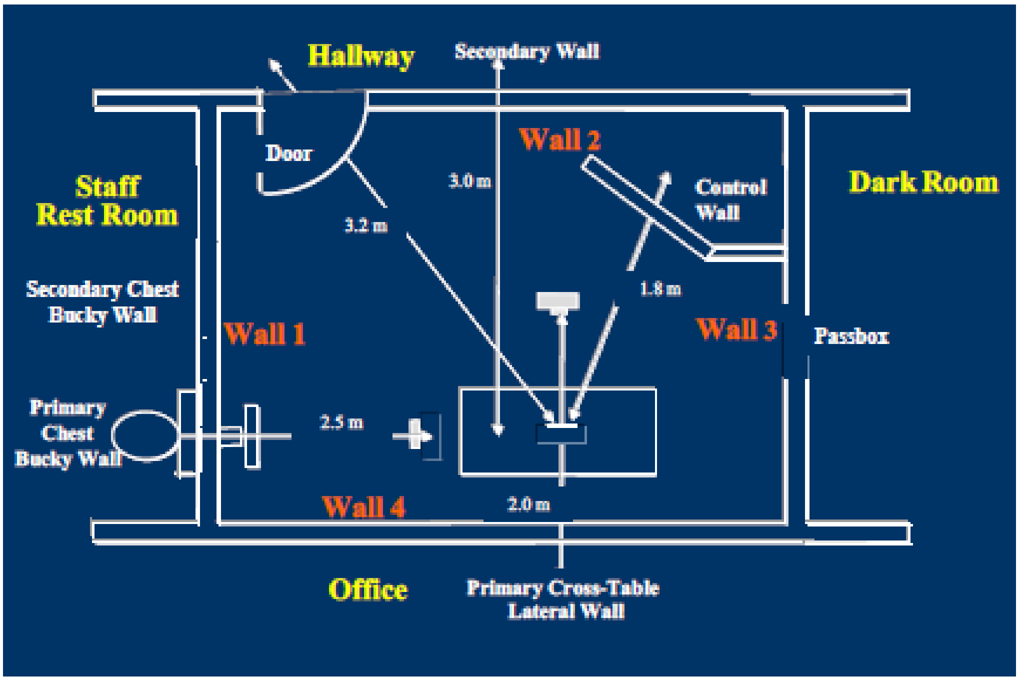


Fig 1.11 General layout of a operation theater

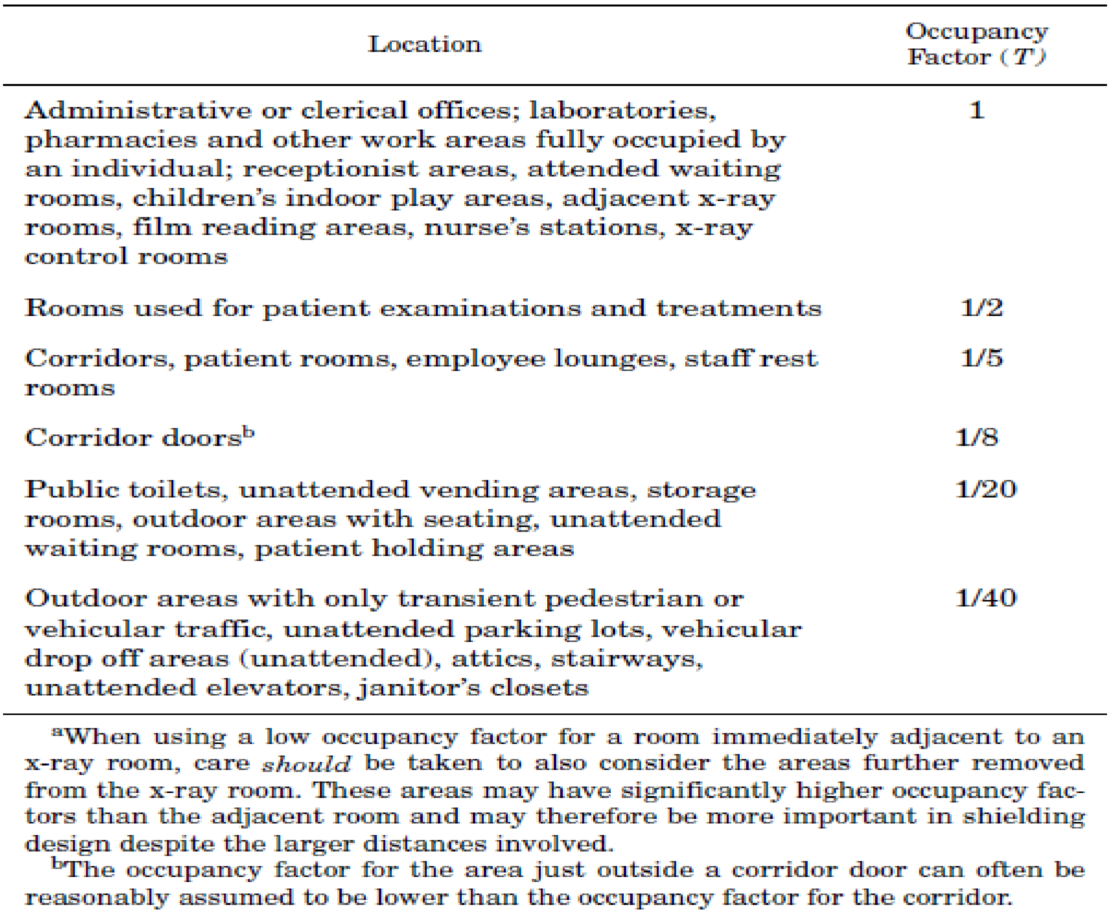
Shielding design goals are used in the design or evaluation of barriers constructed for the protection of employees and members of the public. The weekly shielding design goal for a controlled area is an air-kerma value of 0.1 mGy week–1. The weekly shielding design goal for an uncontrolled area is an air-kerma value of 0.02 mGy week–1.

Distance to the Occupied Area

The distance (d) to the occupied area of interest should be taken from the source to the nearest likely approach of the sensitive organs of a person to the barrier. For a wall this may be assumed to be not <0.3 m. For a source located above potentially occupied spaces, the sensitive organs of the person below can be assumed to be not >1.7 m above the lower floor, while for ceiling transmission the distance of at least 0.5 m above the floor of the room above is generally reasonable. In some special cases, such as a nursing station or outdoor sidewalk, the distance from the barrier to the nearest routinely occupied area may be considerably greater.

Occupancy Factors

The occupancy factor (T) for an area is defined as the average fraction of time that the maximally exposed individual is present while the x-ray beam is on. Assuming that an x-ray unit is randomly used during the week, the occupancy factor is the fraction of the working hours in the week that a given person would occupy the area, averaged over the year. For example, an outdoor area adjacent to an x-ray room having an assigned occupancy factor of 1/40 would imply that a given member of the public would spend an average of 1 h week–1 in that area (while the x-ray beam is activated) every week for a year. A factor of 1/40 would certainly be conservatively safe for most outdoor areas used only for pedestrian or vehicular traffic (e.g., sidewalks, streets, vehicular drop-off areas, or lawn areas with no benches or seating). The occupancy factor for an area is not the fraction of the time that it is occupied by any persons, but rather is the fraction of the time it is occupied by the single person who spends the most time there. Thus, an unattended waiting room might be occupied at all times during the day, but have a very low occupancy factor since no single person is likely to spend >50 h y–1 in a given waiting room. Occupancy factors in uncontrolled areas will rarely be determined by visitors to the facility or its environs who might be there only for a small fraction of a year. The maximally exposed individuals will normally be employees of the facility itself or residents or employees of an adjacent facility. For example, if a staff member typically spent 4h d–1 in a room a physician uses for patient examinations, the resulting occupancy factor would be one-half. In some cases, a clinic may plan to operate radiographic equipment longer than a normal work day. Two common examples are a radiographic room in an emergency department and a CT facility. The workload utilized should be that which occurs during the primary work shift, since the maximally exposed individuals are those working during that shift. For example, the primary 40 h work shift may occur from 8 a.m. to 5 p.m.,5 d week–1. Note that the use of T less than one allows the average air kerma in a partially occupied area to be higher than that for a fully-occupied area by a factor of T–1. The qualified expert should make reasonable and realistic assumptions concerning occupancy factors, since each facility will have its own particular circumstances.



Location	Occupancy Factor (T)
Administrative or clerical offices; laboratories, pharmacies and other work areas fully occupied by an individual; receptionist areas, attended waiting rooms, children's indoor play areas, adjacent x-ray rooms, film reading areas, nurse's stations, x-ray control rooms	1
Rooms used for patient examinations and treatments	1/2
Corridors, patient rooms, employee lounges, staff rest rooms	1/5
Corridor doors[b]	1/8
Public toilets, unattended vending areas, storage rooms, outdoor areas with seating, unattended waiting rooms, patient holding areas	1/20
Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop off areas (unattended), attics, stairways, unattended elevators, janitor's closets	1/40

[a] When using a low occupancy factor for a room immediately adjacent to an x-ray room, care *should* be taken to also consider the areas further removed from the x-ray room. These areas may have significantly higher occupancy factors than the adjacent room and may therefore be more important in shielding design despite the larger distances involved.

[b] The occupancy factor for the area just outside a corridor door can often be reasonably assumed to be lower than the occupancy factor for the corridor.

TABLE 1.2—Suggested occupancy factors (for use as a guide in planning shielding where other occupancy data are not available).

The qualified expert needs to therefore take a larger view of the facility in arriving at the appropriate limitations for shielding design. Radiation workers may be assumed to spend their entire work period in controlled areas. Therefore, controlled areas such as x-ray rooms and control booths should be designed with an occupancy factor of unity

The interior spaces of unrelated offices or buildings adjacent to the x-ray facility that are not under the control of the administrator of the x-ray facility should normally be considered as fully occupied (T = 1), regardless of the nature of the adjacent interior area, since these areas are subject to change in function without the knowledge or control of the x-ray facility. This is also applicable to adjacent space for which future occupancy is anticipated. This does not apply to the grounds of an adjacent building where fractional occupancy factors may be utilized.

Workload and Workload Distribution

The workload (W) of a medical imaging x-ray tube is the time integral of the x-ray tube current over a specified period and is conventionally given in units of mill ampere-minutes. The most common period of time in which the workload is specified is one week. However, it is also useful to define the normalized workload ($W_{norm)}$ as the average workload per patient. Note that Wnorm may include multiple exposures depending on the type of radiographic examination and clinical goal. The product of Wnorm and the average number of patients per week (N) is the total workload per week (W_{tot}):

$$W_{tot} = N\ W_{norm} \ldots\ldots\ (1.1)$$

It is important to distinguish between the number of patients examined in a week (N) as used in this Report [on which is based the average workload per patient (Wnorm) from the AAPM survey (Simpkin, 1996a)] and the number of “examinations” performed in a given x-ray room. An “examination” refers to a specific x-ray procedure (as defined by a uniform billing or current procedural terminology code). A single patient may receive several such “examinations” while in the x-ray room and that may even involve more than one image receptor (e.g., both the image receptor associated with the x-ray table and the one associated with the chest bucky). Although this may produce a notable patient-to-patient workload variance, the average workload per patient for each room type is likely to be close to the W_{norm} values of the AAPM survey. The designer should be aware that workload information provided by facility administrators stated in terms of a weekly number of “examinations” or “patient examinations” is not the proper value to use for N (and may be several times larger than N). Values of N that may be used for various types of x-ray rooms as a guide, if the actual value of N is not available, are provided later is this Section. For a radiographic room, some patients are examined using both the x-ray table and chest bucky, and the average workload per patient has been divided into two components. These components represent the division of the total workload per patient (as well as its kVp distribution) between the x-ray table and the chest bucky for the “average patient” in the survey. It is therefore unnecessary to separately specify the number of patients undergoing chest examinations. Rather the same value of N should be used for both the chest bucky and x-ray table calculations, since the fraction of patients who receive examinations on the x-ray table or at the chest bucky is already accounted for by the value of the workload per patient for each image receptor. This methodology also renders unnecessary the incorporation of a fractional use factor for the primary beam against the chest bucky (i.e., U = 1) when using the Rad Room (chest bucky) workload distribution with the same value of N as is used for all of the calculations for that room.

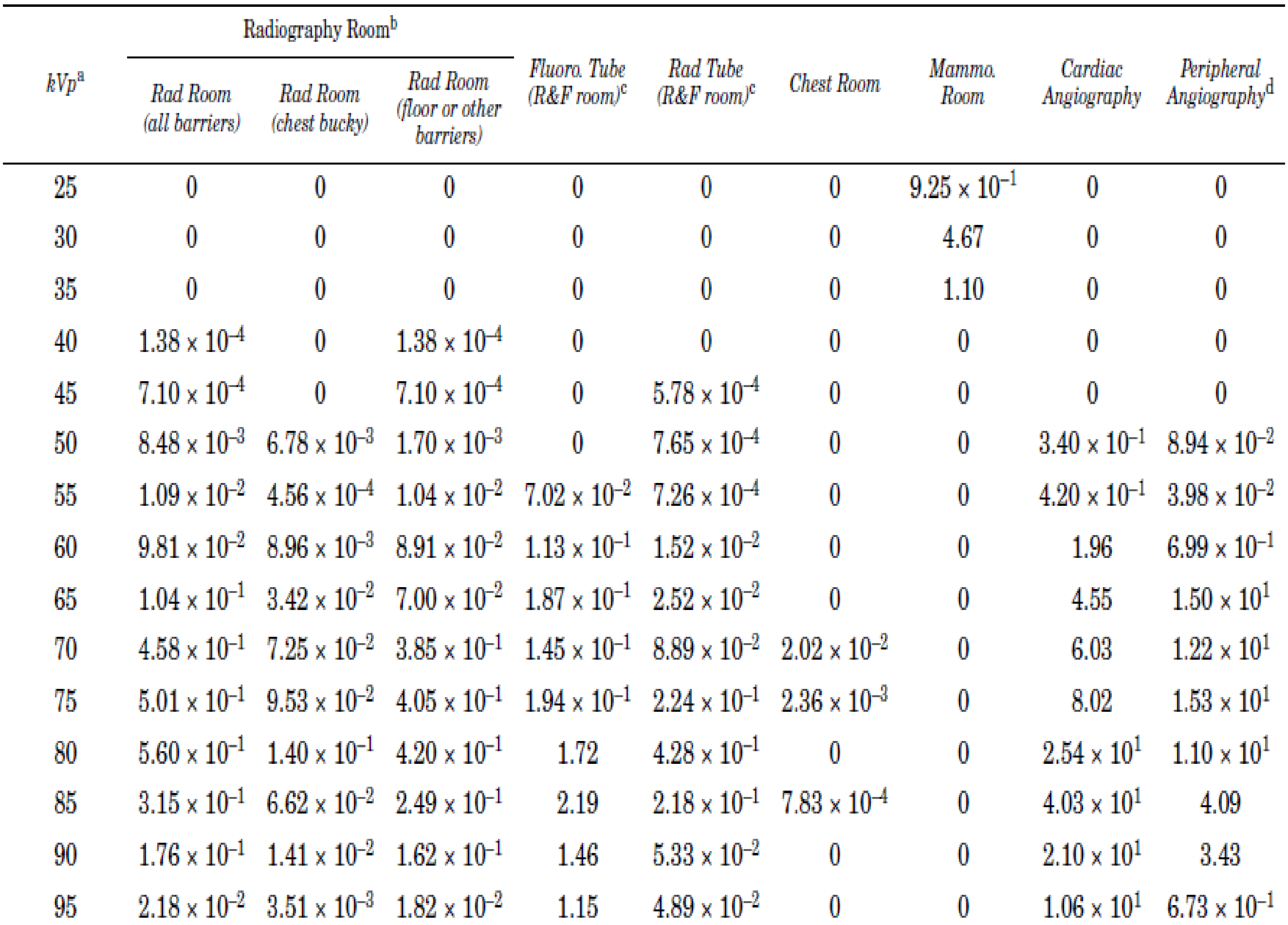
At a given x-ray tube operating potential and a given distance, the air kerma at a given reference point from the primary beam is directly proportional to the workload. Traditional shielding methods have assumed that a conservatively high total workload per week is performed at a single high operating potential, for example, 1,000 mA min week–1 at 100kVp. This assumption ignores the fact that the medical imaging workload is spread over a wide range of operating potentials. For example, in a general purpose radiographic room, extremity examinations (typically about one-third of the total examinations done in the room) are normally performed at about 50 to 60 kVp, abdominal examinations at about 70 to 80 kVp, and chest examinations at >100 kVp, but with a very low tube current-time (mili-ampere minutes) product.

For shielding design, the distribution of workload as a function of kVp is much more important than the magnitude of the workload since the attenuation properties of barriers exhibit a strong kVp dependence. For example, the radiation level on the protected side of a 1 mm lead barrier varies exponentially with kVp (three orders of magnitude over the range of 60 to 100 kVp), whereas it varies only linearly with the workload. Leakage radiation from the x-ray tube housing shows an even more dramatic change with kVp, decreasing by more than eight orders of magnitude over the range from 150 to 50 kVp.Workload distributions were determined at 14 medical institutions involving approximately 2,500 patients and seven types of radiology installations. Values for the kVp distribution of workload in 5 kVp intervals for each type of installation are reported in Table 1.2. These distributions form the basis of a theoretical model that will be used in this Report. Figure 1.10 compares the workload distribution from the survey for the primary x-ray beam directed at the floor of a radiographic room [i.e., Rad Room (Floor or other barriers)] With the single 100 kVp “spike” that results from the assumption that all exposures are made at the same kVp. The surveyed clinical workload distributions are specific for a given type of radiological installation. They will be referred to as:

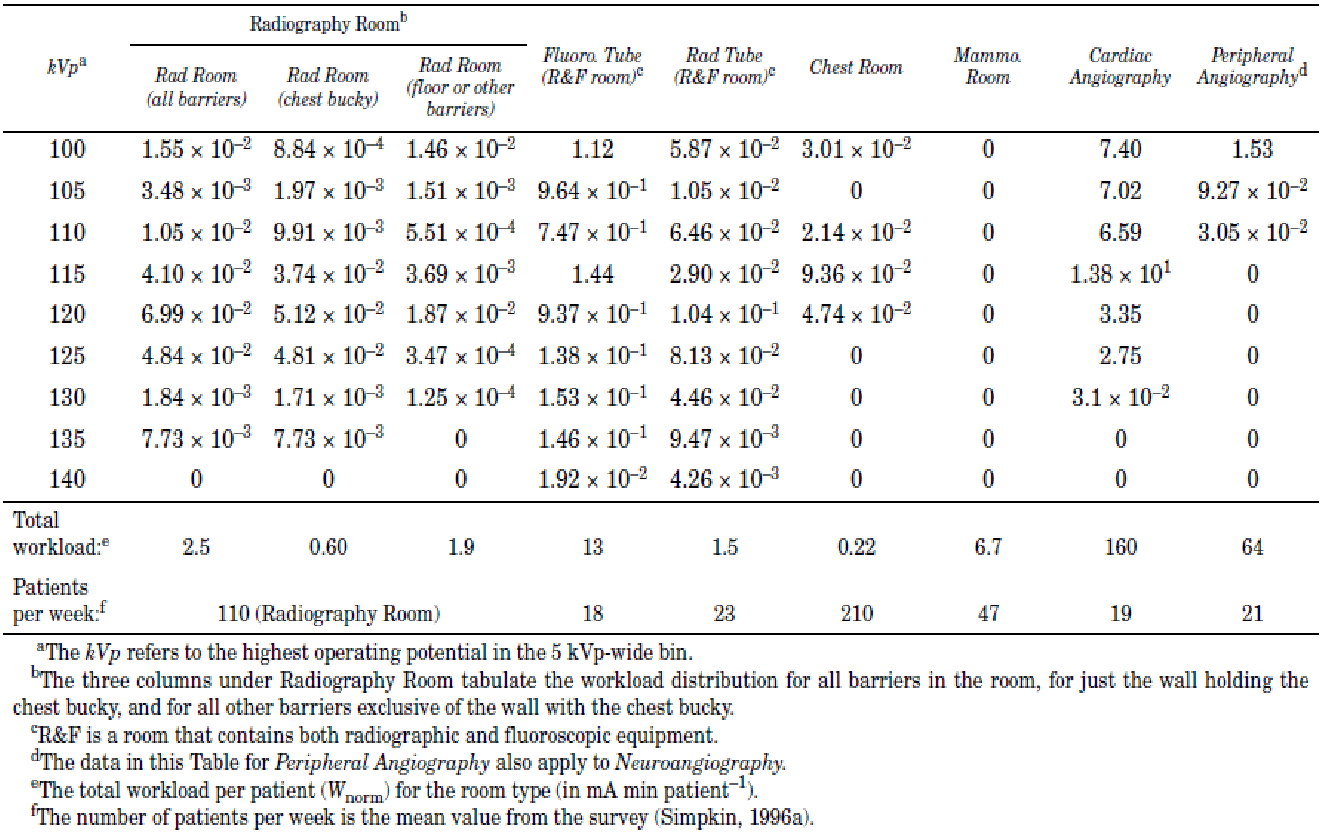
- Rad Room (all barriers) (used only for secondary barriers)
- Rad Room (chest bucky)
- Rad Room (floor or other barriers)
- Fluoroscopy Tube (R&F room)
- Rad Tube (R&F room)
- Chest Room
- Mammography Room
- Cardiac Angiography
- Peripheral Angiography

Where “Rad Room” indicates a room with radiographic equipment only and “R&F room” refers to a room that contains both radiographic and fluoroscopic equipment.

The workload distribution designated Rad Room (all barriers) was measured by the AAPM-TG9 survey (Simpkin, 1996a) for all exposures made in standard radiography rooms which contained a chest bucky and radiographic table but no fluoroscopy capability. This may be broken into the workload directed solely toward the chest bucky and that directed toward all other barriers in the room. There is a significant difference between these two distributions; imaging is performed with the chest bucky typically using higher operating potentials (often >100 kVp) compared with radiation fields directed toward other barriers in the room. Note that the bulk of the Rad Room (floor or other barriers) workload distribution is significantly below 100 kVp. The Rad Room (all barriers) workload distribution describes all radiation exposures produced in the radiographic room. It is composed of the sum of Rad Room (chest bucky) and Rad Room (floor or other barriers) distributions. This latter distribution describes exposures directed at the floor, cross-table wall, and any other beam orientations. Separating the workload into these two barrier-specific distributions provides a more accurate description of the intensity and penetrating ability of the radiation directed at primary barriers. Therefore, it is not necessary to use the Rad Room (all barriers) workload distribution for primary beam calculations; it will only be used for secondary barrier shielding calculations. The actual workload distribution for a given x-ray room will vary from those given in Table 4.2. It will also vary from facility to facility and even from week to week in the same facility. However, the average distribution obtained from the survey represents a more realistic model of x-ray use than the single kVp approximation. It also is independent of the number of patients examined because the workload distributions are scaled per patient. Furthermore, just as a single kVp produces a continuous bremsstrahlung photon spectrum with a corresponding transmission curve for a given shielding material, the workload distribution also produces a continuous spectrum, the attenuation properties of which can also be represented by a single transmission curve.



kVp[a]	Radiography Room[b]								
	Rad Room (all barriers)	*Rad Room (chest bucky)*	*Rad Room (floor or other barriers)*	*Fluoro. Tube (R&F room)*[c]	*Rad Tube (R&F room)*[c]	*Chest Room*	*Mammo. Room*	*Cardiac Angiography*	*Peripheral Angiography*[d]
25	0	0	0	0	0	0	9.25×10^{-1}	0	0
30	0	0	0	0	0	0	4.67	0	0
35	0	0	0	0	0	0	1.10	0	0
40	1.38×10^{-4}	0	1.38×10^{-4}	0	0	0	0	0	0
45	7.10×10^{-4}	0	7.10×10^{-4}	0	5.78×10^{-4}	0	0	0	0
50	8.48×10^{-3}	6.78×10^{-3}	1.70×10^{-3}	0	7.65×10^{-4}	0	0	3.40×10^{-1}	8.94×10^{-2}
55	1.09×10^{-2}	4.56×10^{-4}	1.04×10^{-2}	7.02×10^{-2}	7.26×10^{-4}	0	0	4.20×10^{-1}	3.98×10^{-2}
60	9.81×10^{-2}	8.96×10^{-3}	8.91×10^{-2}	1.13×10^{-1}	1.52×10^{-2}	0	0	1.96	6.99×10^{-1}
65	1.04×10^{-1}	3.42×10^{-2}	7.00×10^{-2}	1.87×10^{-1}	2.52×10^{-2}	0	0	4.55	1.50×10^{1}
70	4.58×10^{-1}	7.25×10^{-2}	3.85×10^{-1}	1.45×10^{-1}	8.89×10^{-2}	2.02×10^{-2}	0	6.03	1.22×10^{1}
75	5.01×10^{-1}	9.53×10^{-2}	4.05×10^{-1}	1.94×10^{-1}	2.24×10^{-1}	2.36×10^{-3}	0	8.02	1.53×10^{1}
80	5.60×10^{-1}	1.40×10^{-1}	4.20×10^{-1}	1.72	4.28×10^{-1}	0	0	2.54×10^{1}	1.10×10^{1}
85	3.15×10^{-1}	6.62×10^{-2}	2.49×10^{-1}	2.19	2.18×10^{-1}	7.83×10^{-4}	0	4.03×10^{1}	4.09
90	1.76×10^{-1}	1.41×10^{-2}	1.62×10^{-1}	1.46	5.33×10^{-2}	0	0	2.10×10^{1}	3.43
95	2.18×10^{-2}	3.51×10^{-3}	1.82×10^{-2}	1.15	4.89×10^{-2}	0	0	1.06×10^{1}	6.73×10^{-1}



kVp[a]	Radiography Room[b]			*Fluoro. Tube (R&F room)*[c]	*Rad Tube (R&F room)*[c]	*Chest Room*	*Mammo. Room*	*Cardiac Angiography*	*Peripheral Angiography*[d]
	Rad Room (all barriers)	*Rad Room (chest bucky)*	*Rad Room (floor or other barriers)*						
100	1.55×10^{-2}	8.84×10^{-4}	1.46×10^{-2}	1.12	5.87×10^{-2}	3.01×10^{-2}	0	7.40	1.53
105	3.48×10^{-3}	1.97×10^{-3}	1.51×10^{-3}	9.64×10^{-1}	1.05×10^{-2}	0	0	7.02	9.27×10^{-2}
110	1.05×10^{-2}	9.91×10^{-3}	5.51×10^{-4}	7.47×10^{-1}	6.46×10^{-2}	2.14×10^{-2}	0	6.59	3.05×10^{-2}
115	4.10×10^{-2}	3.74×10^{-2}	3.69×10^{-3}	1.44	2.90×10^{-2}	9.36×10^{-2}	0	1.38×10^{1}	0
120	6.99×10^{-2}	5.12×10^{-2}	1.87×10^{-2}	9.37×10^{-1}	1.04×10^{-1}	4.74×10^{-2}	0	3.35	0
125	4.84×10^{-2}	4.81×10^{-2}	3.47×10^{-4}	1.38×10^{-1}	8.13×10^{-2}	0	0	2.75	0
130	1.84×10^{-3}	1.71×10^{-3}	1.25×10^{-4}	1.53×10^{-1}	4.46×10^{-2}	0	0	3.1×10^{-2}	0
135	7.73×10^{-3}	7.73×10^{-3}	0	1.46×10^{-1}	9.47×10^{-3}	0	0	0	0
140	0	0	0	1.92×10^{-2}	4.26×10^{-3}	0	0	0	0
Total workload:[e]	2.5	0.60	1.9	13	1.5	0.22	6.7	160	64
Patients per week:[f]	110 (Radiography Room)			18	23	210	47	19	21

[a] The *kVp* refers to the highest operating potential in the 5 kVp-wide bin.

[b] The three columns under Radiography Room tabulate the workload distribution for all barriers in the room, for just the wall holding the chest bucky, and for all other barriers exclusive of the wall with the chest bucky.

[c] R&F is a room that contains both radiographic and fluoroscopic equipment.

[d] The data in this Table for *Peripheral Angiography* also apply to *Neuroangiography*.

[e] The total workload per patient (W_{norm}) for the room type (in mA min patient^{-1}).

[f] The number of patients per week is the mean value from the survey (Simpkin, 1996a).

TABLE 1.3—Operating potential (kVp) distribution of workload (mA min) normalized per patient, from survey conducted by AAPM TG9 (Simpkin, 1996a).

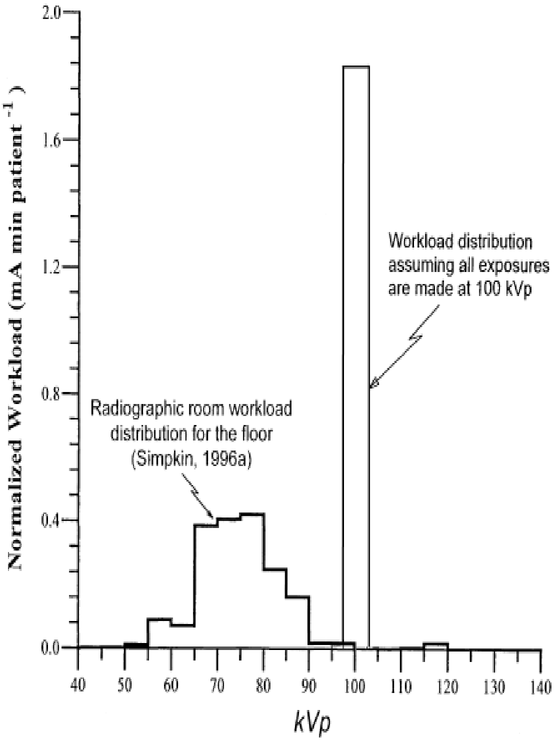


Fig. 1.12 The workload distribution Rad Room

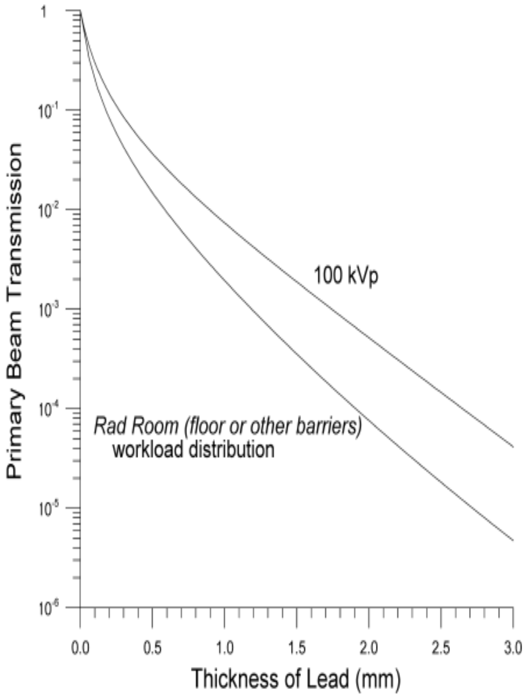


Fig. 1.13. The primary beam transmission through lead for x rays produced at 100 kVp

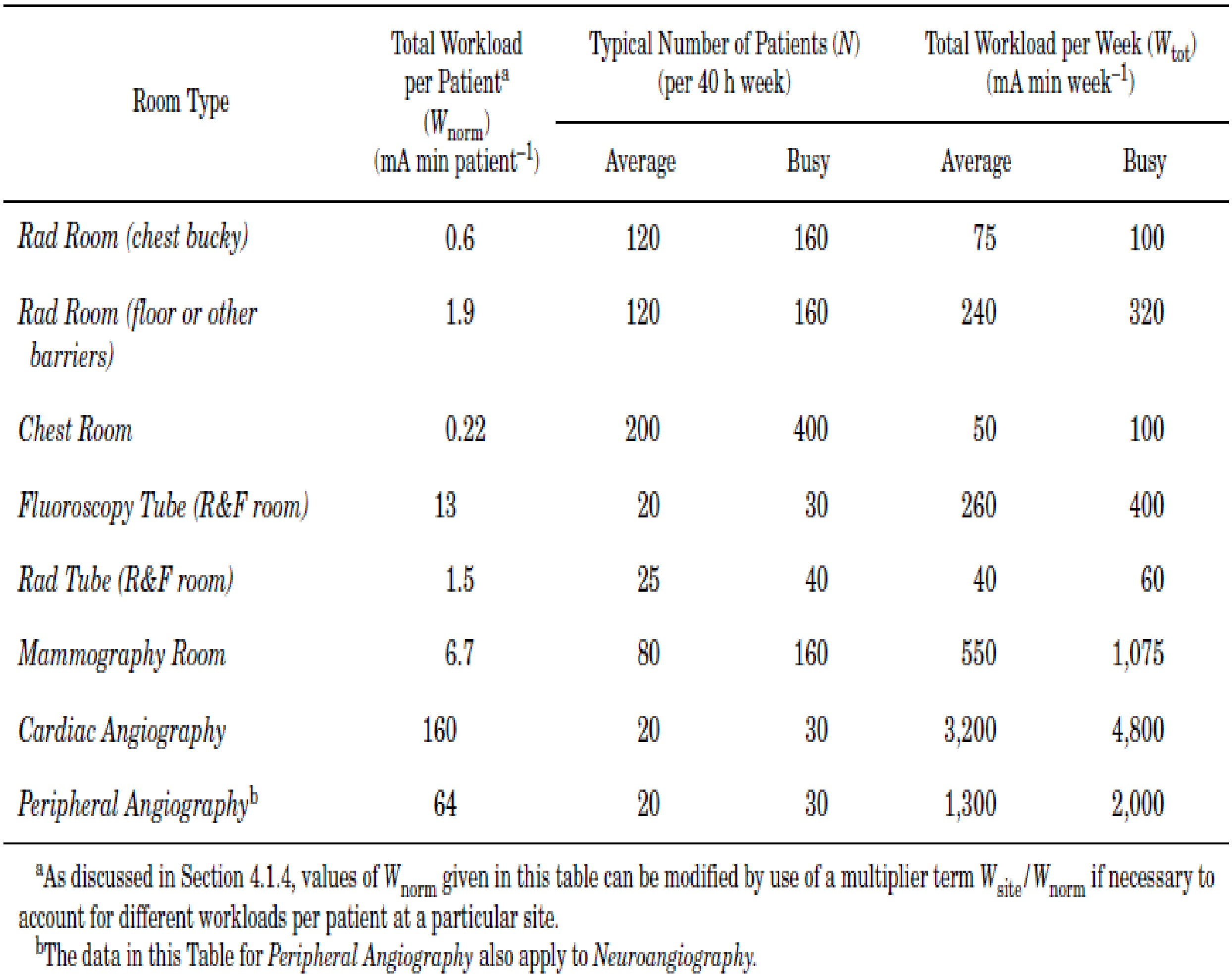
Figure 1.12 shows the primary beam transmission through lead for x rays produced at 100 kVp and also for the Rad Room (floor or other barriers) workload distribution shown in Figure 1.12. The required barrier thickness is that where the transmitted air kerma in the occupied area beyond the barrier does not exceed the weekly shielding design goal scaled by the occupancy factor (i.e., P/T). Using the workload distributions, the unshielded primary or secondary air kerma per patient (or total workload per patient) at 1 m may be calculated. Scaling these by the weekly number of patients imaged in the x-ray room and correcting by the inverse square of the distance yields the unshielded air kerma in the occupied area. By determining the radiation transmission through a given barrier material for this specific workload distribution, the thickness of the barrier that reduces the unshielded air kerma to the desired value of P/T can be determined. This Section and information contained in the appendices contain the data necessary to perform these calculations. Table 1.3 lists the typical number of patients for various types of medical x-ray imaging facilities including hospitals and clinics with different patient volume levels. These values may be employed if more accurate information on the number of patients is not available. The qualified expert needs to keep in mind, however, that per patient values of W_{norm} shown in Table 1.3 could change in the future or they may currently be different for the site being considered. For example, newer modalities such as digital radiography and digital mammography may use techniques that could result in values of W_{norm} different from those listed. In these cases, use of a modifying factor given by W_{site} / W_{norm} is required, where W_{site} is the total workload per patient at the installation under consideration. Equation 4.1 may then be modified as follows:

$$W_{\text{tot}} = \frac{W_{\text{site}}}{W_{\text{norm}}} N \, W_{\text{norm}} . \qquad \text{……….(1.2)}$$

The following discussions in this Report will utilize Equation 4.1 and the values in Table 1.3. However, adjustments to W_{norm} shall be made by the qualified expert when appropriate.

Use Factor

The use factor (U) is the fraction of the primary beam workload that is directed toward a given primary barrier. The value of U will depend on the type of radiation installation and the barrier of concern. In radiographic and R&F rooms, the equipment is arranged to allow many different beam orientations, so that different barriers may have different use factors. For example, the workload represented by the Rad Room (chest bucky) distribution is directed entirely toward the wall-mounted chest bucky. Therefore U = 1 for the area of the wall behind that image receptor and the Rad Room (chest bucky) workload distribution contributes only secondary radiation to all other barriers in the room. These other barriers, which include the floor, door(s), and walls (except the wall on which the chest bucky is attached) may serve as primary barriers to some fraction U of the Rad Room (floor or other barriers) workload distribution.



Room Type	Total Workload per Patient[a] (W_{norm}) (mA min patient^{-1})	Typical Number of Patients (N) (per 40 h week)		Total Workload per Week (W_{tot}) (mA min week^{-1})	
		Average	Busy	Average	Busy
Rad Room (chest bucky)	0.6	120	160	75	100
Rad Room (floor or other barriers)	1.9	120	160	240	320
Chest Room	0.22	200	400	50	100
Fluoroscopy Tube (R&F room)	13	20	30	260	400
Rad Tube (R&F room)	1.5	25	40	40	60
Mammography Room	6.7	80	160	550	1,075
Cardiac Angiography	160	20	30	3,200	4,800
Peripheral Angiography[b]	64	20	30	1,300	2,000

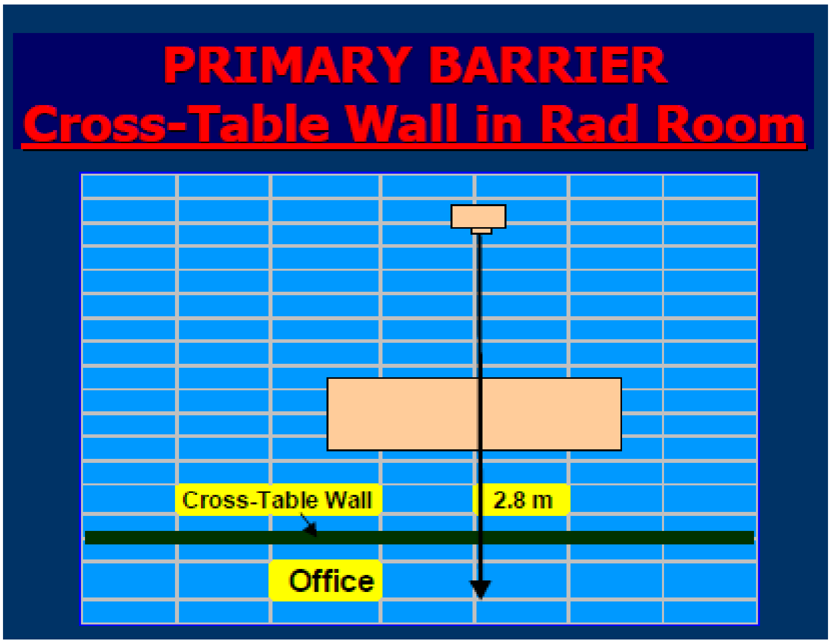
[a] As discussed in Section 4.1.4, values of W_{norm} given in this table can be modified by use of a multiplier term W_{site}/W_{norm} if necessary to account for different workloads per patient at a particular site.

[b] The data in this Table for *Peripheral Angiography* also apply to *Neuroangiography*.

TABLE 1.4—Estimated total workloads in various medical x-ray imaging installations in clinics and hospitals. The total workload values are for general guidance and are to be used only if the actual workloads are not available.

The primary beam use factors measured by the AAPM-TG9 survey (Simpkin, 1996a) applicable to the Rad Room (floor or other barriers) workload distribution are shown in Table 1.4. For convenience, the qualified expert may choose to round these values up to unity for the floor and 0.1 for the cross-table wall. Note that the ceiling and control booth are generally considered secondary barriers in a radiographic room. The AAPM-TG9 survey (Simpkin, 1996a) observed U = 0 for those barriers. Since the image-receptor assemblies for mammography and image-intensified fluoroscopy act as a primary beam stop, U = 0 for those applications, and only secondary radiation need be considered.

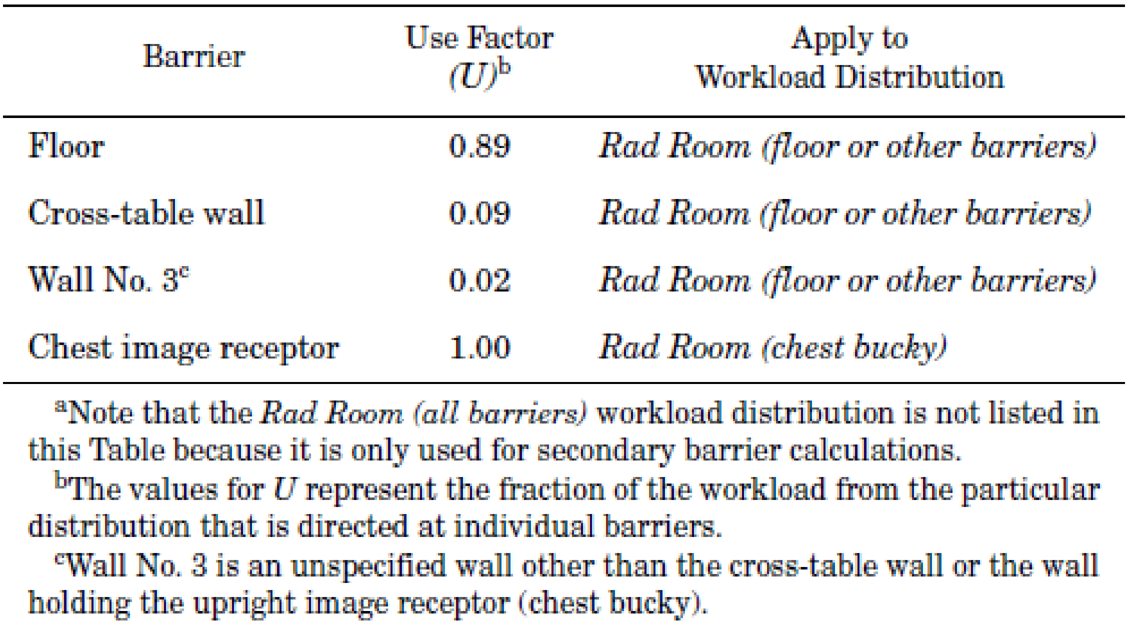
Primary Barriers


PRIMARY BARRIER

Cross-Table Wall in Rad Room

Fig 1.14: Primary Barrier

A primary barrier is one designed to attenuate the primary beam to the shielding design goal. Primary protective barriers are found in radiographic rooms, dedicated chest installations and radiographic/fluoroscopic rooms. Primary barriers include the portion of the wall on which the vertical cassette holder or "chest bucky" assembly is mounted, the floor, and those walls toward which the primary beam may occasionally be directed. Figure 4.3 illustrates the relationship of the x-ray source and patient to the primary barrier and shows the primary distance d_P measured from the source to 0.3 m beyond the barrier.



Barrier	Use Factor *(U)*[b]	Apply to Workload Distribution
Floor	0.89	*Rad Room (floor or other barriers)*
Cross-table wall	0.09	*Rad Room (floor or other barriers)*
Wall No. 3[c]	0.02	*Rad Room (floor or other barriers)*
Chest image receptor	1.00	*Rad Room (chest bucky)*

[a] Note that the *Rad Room (all barriers)* workload distribution is not listed in this Table because it is only used for secondary barrier calculations.

[b] The values for *U* represent the fraction of the workload from the particular distribution that is directed at individual barriers.

[c] Wall No. 3 is an unspecified wall other than the cross-table wall or the wall holding the upright image receptor (chest bucky).

TABLE 1.5–Primary beam use factors (U) for a general radiographic room determined from the survey of clinical sites (Simpkin, 1996a).a

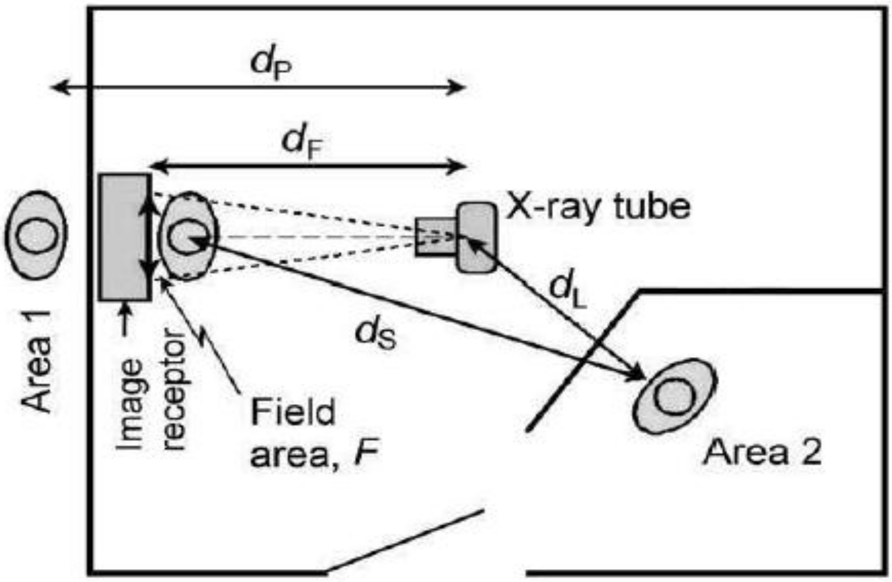
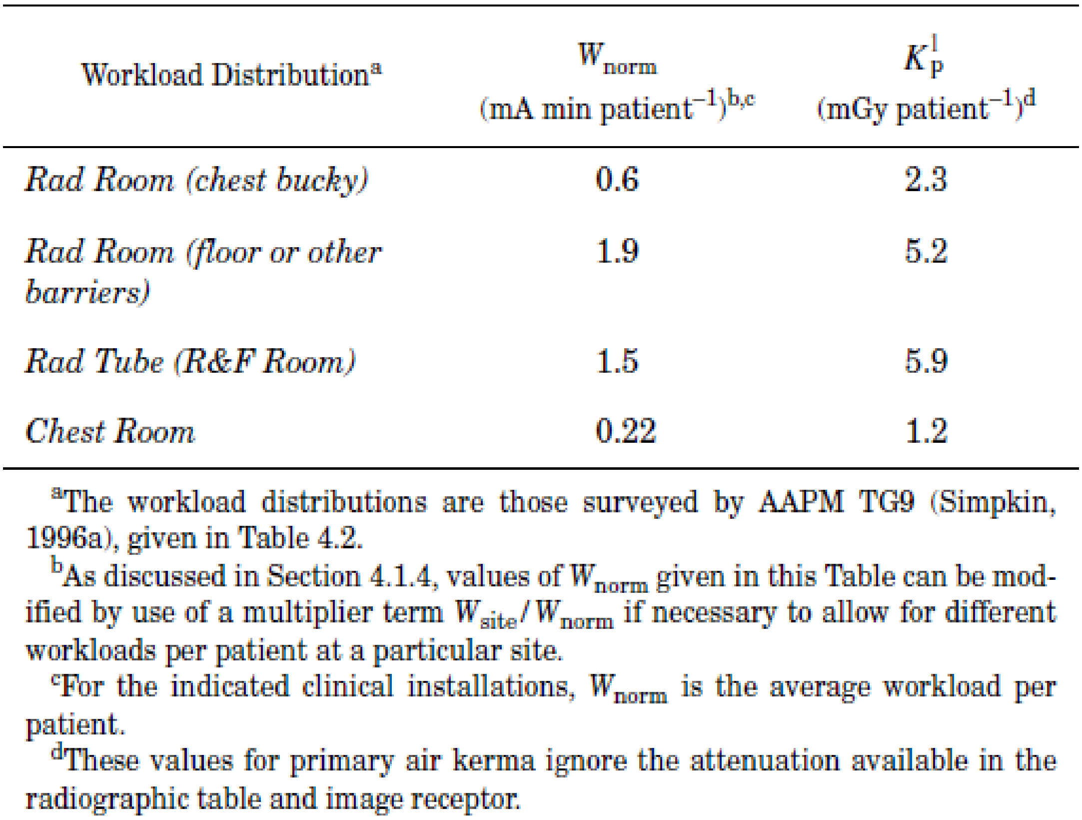


Fig.1.15 A typical medical imaging x-ray room layout. For the indicated tube orientation, the individual in Area 1 would need to be shielded from the primary beam, with the distance from the x-ray source to the shielded area equal to d_P . The person in Area 2 would need to be shielded from scattered and leakage radiations, with the indicated scattered radiation distance d_S and leakage radiation distance d_L. The primary x-ray beam has area F at distance d_F. It is assumed that individuals in occupied areas reside 0.3 m beyond barrier walls, 1.7 m above the floor below, and 0.5 m above occupied floor levels in rooms above the imaging room.

Since the image intensifier in general fluoroscopy, cardiac and peripheral angiography, and the breast support tray in mammography are required by regulation to act as primary beam stops (FDA, 2003c) these rooms do not normally contain primary barriers. Unshielded Primary Air Kerma. Table 1.6 shows the total workload per patient (W_{norm}) as well as the unshielded primary air kerma per patient at 1 m for each of the workload distributions. The weekly unshielded primary air kerma [$K_P(0)$] in the occupied area due to N patients examined per week in the room is:

$$K_P(O) = \frac{K_P^1 \; U \, N}{d_P^2}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots..(1.3)$$



Workload Distribution[a]	W_{norm} (mA min patient^{-1})[b,c]	K_P^1 (mGy patient^{-1})[d]
Rad Room (chest bucky)	0.6	2.3
Rad Room (floor or other barriers)	1.9	5.2
Rad Tube (R&F Room)	1.5	5.9
Chest Room	0.22	1.2

[a] The workload distributions are those surveyed by AAPM TG9 (Simpkin, 1996a), given in Table 4.2.

[b] As discussed in Section 4.1.4, values of W_{norm} given in this Table can be modified by use of a multiplier term W_{site}/W_{norm} if necessary to allow for different workloads per patient at a particular site.

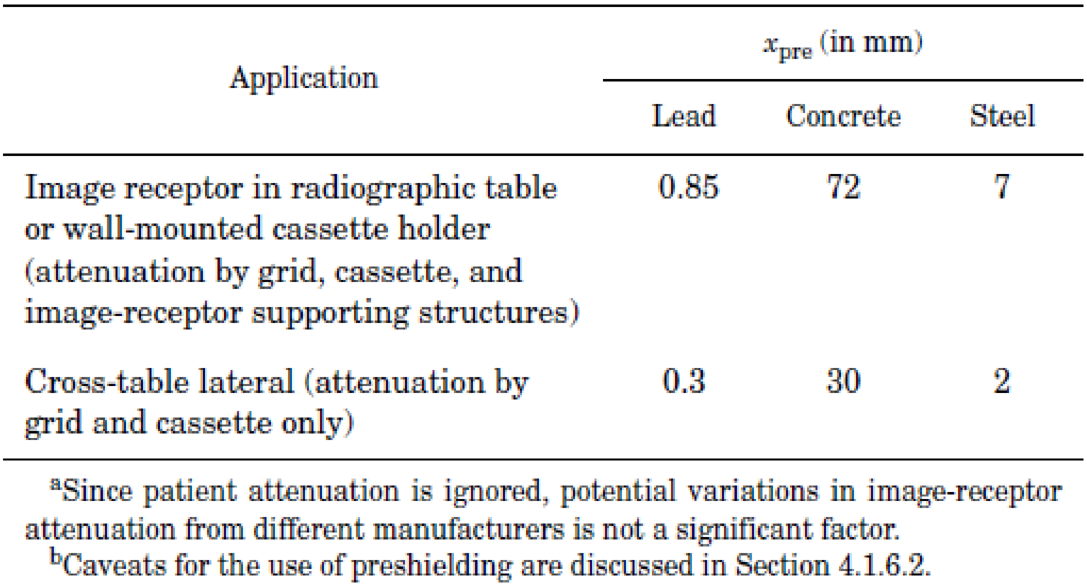
[c] For the indicated clinical installations, W_{norm} is the average workload per patient.

[d] These values for primary air kerma ignore the attenuation available in the radiographic table and image receptor.

TABLE 1.6—Unshielded primary air kerma per patient [(in mGy patient^{-1})] for the indicated workload [W_{norm} (mA min patient^{-1})] and workload distribution, normalized to primary beam distance d_P = 1 m. where d_P is the distance (in meters) from the x-ray tube to the occupied area.

Pre shielding. For primary barrier shielding calculations, it has been traditionally assumed that the unattenuated primary beam is incident on the floor or walls that constitute primary barriers.

In fact, the primary beam intensity is substantially reduced due to attenuation by the patient, the image receptor, and the structures supporting the image receptor. The primary beam is not, however, always totally intercepted by the patient since part of it may fall off the patient and impinge directly on the grid or cassette for some projections and patients. The area in which this occurs will, however, be spatially averaged over the primary beam area when the total patient population is considered. Thus, shielding provided by the patient remains a significant factor. Often, a suitably safe approach is to ignore the significant attenuation provided by the patient, and consider only attenuation by the imaging hardware in the x-ray beam. Dixon (1994) and Dixon and Simpkin (1998) have shown that for properly collimated primary beams, the x-ray film cassettes, grids, radiographic tables, and wall mounted cassette holders significantly reduce the intensity of primary radiation incident on the barrier. The attenuation provided by this imaging hardware can be expressed as an equivalent thickness of a shielding material. This equivalent thickness of "pre shielding" material is designated Xpre. Table 1.6 shows the minimum equivalent value of x_{pre} that may be used with any of the workload distributions in Table 1.2 for table or wall-mounted cassette holders, or for the grid and cassette. If the qualified expert confirms that these image receptors are present in the beam, the net structural barrier required may be determined by subtracting Xpre from the computed total primary barrier thickness obtained by assuming that the raw primary beam impinges directly on the barrier. However, the use of pre shielding material should be carefully evaluated by the qualified expert to ensure that it is applicable to the barrier under consideration. For table radiography with the beam directed at the floor, the use of pre shielding is normally appropriate (Sutton and Williams, 2000). In some cases, however, it may be prudent to ignore the pre shielding. For example, in cross-table lateral examinations the beam may not always be fully collimated to the patient and cassette. A chest receptor in some small clinics may consist only of a wall mounted cassette holder which will not contain all of the associated chest-bucky hardware listed in Table 1.6. The examples given in Section 5 show computations of barrier requirements with and without preshielding for completeness. The decision on whether the use of pre shielding is appropriate rests with the qualified expert.



Application	x_{pre} (in mm)		
	Lead	Concrete	Steel
Image receptor in radiographic table or wall-mounted cassette holder (attenuation by grid, cassette, and image-receptor supporting structures)	0.85	72	7
Cross-table lateral (attenuation by grid and cassette only)	0.3	30	2

[a] Since patient attenuation is ignored, potential variations in image-receptor attenuation from different manufacturers is not a significant factor.

[b] Caveats for the use of preshielding are discussed in Section 4.1.6.2.

TABLE 1.7—Equivalent thickness of primary beam pre shielding (xpre) (Dixon, 1994).

The qualified expert should realize, in any case, that the probability of the primary beam not being intercepted either by the patient or bucky hardware is small.

Secondary Barriers

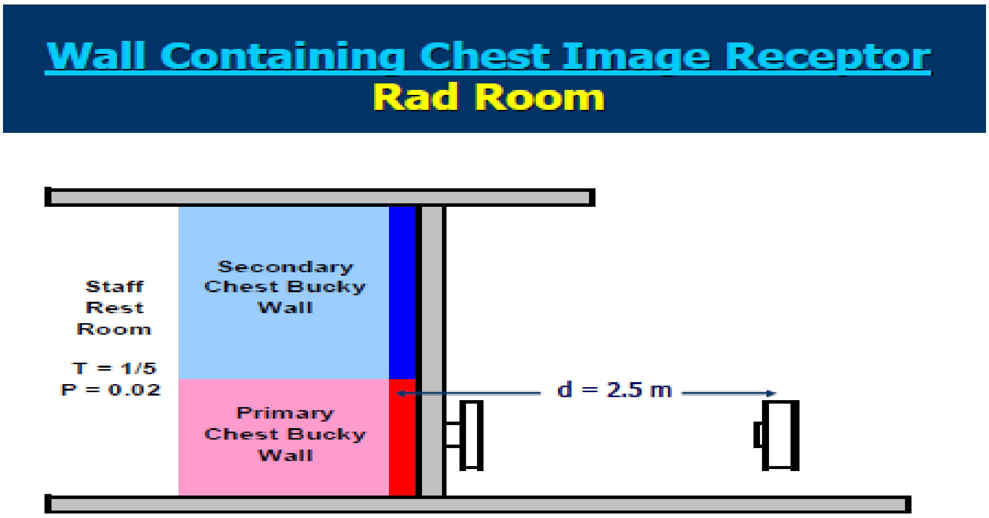


Fig: 1.16 Secondary Barriers

A secondary barrier is one that limits the air kerma from scattered and leakage radiations generated by the radiographic unit to the appropriate shielding design goal or less. The scattered radiation component is due to photons scattered by the patient and other objects in the path of the primary x-ray beam. The intensity of the scattered radiation increases with the intensity and area of the useful beam. Leakage radiation is that created at the x-ray tube anode and transmitted through the tube housing and the collimator outside of the useful beam area. Manufacturers are currently required by regulation to limit the leakage radiation to 0.876 mGy h–1 air kerma (100 mR h–1 exposures) at 1 m (FDA, 2003a). Compliance with this requirement is evaluated using the maximum operating potential and the maximum beam current at that potential for continuous x-ray tube operation.

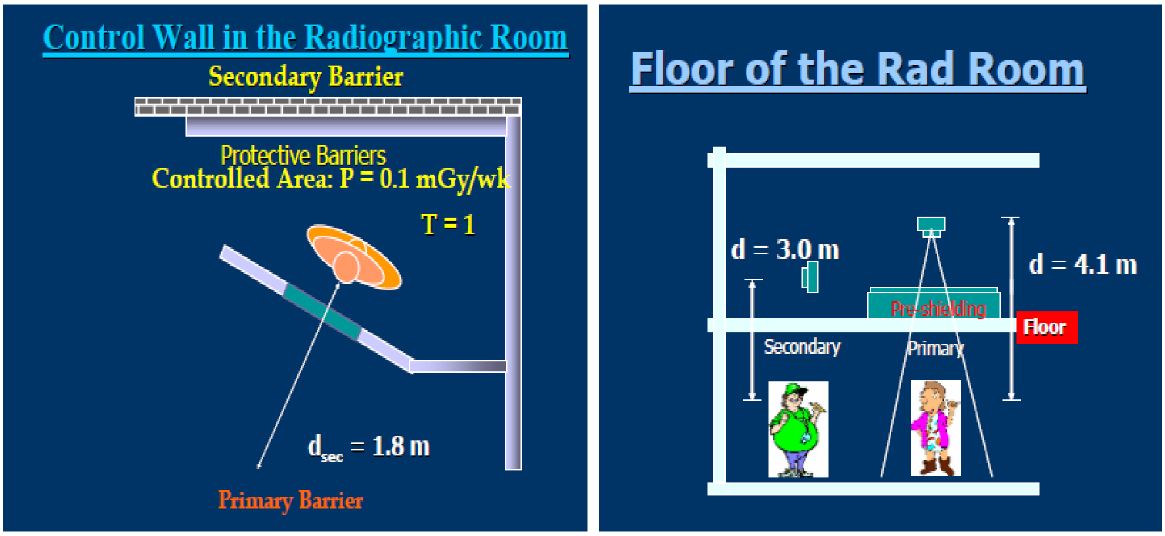
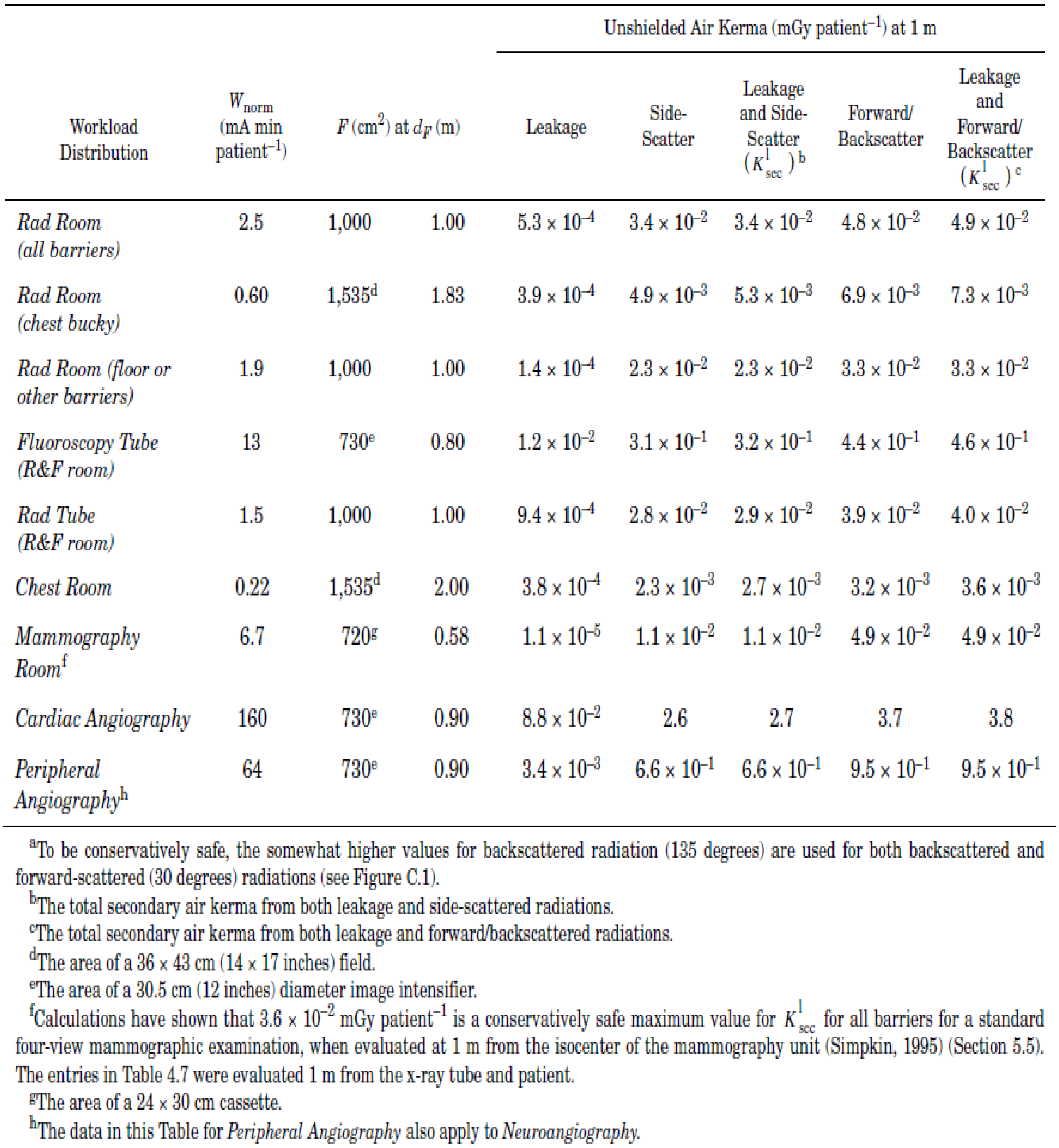


Fig: 1.17 Secondary Barriers

The relationship of the x-ray source and patient to the secondary barrier and defines the symbols representing the distances important to secondary barrier calculations. The air kerma from leakage radiation can be estimated by first assuming that the leakage radiation intensity with no housing matches that of the primary beam. At a typical set of leakage radiation technique factors of 150 kVp and 3.3 mA, the x-ray tube housing thickness required to reduce leakage radiation to the regulatory limit given above is equivalent to 2.3 mm of lead. The exposure-weighted workload in each kVp interval of the clinical workload distribution is then attenuated by this equivalent lead thickness and summed to provide the unshielded leakage air kerma per patient at 1 m and is given in Table 1.7. For equipment with maximum operating potentials below 150 kVp, the equivalent x-ray tube housing thickness may be <2.3 mm of lead, but the unshielded secondary air kerma can still be determined using the kVp-specific data available in Simpkin and Dixon (1998).



				Unshielded Air Kerma (mGy patient^{-1}) at 1 m				
Workload Distribution	W_{norm} (mA min patient^{-1})	F (cm^2) at d_F (m)		Leakage	Side-Scatter	Leakage and Side-Scatter (K^1_{sec})[b]	Forward/ Backscatter	Leakage and Forward/ Backscatter (K^1_{sec})[c]
Rad Room (all barriers)	2.5	1,000	1.00	5.3×10^{-4}	3.4×10^{-2}	3.4×10^{-2}	4.8×10^{-2}	4.9×10^{-2}
Rad Room (chest bucky)	0.60	1,535[d]	1.83	3.9×10^{-4}	4.9×10^{-3}	5.3×10^{-3}	6.9×10^{-3}	7.3×10^{-3}
Rad Room (floor or other barriers)	1.9	1,000	1.00	1.4×10^{-4}	2.3×10^{-2}	2.3×10^{-2}	3.3×10^{-2}	3.3×10^{-2}
Fluoroscopy Tube (R&F room)	13	730[e]	0.80	1.2×10^{-2}	3.1×10^{-1}	3.2×10^{-1}	4.4×10^{-1}	4.6×10^{-1}
Rad Tube (R&F room)	1.5	1,000	1.00	9.4×10^{-4}	2.8×10^{-2}	2.9×10^{-2}	3.9×10^{-2}	4.0×10^{-2}
Chest Room	0.22	1,535[d]	2.00	3.8×10^{-4}	2.3×10^{-3}	2.7×10^{-3}	3.2×10^{-3}	3.6×10^{-3}
Mammography Room[f]	6.7	720[g]	0.58	1.1×10^{-5}	1.1×10^{-2}	1.1×10^{-2}	4.9×10^{-2}	4.9×10^{-2}
Cardiac Angiography	160	730[e]	0.90	8.8×10^{-2}	2.6	2.7	3.7	3.8
Peripheral Angiography[h]	64	730[e]	0.90	3.4×10^{-3}	6.6×10^{-1}	6.6×10^{-1}	9.5×10^{-1}	9.5×10^{-1}

[a] To be conservatively safe, the somewhat higher values for backscattered radiation (135 degrees) are used for both backscattered and forward-scattered (30 degrees) radiations (see Figure C.1).

[b] The total secondary air kerma from both leakage and side-scattered radiations.

[c] The total secondary air kerma from both leakage and forward/backscattered radiations.

[d] The area of a 36 x 43 cm (14 x 17 inches) field.

[e] The area of a 30.5 cm (12 inches) diameter image intensifier.

[f] Calculations have shown that 3.6×10^{-2} mGy patient^{-1} is a conservatively safe maximum value for K^1_{sec} for all barriers for a standard four-view mammographic examination, when evaluated at 1 m from the isocenter of the mammography unit (Simpkin, 1995) (Section 5.5). The entries in Table 4.7 were evaluated 1 m from the x-ray tube and patient.

[g] The area of a 24 x 30 cm cassette.

[h] The data in this Table for *Peripheral Angiography* also apply to *Neuroangiography*.

TABLE 1.8—Unshielded leakage, scattered and total secondary air kermas (in mGy patient–1) for the indicated workload distributions at dS = dL= 1 m. The workload distributions and total workloads per patient (Wnorm) for the indicated clinical sites are the average per patient surveyed by AAPM TG9 (Simpkin, 1996a), listed in Table 4.2. The primary field size F (in cm2) is known at primary distance dF . Side-scattered radiation is calculated for 90 degree scatter. Forward- and backscattered radiations are calculated for 135 degree scatter.a Leakage radiation technique factors are 150 kVp at 3.3 mA to achieve 0.876 mGy h–1 (100 mR h–1) for all tubes except mammography, which assumes leakage radiation technique factors of 50 kVp at 5 mA.

That is, the air kerma due to the workload in each kVp interval of the workload distribution is transmitted through the barrier of thickness xbarrier with a transmission factor , and summed to get the total transmitted air kerma due to leakage radiation.

Scattered Radiation. The magnitude of the air kerma due to scattered radiation is a function of the scattering angle, the number and energy of primary photons incident on the patient, location of the beam on the patient, and the size and shape of the patient. It is assumed that scattered radiation intensity is proportional to the primary beam area at a distance from the focal spot. These parameters are conveniently taken as the image-receptor area and the source-to-image-receptor distance (SID), respectively.

The scatter fraction (a_1) is defined as the ratio of the scattered air kerma 1 m from the center of the primary beam area at the patient to the primary air kerma 1 m from the x-ray tube for a given primary beam area. The air kerma for scattered radiation is assumed to scale linearly with primary field area. This reference field size is conveniently taken as the image-receptor area at the SID.

Total Contribution from Secondary Radiation. Table 1.8 gives values for unshielded leakage, scattered and total secondary air kermas (the latter being) calculated for the clinical workload distributions for the case where the leakage and scattered air kerma distances are both 1 m. The assumed values of the primary beam area (F) at the primary distance (d_F) in meters and the total workload per patient (W_{norm}) used to obtain the values of scattered air kerma (i.e., for side-scattered and forward/backscattered radiations), are also given in Table 1.7. The air kerma from unshielded secondary radiation [$K_{sec}(0)$] at a distance d_{sec} for N patients is:

$$K_{\text{sec}}(0) = \frac{K^1_{\text{sec}}\, N}{d^2_{\text{sec}}}. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.4)$$

Strictly speaking, this simplified expression is only correct when d_L and d_S, the distances relevant for leakage and scattered radiation, respectively, are equal. Using the shorter of these two distances for d_{sec} is one acceptable solution.

Shielding Calculation Methods

This Section introduces the general equations that will be used to determine barrier requirements and then applies these concepts to primary and secondary barriers.

General Shielding Concepts

The objective of a shielding calculation is to determine the thickness of the barrier that is sufficient to reduce the air kerma in an occupied area to a value ≤P/T, the weekly shielding design goal modified by the occupancy factor for the area to be shielded. The broad-beam transmission function [B(x)] is defined as the ratio of the air kerma behind a barrier of thickness x to the air kerma at the same location with no intervening radiation barrier. An acceptable barrier thickness ($x_{barrier}$) is one in which the value of the broad-beam transmission function is:

$$B(x_{\text{barrier}}) = \left(\frac{P}{T}\right)\frac{d^2}{K^1\, N} \quad \ldots\ldots \quad 1.5$$

Where d is the distance between the radiation source and the individual beyond the barrier, K1 is the average unshielded air kerma per patient at 1 m from the source, and N is the expected number of patients examined in the room per week. The transmission characteristics of broad-beam x-ray sources are discussed in Appendix A; transmission curves are provided; and parameters (α, β and γ) are provided for a model that permits an algebraic solution for xbarrier as:

$$x_{\text{barrier}} = \frac{1}{\alpha\gamma} \ln \left[\frac{\left(\frac{N T K^{1}}{P d^{2}}\right)^{\gamma} + \frac{\beta}{\alpha}}{1 + \frac{\beta}{\alpha}} \right] \quad \text{..... (1.6)}$$

Note that the broad-beam transmission fitting parameters (α, β and γ) depend on the material of the barrier, as well as the workload distribution as a function of kVp.

Shielding for Primary Barriers

The barrier transmission factor (BP) sufficient to decrease KP(0) (the air kerma from unshielded primary radiation at a distance dP) to P/T is given by:

$$B_{\text{P}}(x_{\text{barrier}} + x_{\text{pre}}) = \left(\frac{P}{T}\right) \frac{d_{\text{P}}^{2}}{K_{\text{P}}^{1}\, U N}. \quad \text{....... 1.7}$$

Appropriate values for, the unshielded primary air kerma per patient at 1 m, are provided for each of the clinical workload distributions in Table 1.5. The other parameters have already been discussed: P is the weekly shielding design goal, T is the occupancy with suggested values in Table 1.1, U is the use factor, and dP is the distance from the source to the location of the maximally exposed individual beyond the primary barrier. The primary beam transmission functions [BP(xbarrier)] for each workload distribution for a variety of shielding materials have been derived. These were calculated by summing the air kerma in each kVp interval transmitted through a given barrier thickness and dividing that by the total air kerma expected with no barrier. The structural barrier thickness (x_{barrier}) required to adequately shield against primary radiation may be calculated by determining the total shielding thickness required (x_{barrier} + x_{pre}), and then if applicable, subtracting the equivalent "pre shielding" thickness xpre given in Table 1.7 to obtain x_{barrier}. Alternatively, an algebraic solution for x_{barrier}, given in Equation 4.8, may be calculated based on the model of Archer et al. (1983) for broad-beam transmission (Appendix A):

$$x_{\text{barrier}} = \frac{1}{\alpha\gamma} \ln \left[\frac{\left(\frac{N T U K_{\text{P}}^{1}}{P d_{\text{P}}^{2}}\right)^{\gamma} + \frac{\beta}{\alpha}}{1 + \frac{\beta}{\alpha}} \right] - x_{\text{pre}}. \quad \text{.......... (1.8)}$$

The fitting parameters (α, β and γ) for primary radiation generated by the clinical workload distributions .

Shielding for Secondary Barriers

The barrier transmission factor [Bsec($x_{barrier}$)] that reduces $K_{sec}(0)$ (the air kerma from unshielded secondary radiation at a distance d_{sec}) to P/T for secondary radiation is:

$$B_{sec}(x_{barrier}) = \left(\frac{P}{T}\right)\frac{d^{2}_{sec}}{K^{1}_{sec}\,N}\ .$$

……... 1.9

Appropriate values for the unshielded secondary air kerma per patient at 1 m, are provided for each of the clinical workload distributions in Table 1.8. The other parameters have already been discussed: P is the weekly shielding design goal, T is the occupancy factor with suggested values in Table 1.1, and d_{sec} is the distance from the source of the secondary radiation to the location of the maximally-exposed individual beyond the secondary barrier. The thickness xbarrier satisfying Equation 1.9 can be graphically determined. As before, an algebraic determination of $x_{barrier}$ may also be made. The secondary transmission [Bsec($x_{barrier}$)] has been fitted to the form of Equation:

$$x_{barrier} = \frac{1}{\alpha\gamma}\ln\left[\frac{\left(\frac{N\,T\,K^{1}_{sec}}{P d^{2}_{sec}}\right)^{\gamma} + \frac{\beta}{\alpha}}{1 + \frac{\beta}{\alpha}}\right].$$

..........................(1.10)

Additional Method for Representative Radiographic Rooms, and Radiographic and Fluoroscopic Rooms The previously described methods for calculating shielding barrier thicknesses can be readily applied to rooms having an x-ray tube whose orientation is fixed, such as in a dedicated chest unit, or an installation in which only secondary radiation is present, such as for C-arm fluoroscopy. However, the complexity of calculations for installations with multiple x-ray tubes, or variable tube locations and orientations, such as radiographic and R&F rooms, makes these methods more cumbersome. Consider, for example, the cross-table wall in a radiographic room. This barrier has to protect against three radiation sources, namely, the primary radiation from cross-table exposures, scattered and leakage radiations from over-table projections, and secondary radiation from chest-bucky projections. Because of the variety of distributions of kVp and distance among these radiation sources, this is a surprisingly difficult shielding problem.

To simplify this problem, assumptions may be made regarding the number, orientation and location of x-ray tubes, workload distributions, use factors, and equipment layout typical of clinical installations.. Primary x-ray beams are directed toward the radiographic table and the wall-mounted chest bucky, as well as across the table. A shielding barrier in this room needs to reduce the total of both the primary radiation and the sum of transmitted air kerma from all secondary radiation sources to a value no larger than P/T. While it has traditionally been assumed that the primary radiation would predominate, this may not be true for barriers of low primary workload or use factor. The small size of the model room in Figure 4.4, when viewed as a radiographic room, ensures that the contributions of these various secondary sources are high. The thickness requirements for the various barriers around this room have been calculated using representative workload distributions and use factor information. These barrier thicknesses were calculated assuming the Rad Room (floor or other barriers) kVp workload distribution (Wnorm is 1.9 mA min patient^{-1}) was directed toward an image receptor of 1,000 cm^{2} area in the radiographic table (at 100 cm SID), and at a similarly-sized image receptor for the cross-table lateral exposures. This workload was distributed so that 89 percent was directed down onto the table, two percent directed at the wall opposite the chest bucky, with the remaining nine percent at the cross-table wall. Radiographic exposures following the Rad Room (chest bucky) workload distribution (Wnorm is 0.6 mA min patient–1) were directed at the chest-bucky image receptor (area is 1,535 cm2 at 1.83 m SID). From Equations 1.7 and 1.9, it is apparent that the shielding requirements for a given barrier depend on NT/Pd2. The required thicknesses of lead and concrete for the various barriers in the radiographic room have been calculated as a function of NT/Pd2. For these graphs, P is in milligray per week, N is the number of patients examined each week, and distance d is in meters. The barrier requirements may be applied to a radiographic room by using the value of d appropriate for the barrier of interest in that room. The distance

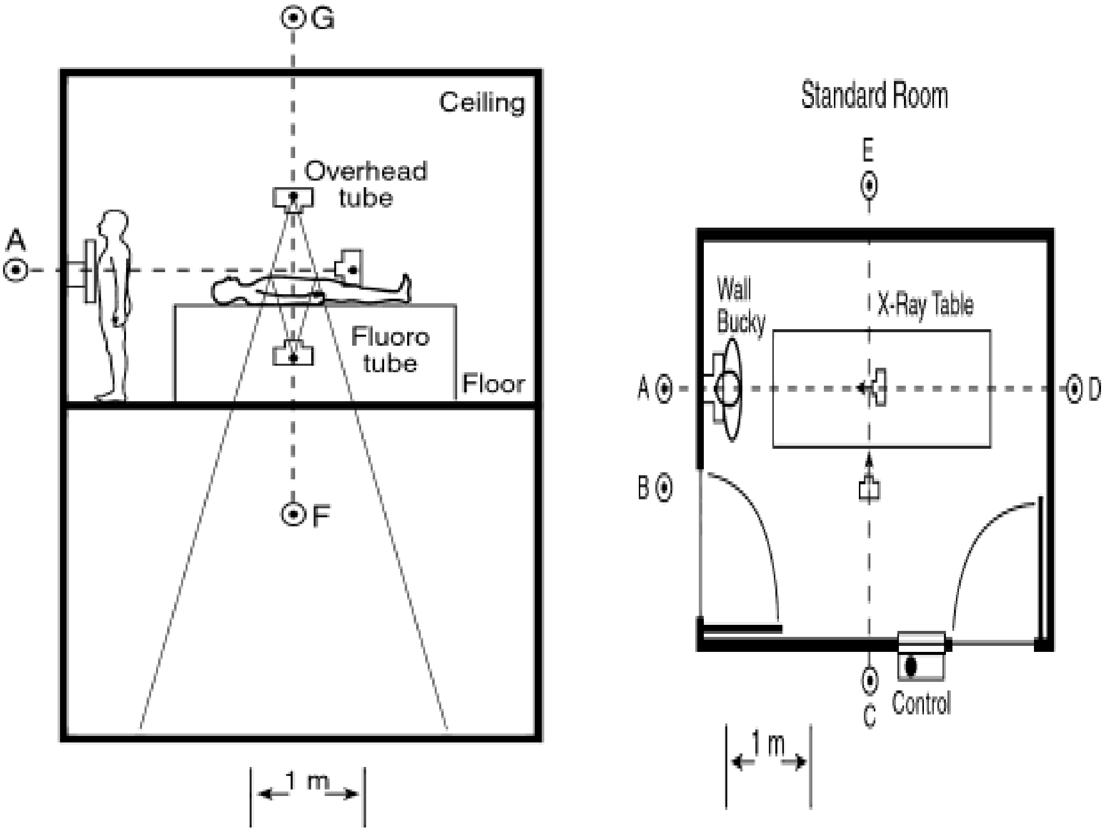


Fig. 1.18 Elevation (left) and plan (right) views of a representative radiographic (or radiographic and fluoroscopic) room. Points A, B, C, D and E represent a distance of 0.3 m from the respective walls. Point F is 1.7 m above the floor below. Point G is taken at 0.5 m above the floor of the room above.

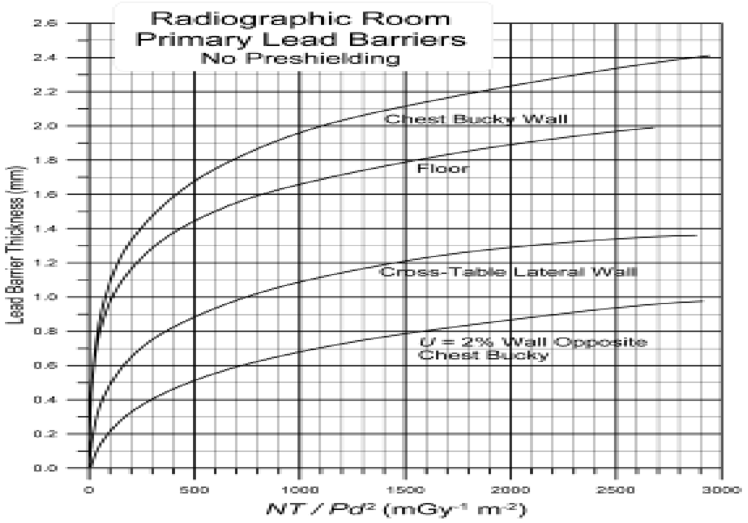


Fig.1. 19, The lead thickness requirements for primary barriers assuming no preshielding (xpre) in the representative radiographic room as a function of NT/Pd2. P is in milligray per week, N is the weekly total number of patients examined in the radiographic room, and d (in meters) is chosen as the distance from the most intense radiation source to the occupied area. If the Wnorm values given in Table 1.5 do not match the per patient workload for the facility under consideration, then the original value of NT/Pd2 can be multiplied by Wsite / Wnorm, and the modified value can be used to obtain the required shielding from Figure 1.19

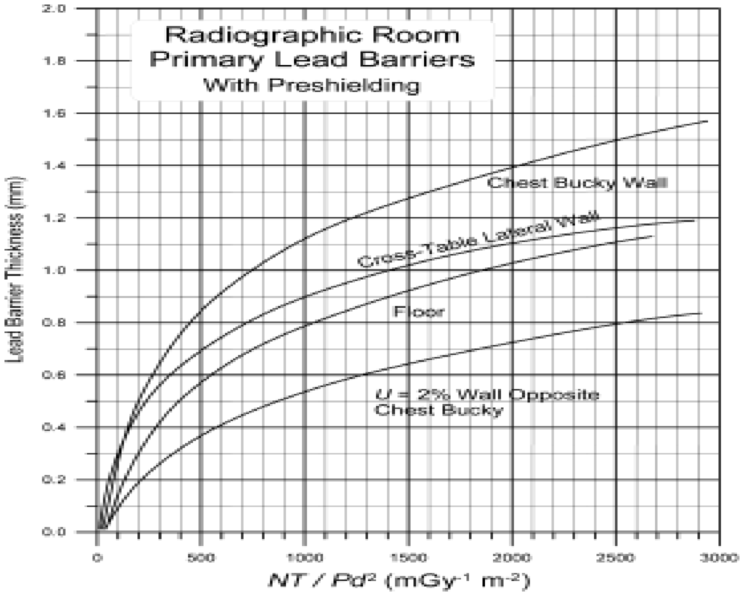


Fig. 1.20. The lead thickness requirements for primary barriers assuming preshielding (xpre) in the representative radiographic room as a function of NT/Pd2. P is in milligray per week, N is the weekly total number of patients examined in the radiographic room, and d (in meters) is chosen as the distance from most intense radiation source to the occupied area. The chest-bucky wall and floor are assumed primary barriers with a cassette, grid, and supporting structures present. The cross-table lateral wall and wall with two percent use factor assume the presence of just a cassette and grid. If the Wnorm values given in Table 4.5 do not match the per patient workload for the facility under consideration, then the original value of NT/Pd2 can be multiplied by Wsite / Wnorm, and the modified value can be used to obtain the required shielding from Figure 1.20

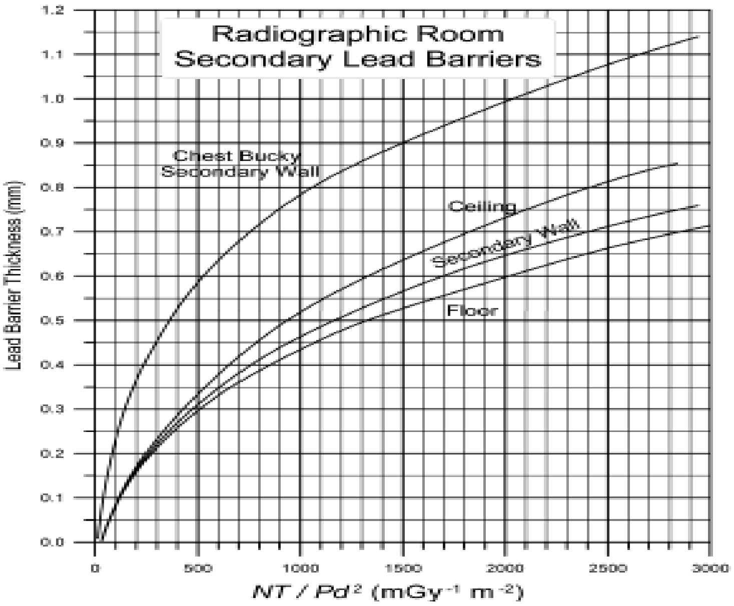


Fig. 1.21. The lead thickness requirements for secondary barriers in the representative radiographic room as a function of NT/Pd2. P is in milligray per week, N is the weekly total number of patients examined in the radiographic room, and d (in meters) is chosen as the distance from the most intense radiation source to the occupied area. If the Wnorm values given in Table 4.5 do not match the per patient workload for the facility under consideration, then the original value of NT/Pd2 can be multiplied by Wsite / Wnorm, and the modified value can be used to obtain the required shielding from Figure 1.21..

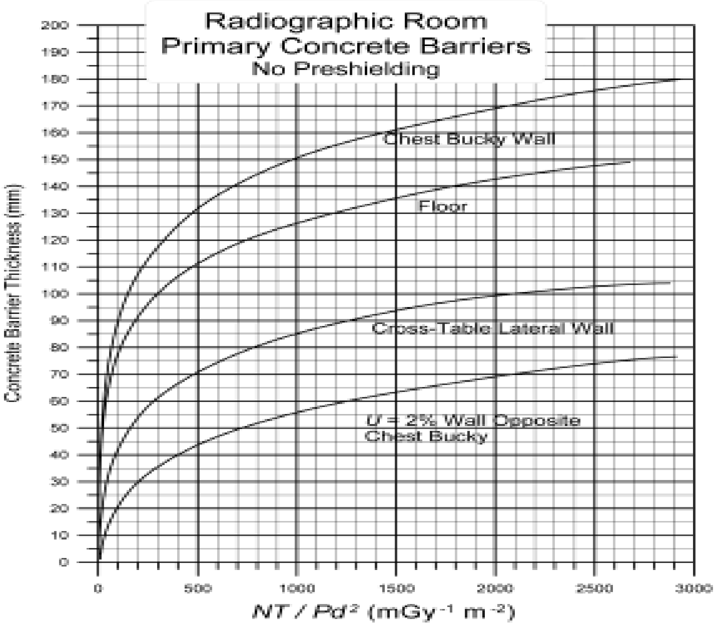


Fig. 1.22. The concrete (standard-weight) thickness requirements for primary barriers assuming no preshielding (xpre) in the representative radiographic room as a function of NT/Pd2. P is in milligray per week, N is the weekly total number of patients examined in the radiographic room, and d (in meters) is chosen as the distance from the most intense radiation source to the occupied area. If the Wnorm values given in Table 4.5 do not match the per patient workload for the facility under consideration, then the original value of NT/Pd2 can be multiplied by Wsite/ Wnorm, and the modified value can be used to obtain the required shielding from Figure 1.22

1.7 Examples of Shielding Calculations

This Section demonstrates how the theoretical information and data contained in this Report may be used to determine the minimum barrier thickness required to shield different types of medical x-ray imaging rooms. However, it is important to stress that these examples and the methodology used are not intended to represent the only techniques and assumptions capable of providing acceptable radiation protection. Alternate methods may prove equally satisfactory. The professional judgement of the qualified expert is required in each design specification to ensure that the necessary degree of radiation protection is achieved as effectively and economically as possible. The final assessment of the adequacy of the design and construction of structural shielding is based on the radiation survey of the completed installation as described. To ensure that the appropriate shielding design goals for controlled and uncontrolled areas are not exceeded, direct measurements are recommended. If the assessment survey shows deficiencies, additional shielding or modification of equipment and procedures are required. To avoid such deficiencies, the qualified expert needs to consider the ALARA principal and use a conservatively safe approach in specifying radiation barriers. The cost of adding shielding to an existing facility is many times greater than increasing it in the initial phase of construction. Table 1.5 provides a summary of the resources in this Report that are included to assist the qualified expert in specifying shielding requirements.

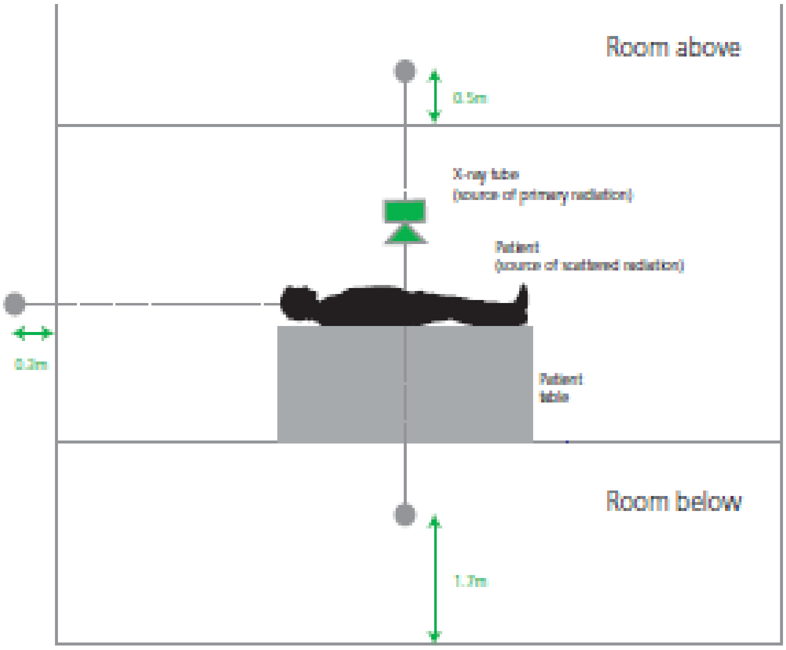


Fig: 1.23

For completeness and as an instructional tool, many of these examples contain more than one method of determining one particular barrier requirement. As shown in the examples, similar results for these barriers can be obtained using the figures in Appendices B and C with conventional computational methods. These computational methods are also employed for cardiac and peripheral angiography, and mammography rooms. Finally, the data and information contained in the tables and graphs in these appendices can be readily employed in computer-based spreadsheet solutions. The first example considers a straight-forward case of a single x-ray source with secondary barriers. The more complicated cases of multiple x-ray sources with variable beam locations will then be considered for radiographic and R&F rooms.

The Radiographic Room

Consider next the radiographic room in Figure 1.18 (elevation drawing) and Figure 5.2 (plan drawing). Assume N = 125 patients per week are radiographed in this room. The workload distribution is assumed to follow that of the radiographic room from the AAPM-TG9 survey (Simpkin, 1996a).The areas exposed to primary radiation include the office beneath the floor, the staff rest room adjacent to the chest image receptor, and the cross-table wall

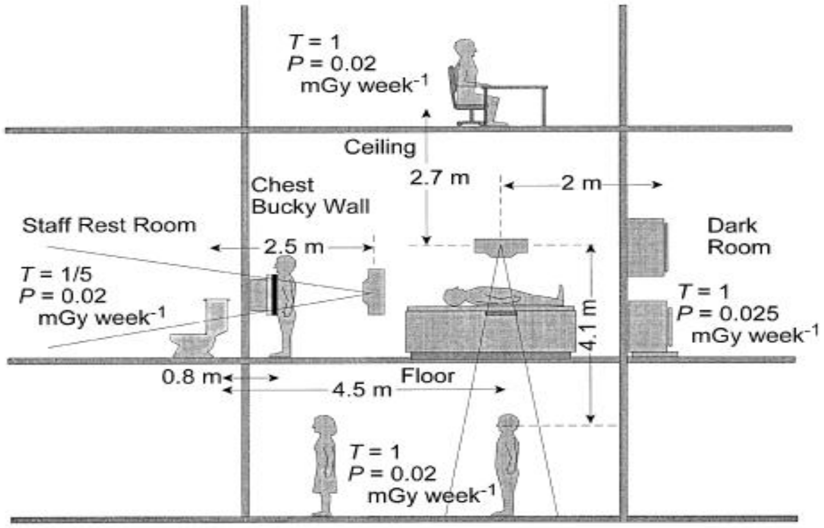


Fig. 1.24. Elevation drawing of the radiographic room. The dimensions are used in sample calculations in Section 5.3. This same layout is also used for the R&F room examples in Section 5.4, with the addition of a fluoroscopy x ray tube beneath the table and an image intensifier over the table.

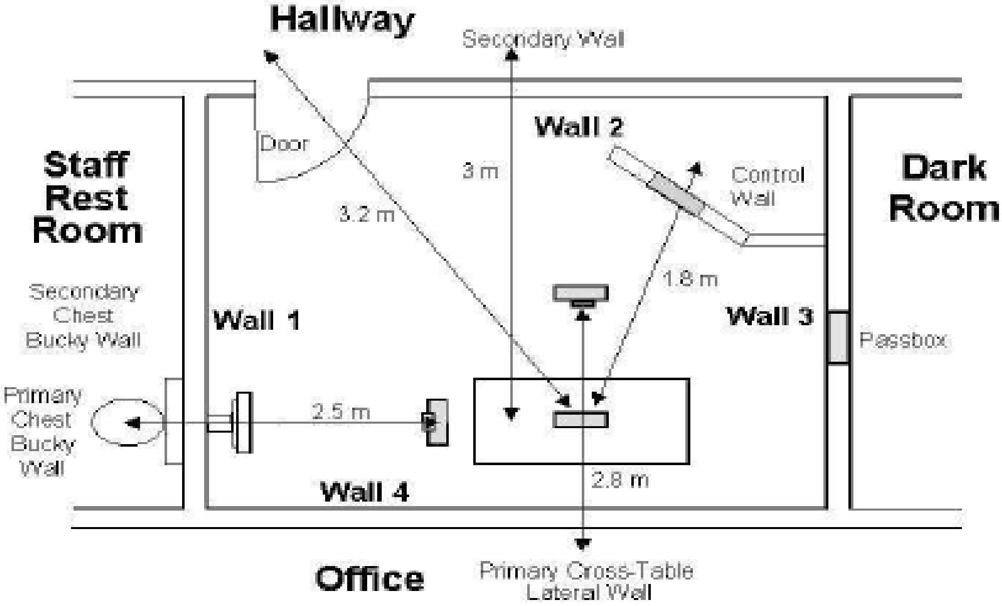


Fig. 1.25. Plan drawing of the radiographic room shown in Figure 1.24.

(Wall 4 behind the x-ray table as shown in Figure 1.25). All other areas are assumed to be exposed only to secondary radiation. The values for other shielding parameters that need to be determined by the qualified expert for this room are noted either in Figure 1.24, Figure 1.25, or in the examples.

The Floor of the Radiographic Room

Assume the area below the radiographic room is an uncontrolled area with a shielding design goal of P = 0.02 mGy week–1 with an occupancy factor T = 1. This area will be irradiated by primary radiation directed at the image receptor in the radiographic table, as well as by secondary radiation.

Primary Barrier Calculation for Floor Beneath the Radiographic Table. From Table 1.5, the unshielded primary air kerma per patient for the Rad Room (floor or other barriers) workload distribution is 5.2 mGy patient–1 at 1 m. While the use factor (U) for this workload distribution directed on the floor is 0.89 (Table 1.4), one may use a conservatively safe assumption that U = 1. Thus, at the location 1.7 m above the lower floor (i.e., dP = 4.1 m), the total unshielded primary air kerma per week, from Equation 1.3, is:

$$K_{\mathrm{P}}(0) = \frac{5.2 \text{ mGy patient}^{-1} \times 1 \times 125 \text{ patients week}^{-1}}{(4.1 \text{ m})^{2}} = 39 \text{ mGy week}^{-1}$$

The primary barrier transmission required for T = 1 and P = 0.02 mGy week–1 is:

$$B_{\mathrm{P}}(x_{\text{barrier}} + x_{\text{pre}}) = \frac{0.02 \text{ mGy week}^{-1}}{39 \text{ mGy week}^{-1}} = 5.1 \times 10^{-4}.$$

Use of the primary transmission curve for concrete for the Rad Room (floor or other barriers) workload distribution, results in a required total thickness (xbarrier + xpre) of 107 mm concrete. From Table 1.6, the attenuation provided by a typical radiographic table and image receptor (ignoring patient attenuation) is equivalent to 72 mm concrete. Thus, Xpre = 72 mm concrete and the net thickness required in the floor under the x-ray table to attenuate the primary beam is xbarrier = (107 – 72 mm) = 35 mm. These results may also be obtained from Equation 4.8 using the fitting parameters for the primary beam transmission for the Rad Room (floor or other barriers) workload distribution. This result may also be quickly arrived at using the method described. Using the same parameters as before, the first step is to determine the value of NT/Pd2:

$$\frac{NT}{Pd^{2}} = \frac{125 \text{ patients week}^{-1} \times 1}{0.02 \text{ mGy week}^{-1} \times (4.1 \text{ m})^{2}} = 372 \text{ mGy}^{-1} \text{ m}^{-2}.$$

Then, using this value (to account for the attenuation from the image receptor and radiographic table), a net barrier thickness of 37 mm concrete is required. This calculation includes the secondary radiation present from procedures done against the chest bucky and cross-table lateral work. This result is similar to the 35 mm concrete barrier calculated previously. However, the first calculation only considered the primary beam contribution from the over-table tube.

Secondary Barrier Calculation for Floor. Floor areas away from the table need to serve as a secondary barrier for exposures directed at the patient on the table and chest image receptor and their shielding adequacy needs to be verified. For example, shielding required at the location of the woman in Figure 1.18 needs to be determined. There are two independent secondary radiation sources that need to be considered, namely the patient on the radiographic table and the patient against the chest image receptor. Note that this secondary radiation will be assumed to impact the floor directly without attenuation by the table-mounted image-receptor hardware. The workload distribution Rad Room (all barriers) that includes scattered and leakage radiations from both sources is utilized. A conservatively safe assumption is that the x-ray tube is located so that the scattered and leakage radiation distances are equal to the vertical distance from the patient to the location of the woman. Thus, from Equation 1.4, the unshielded secondary air kerma for 125 patients per week is:

$$K_{\text{sec}}(0) = \frac{3.4 \times 10^{-2}\ \text{mGy patient}^{-1} \times 125\ \text{patients week}^{-1}}{(3\ \text{m})^2} = 0.47\ \text{mGy week}^{-1}.$$

To reduce this to 0.02 mGy week–1, a secondary barrier transmission is required.

$$B_{\text{sec}}(x_{\text{barrier}}) = \frac{0.02\ \text{mGy week}^{-1}}{0.47\ \text{mGy week}^{-1}} = 4.3 \times 10^{-2}$$

For the transmission of secondary radiation through concrete and utilizing the curve for the Rad Room (all barriers) workload distribution, the concrete floor thickness required beyond the radiographic table is 33 mm. Hence, the 35 mm concrete thickness required from the primary barrier calculation under the radiographic table will suffice for the entire floor. This result can be reproduced using the method described. Here d = 3 m. As before, first determine the value of NT/Pd^2:

$$\frac{NT}{Pd^2} = 694\ \text{mGy}^{-1}\ \text{m}^{-2}.$$

Then, for the off-table secondary floor, it is seen that a barrier thickness of 33 mm concrete is again found.

The Ceiling of a Radiographic Room

This area is uncontrolled (P = 0.02 mGy week–1) with an occupancy factor T = 1. This barrier is purely a secondary barrier. Assume, as above, that only one x-ray tube location is needed, with dL = 2.7 m and dS = 3.5 m. To be conservatively safe, set dS = dL = dsec = 2.7 m. Assuming leakage plus forward/backscatter (a conservatively high assumption) from Table 1.8, it is found that the total unshielded air kerma per patient is 4.9*10–2 mGy for the Rad Room (all barriers) workload distribution. The unshielded total air kerma, from Equation 1.4, is then:

$$K_{\text{sec}}(0) = \frac{4.9 \times 10^{-2}\ \text{mGy patient}^{-1} \times 125\ \text{patients week}^{-1}}{(2.7\ \text{m})^2} = 0.84\ \text{mGy week}^{-1}.$$

To reduce this to 0.02 mGy week–1 requires a secondary barrier transmission of:

$$B_{\text{sec}}(x_{\text{barrier}}) = \frac{0.02\ \text{mGy week}^{-1}}{0.84\ \text{mGy week}^{-1}} = 2.4 \times 10^{-2}.$$

yields a required barrier thickness of 44 mm concrete for the ceiling. Note that the distance from the patient to the occupied area (dS) was assumed to be the same distance as the distance from the x-ray tube head (dL), the closer of the two sources of secondary radiati

$$\frac{NT}{Pd^2} = 857 \text{ mGy}^{-1} \text{ m}^{-2}$$

the required ceiling thickness is found to be 39 mm of concrete. This result is slightly lower than that calculated previously, since it was generated using more accurate distances from the patient at the chest bucky and the table to the ceiling. These slightly greater distances diminish the scattered radiation contribution to the air kerma at the ceiling, thereby allowing a thinner barrier. Wall Containing the Chest Image Receptor in the Radiographic Room As shown in Figure 1.18, the area behind the chest image receptor is a staff rest room. Since employees who do not work with radiation sources also use this rest room, the shielding design goal for an uncontrolled area applies, namely P = 0.02 mGy week–1. From Table 1.1, the suggested occupancy factor for a staff rest room is
T = 1/5. Therefore, P/T = 0.1 mGy week–1.

Primary Barrier: Chest Image Receptor. The use factor for the Rad Room (chest bucky) workload distribution is U = 1 for exposures made on the chest image receptor. N is also 125 patients week–1 for this barrier. Using Table 1.6 with the Rad Room (chest bucky) workload distribution, the weekly unshielded primary air kerma at 2.5 m from the chest tube position, from Equation 1.3, is:

$$K_P(0) = \frac{2.3 \text{ mGy patient}^{-1} \times 1 \times 125 \text{ patients week}^{-1}}{(2.5 \text{ m})^2} = 46 \text{ mGy week}^{-1}.$$

The primary barrier transmission is then:

$$B_P(x_{\text{barrier}} + x_{\text{pre}}) = \frac{0.1 \text{ mGy week}^{-1}}{46 \text{ mGy week}^{-1}} = 2.2 \times 10^{-3}.$$

the required total (xbarrier + xpre) lead thickness for this workload distribution is 1.3 mm. From Table 1.6, the attenuation provided by a typical wall-mounted image receptor is equivalent to xpre = 0.85 mm of lead. The recommended wall shielding therefore would be xbarrier = 0.45 mm lead, and 0.79 mm (1/32 inch) lead (the thinnest available thickness of sheet lead) should be specified.. Here d = 2.5 m from the chest x-ray tube to the occupied area. Then:

$$\frac{NT}{Pd^2} = 200 \text{ mGy}^{-1} \text{ m}^{-2}.$$

a barrier of 0.5 mm lead is indicated. This is in agreement with the calculation above.

Secondary Barrier: Chest Image-Receptor Wall. The area of the staff rest room that is outside the primary beam is irradiated by secondary radiation that is not attenuated by the chest image receptor. There are two scattered and leakage radiation sources to consider. One is the secondary radiation generated by the over-table exposures. The other is the secondary radiation from exposures made against the chest image receptor itself. The unshielded secondary air kerma from the over-table x-ray tube location can be determined using Table 1.7. Assume leakage radiation plus side-scattered radiation, and the Rad Room (floor or other barriers) workload distribution with dsec = 4.5 m. Then, from Equation 1.4:

$$K_{\text{sec}}(0) = \frac{2.3 \times 10^{-2} \text{ mGy patient}^{-1} \times 125 \text{ patients week}^{-1}}{(4.5 \text{ m})^2} = 0.14 \text{ mGy week}^{-1}.$$

The scattered and leakage radiations due to exposures made against the chest image receptor should be considered independently, since the scattered and leakage radiation distances are significantly different. Let the scattered radiation distance from the patient against the chest image receptor to the occupied area be dS = 0.8 m. The leakage radiation distance from the x-ray tube to this area is dL = 2.5 m. Then from Table 1.7, for the Rad Room (chest bucky) workload distribution, the unshielded sidescattered and leakage air kermas from these sources are 4.9 *10–3 and 3.9 *10–4 mGy patient–1, respectively. From Equation 1.4, the sum of these contributions is:

$$K_{\mathrm{sec}}(0) = \left[\frac{4.9\times10^{-3}\ \mathrm{mGy\ patient}^{-1}}{(0.8\ \mathrm{m})^2} + \frac{3.9\times10^{-4}\ \mathrm{mGy\ patient}^{-1}}{(2.5\ \mathrm{m})^2}\right] \times 125\ \mathrm{patients\ week}^{-1}$$

Or,

$$K_{\mathrm{sec}}(0) = 0.96 + 0.008 = 0.97\ \mathrm{mGy\ week}^{-1}.$$

To this sum is added the previously calculated secondary radiation from the over-table tube location. Thus, the total unshielded secondary air kerma is:

$$K_{\mathrm{sec}}(0) = 0.97 + 0.14 = 1.1\ \mathrm{mGy\ week}^{-1}.$$

and the required barrier transmission factor is:

$$B(x_{\mathrm{barrier}}) = \frac{0.1\ \mathrm{mGy\ week}^{-1}}{1.1\ \mathrm{mGy\ week}^{-1}} = 9.1\times10^{-2}.$$

The greatest contribution to the secondary air kerma is due to exposures against the chest bucky. Therefore, for simplicity and to be conservatively safe, assume the more penetrating Rad Room (chest bucky) workload distribution. a barrier of 0.35 mm lead is required. A more realistic calculation using the correct location for each scattered or leakage radiation source and a 30 degree scattering angle for the chest source with the correct workload distribution for each tube location yields 0.3 mm lead.Here d = 2.5 m from the chest tube to the occupied area. Substituting N = 125 patients' week–1 and P/T = 0.1 mGy week–1 then:

$$\frac{NT}{Pd^2} = 200\ \mathrm{mGy}^{-1}\ \mathrm{m}^{-2}.$$

a barrier of 0.37 mm lead is obtained, which is in good agreement with the values given above. Since the primary shielding is greater than the secondary wall requirements, the entire wall can be shielded with a minimum of the primary requirement, 0.45 mm or 1/32 inch lead, the nearest greater standard thickness.

Chapter -2: Details design and description of each component with innovative materials

2.1 Honeycomb Wall panel

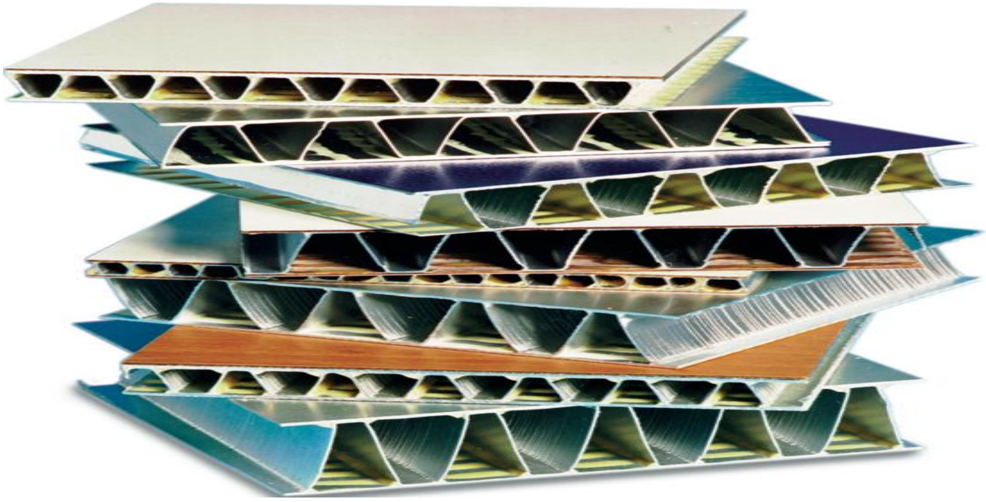


Fig 2.1: Honeycomb wall

The main feature of the panels is a corrugated sheet obtained in accordance with a system of cold forming. The panel production is obtained bolding the corrugated sheet between two flat sheets, to obtain an extremely rigid sandwich panel, with high mechanical properties. There are many possibilities for the finish of the panel, like the HPL solution. Wall panel allows workability with normal woodworking equipment. The use of work centers allows the execution of cuts, grooves, notches in edges, etc. and the supply of finished panels, ready for installation.

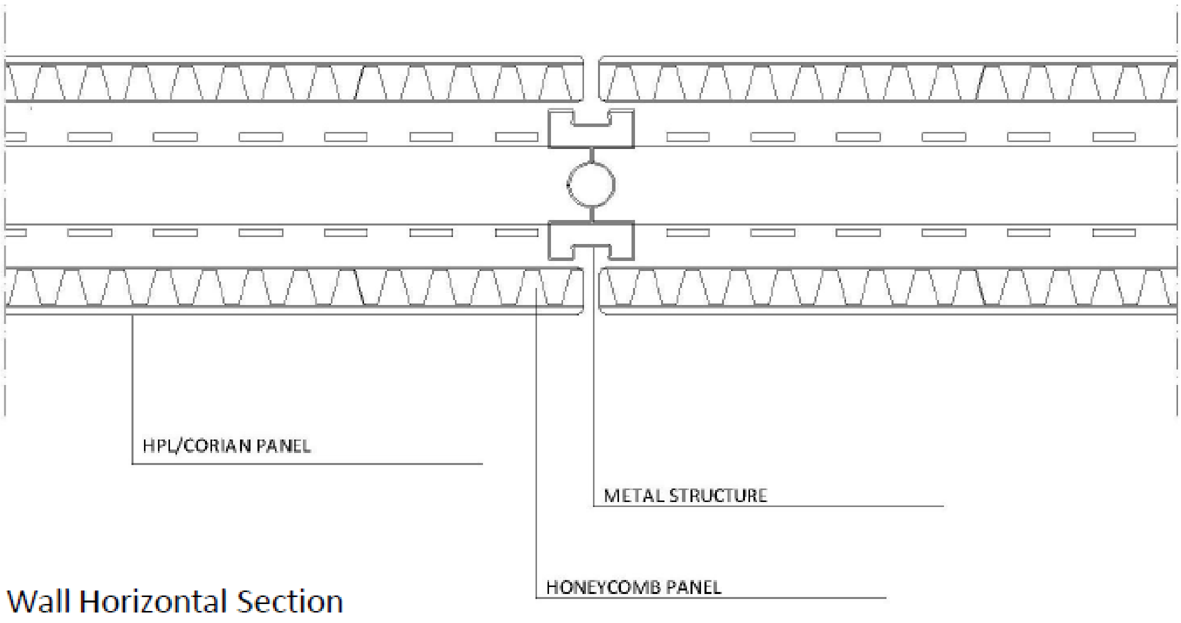


Fig 2.2

GENERAL SPECIFICATIONS

DESCRIPTION

This type of honeycomb partition wall is an internationally patented structural panel consisting of a trapezoidal metal corrugated core glued between two flat metal sheets.

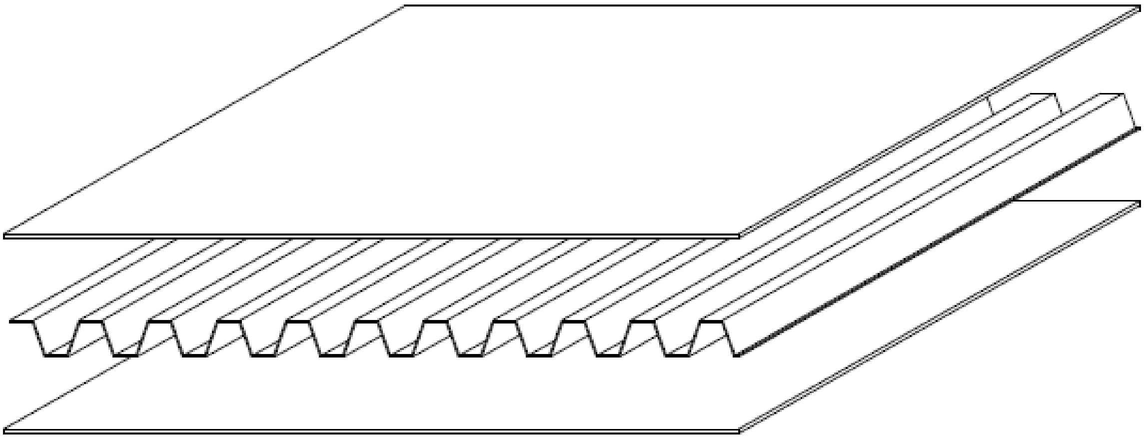


Fig. 2.3 wall panel structure

These elements are joined to form a lightweight panel with exceptional bending and compressive resistance. The wall panel is available in natural aluminum, anodized aluminum, pre-painted aluminum, PVC coated aluminum, stainless steel, porcelainized steel, PVC coated steel or galvanized sheet (the thickness of the metal starts from 0.1 mm). The nominal standard thickness of wall panels can range from 4 to 28 mm, which means you can use them in many different fields and applications by choosing the most suitable dimensions. The panel can also be covered with a wide variety of finishes, such as laminates, upholstery, fabrics, tiles, marble or stone, glass, liquid paint, real wood veneer, dip printing or direct digital printing.

Wall panels have the following properties and advantages:

- Extraordinary mechanical and dynamic strength of the sandwich structure, due to the trapezoidal corrugated core and the large gluing surface. Two crisscrossed layers of corrugated sheet can be used for special applications.
- certified as incombustible
- Eco-friendly and 100% recyclable
- Wide range of thicknesses and dimensions
- Low weight and smooth surface
- Wide variety of surface finishes
- Easily machined and therefore adaptable to unconventional solutions, offering total freedom of design (e.g. round or angular elements, coatings with laminates or PVC, etc.) In the standard wall panel, the corrugation is parallel to the short side (1000, 1250 or 1500 mm). Panels can also be produced with the corrugation parallel to the long side. This must be specified in the request for a quotation. For panels 6 and 10 mm thick, special corrugated cores can be made in single pieces up to 2900 mm long. The glue used for fabricating the panel is not subject to structural changes at temperatures between –10° and +80°C.

THICKNESSES

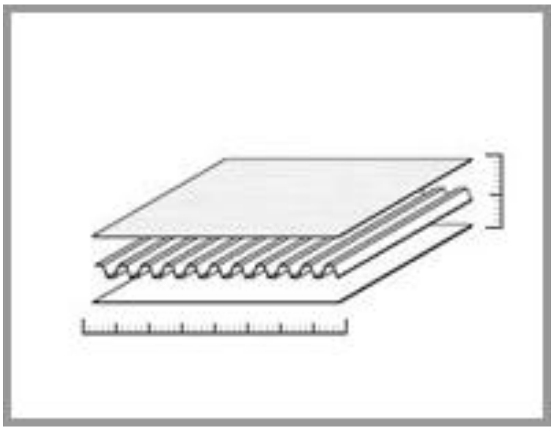


Fig 2.4

The standard thicknesses are: 4, 6, 8, 10, 15, 18, 20, 23, 25 and 28 mm. The thicknesses are considered nominal (indicative) because the actual thickness of the panel (and the corrugated core) varies depending on the type of coating applied. Machine tools are currently being developed for the production of a new corrugated core 42 mm thick

Dimensions

The standard dimensions of panels vary depending on the type of material used.

NATURAL SILVER ANODIZED ALUMINIUM

Standard anodizing: 5 or 10 microns;
Standard thickness: 1 mm;
Standard dimensions: 1000 x 2000 mm; 1250 x 2500 mm; 1250 x 3000 mm,1500 x 3500 mm

Pre-painted aluminum with liquid or powder paint

Standard colors: RAL and NCS charts;
Standard thickness: 0.8, 0.9 and 1 mm;
Standard dimensions: 1250 x 2500 mm; 1250 x 3000 mm.
Other dimensions are available upon request.
All pre-painted panels are supplied with an 80 micron protective film.

Raw aluminum

Standard thickness: 0.3, 0.6, 0.8 and 0.9 mm;
Standard width: 1020 or 1250 mm;
Standard length: up to 5000 mm.

All anodized aluminum panels, whether pre-painted or raw, have to be trimmed at least 25 mm on each side parallel to the corrugation and at least 10 mm on the other two sides. e.g. a 1250 x 2550 mm panel, with a corrugated core 1250 mm long (parallel to the 1250 mm side), will be trimmed down to 1230 x 2500 mm; while a 1250 x 2500 mm panel with a corrugated core 2500 mm long will be trimmed down to 1200 x 2480 mm.

Mechanical properties

Depending on the panel thickness and type of material used, the corrugated core and large gluing surface of these panels make them highly resistant to bending stress. The 9-3-9 aluminum wall panels (i.e. with outer skins 0,9 mm thickness and corrugated sheet 0,3 mm thickness) with a nominal thickness of 10 mm, real thickness of 11 mm and a weight of 6,78 kg/m^2, has a bending stiffness of E x I transverse = 1.768 Nm2/m and a value of E x I longitudinal = 3.310 Nm^2/m. A similar 9-3-9 panel with a nominal and real thickness of 20 mm and a weight of 7,30 kg/m^2 has a value of E x I transverse = 3.085 Nm^2/m and a value of E x I longitudinal = 12.102 Nm^2/m.

The stainless steel wall panel is the ideal solution for industries needing a perfect finish and a totally washable surface for hygiene purposes. These panels have been used for fabricating worktops, walls, floors and ceilings in industrial kitchens; while in food and pharmaceutical industries, they have been used for building sterile rooms and completely washable laboratories and departments. They have also been used for building hospital operating rooms and railway wagons. The stainless steel panel is available with an attractive polished or satin finish. Extremely lightweight, flat and stiff, aluminum panels have a corrugated core made of aluminum strips from 0.3 mm to 0.5 mm thickness. This is joined to flat aluminum sheets at least 0,3 mm thickness using structural glues. One-sheet wall panel is a flexible panel ideal for creating curved paneling for columns or shaped walls. In the sandwich version, the panel is also ideal for building partition walls, false ceilings, and doors and as a support for materials like marble, granite, tiles and upholstery. A wide range of aluminum profiles are also available for assembly. The aluminum wall panel is 100% recyclable. The panels can be used for making furniture such as bookshelves, tables, chairs, fitted walls and drawer units. Wall panels are the ideal solution for fabricating building facades, as they guarantee excellent stability over time due to the high chemical and physical strength of the materials used. In the shipbuilding industry, they have been used for making doors, hatches and partition panels for fast ferries as well as shaped sinks and basins, dividing walls and accessories for public areas.

PANEL TYPES

Aluminum panels are marked by an alphanumeric code which stands for seven things:
e.g. code X04AA08063C125250
- X identifies the family of wall panels;
- The two numbers indicate the nominal thickness (04);
- The two letters indicate the panel materials (AA);
- The five numbers indicate the nominal thickness of the outer skin (08), the inner skin (06) and the corrugated core (3);
- C indicates that corrugation is parallel to the width of the panel;
- The three numbers indicate the width of the panel in cm (125);
- The last three numbers indicate the length of the panel in cm (250).

Furthermore:
“ZZ” indicates panels with two galvanized skins;
“AA” indicates panels with two treated raw aluminum skins;
“PP” indicates panels with two pre-painted aluminum skins;
“CC” indicates panels with two natural silver anodized aluminum skins (5 microns);
“PA” indicates panels with pre-painted aluminum outer skin and treated raw aluminum inner skin;
“CA” indicates panels with a natural silver anodized aluminum outer skin (5 microns) and a treated raw aluminum inner skin;
“CB” indicates panels with a natural silver anodized aluminum outer skin (5 microns) and a pre-painted aluminum inner skin.

The above code therefore identifies a wall panel featuring: a nominal thickness of 4 mm; a treated raw aluminum outer skin with a nominal thickness of 0.8 mm; a treated raw aluminum inner skin with a nominal thickness of 0.6 mm; an aluminum corrugated core 0.3 mm thick, parallel to the width (1250); and dimensions 1250 x 2500 mm.

The color codes for pre-painted panels are indicated separately.

MACHINING PANELS

Sandwich panels can be worked and machined with common carpentry tools. Machining centres are used for cutting, milling, making holes, edging or creating finished panels ready for installation. These panels can be modified on site using a circular saw. The panels are shaped by milling lengthwise along the back of them panel or by using a template. This makes the panel extremely sturdy, high quality and economy.

CUTTING WITH SAW

Aluminum panels can be cut using a circular saw, a belt saw or hacksaws. It is recommended to use Vidiam tools with flat trapezoidal teeth (5-axes technology). (Fig.2.5)

Fig.2.5 Saw for aluminium diam. 250 mm, bore 32 mm; 72 teeth; max rpm: 8000; recommended rpm: 3800.

Repetitive or more complex machining requires routers or machining centres. For best results, use mechanical or pneumatic vacuum clamping systems to stop vibrations for clean, precise cuts. We also recommend down-cutting to achieve a well-defined cutting depth. Alternatively, machines with a tracer point also guarantee high precision.

"V" grooves can be made using circular saws with 90° V-teeth (e.g. using a disk saw with Vidiam tools, 48 teeth, 250 mm in diameter, 92°-94° tooth angle to obtain a V-cut with a 90° nominal angle). Alternatively, use a flat tooth saw tilted at a 45° angle from the panel surface. In this case, we suggest using a machining center with a crosscutting blade on solid grounded benches covered with MDF panels.

To create 90° joints, e.g. for making containers, you can glue square cut elements with a 45° angle or use folding machines for cutting. Panel sizing can be done manually using common electrical tools such as small circular saws. (Fig.2.6)

Fig. 2.6 Manual panel sizing

CUTTING WITH SHEARING MACHINE AND FORMING

Whenever you cut a wall panel with ordinary hammer shears, or by forming, corner notching or mechanical or hydraulic punching, the panel edge will always be slightly buckled on one side (Fig. 2.7). You can cover up this buckling with a "C" shaped or similar extruded aluminum edging. Avoid this cutting method on panels thicker than 6 mm.

Fig. 2.7 Detail of wall panel cut with hydraulic corner notcher.

PANTOGRAPHING (CUTTING) WITH WATER JET MACHINE

Low thickness wall panels can be cut with a water jet machine. However, due to its low cutting speed and high operating costs, this process can only be used on wall panels made of steels or similar materials, or for cutting complex curved patterns.

MILLING

Aluminum wall panels are easily milled using automatic or hand-operated tools. Wall panels are milled very like wood and therefore do not require particular precautions such as lubrication or cooling. There are two main cutting methods requiring different milling machines or hand tools:

- The corrugated core (Fig. 2.8) is usually milled in order to insert a T-shaped profile as an edge cover or an aluminum plate (e.g. 40 x 2 mm) for joining the two panels.

With two passes, you can completely cut away the corrugated aluminum sheet to cover the edge with laths made of wood or similar materials.

This type of milling can be carried out using:

- A 50 mm diameter manual trimming disk
- a machining center or toupee equipped with circular blades with a minimum diameter of 125 mm.

Fig. 2.8 Lateral milling to fit a T-shaped profile.

- chamfering or scarfing (included both aluminum skins) is carried out using:
- a hand-operated router (Fig. 2.9)
- a machining center or toupee equipped with circular blades or crosscutting milling

CUTTERS

Fig. 2.9 Cutting

All the above hand-operated tools can be found in the shops and do not need to be custom-built with extra features to work wall panels.

DRILLING

The wall panel can be drilled using standard pillar or hand drills on the market, using a twist drill for aluminum or a hollow mill. Machining centers are recommended for repetitive, high precision drilling. If you need to make holes which do not pass right through the panel (e.g. for inserting threaded inserts) we recommended using a depth limiting device to avoid damaging the lower outer sheet.

SURFACE FINISHES

SURFACE TREATMENT

Wall panels are made using aluminum treated with light surface anodizing to protect the aluminum from corrosion and allow liquid painting or the gluing of finishing material. Finishing material and painting can be applied without any preliminary treatment. If we wish to degrease the panels, use cloths soaked in detergent; do not soak the panels in acids or solvents or use them at temperatures above 80° C.

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COATINGS

The wall panel can be coated with almost any material. The most common coatings are:

- HPL laminated plastic;
- CPL laminated plastic;
- Wood veneer;
- Natural or synthetic leather;
- Wallpaper or upholstery;
- Fabric;
- Tiles;
- Marble or stone;
- Glass;
- Corian and similar materials;
- Fiberglass.

Observe the following when coating with non-metallic materials:

- The operating temperature depends on the properties of the coating materials. Temperatures should never exceed 80°C; otherwise they will alter the glue structure.
- The wall panels and the coating materials have different coefficients of thermal expansion. This is why most coatings are applied and glued at ambient temperature (max 35° C).

PAINTING

When choosing the painting technique for wall panels, take note of the following:

- whatever the painting technique, the maximum temperature must be under 80°C (which is why powder painting is excluded);
- Wall panels can be painted without any preliminary treatment such as a primer. Wall panels can be made using aluminum sheet which has already been painted with liquid or powder paint. There are now new technologically advanced surface finishes which imitate marble, stone, wood and Venetian stucco, etc..

PLASTIC LAMINATES

When applying plastic laminates, the glue should be elastic enough to compensate for expansion or deformation. It also must be used in small amounts and spread evenly. The surface of both the panel and the laminate should be perfectly clean; otherwise any dirt could ruin the appearance of the finished panel. Generally, panels with skins thicker than 0.6 mm do not need another laminate on the other side. To avoid an uneven appearance, especially when applying very smooth or shiny laminates, use panels with skins at least 0.8 mm thick.

Precautions

SURFACE FINISHES

Sandwich panel can be produced with different surface finishes such as anodized aluminum, sublimed aluminum, imprinted aluminum, PVC coated aluminum, preprinted or galvanized sheet, porcelain zed sheet and stainless steel. It can also be painted, glued to wood or plastic laminates, upholstered with carpet or wallpaper or faced with tiles, granite, marble, Corian and Kerlite. On pre-painted and anodized aluminum panels, the appearance of the paint or anodizing finish can vary from one delivery to another. The anodizing direction, especially when fabricating small elements as it could create contrasting effects.

FINAL CLEANING

After removing the PVC protective film, if we need to clean the finished element (such as a piece of furniture, shelves or doors, etc.), use a soft and clean cloth lightly soaked in non-abrasive pH neutral detergents, especially if the element is made of anodized aluminum.

THERMAL EXPANSION

Wall panels are mostly made of aluminum, so the linear thermal expansion coefficient, at a gradient of 100°C, is approx. 2.4 mm per meter.

DIMENSIONAL TOLERANCES

Sheet thickness: ref. UNI 485-4 and UNI 10143;
Length and width for panels not square cut to size: +/- 10 mm;
Misalignment between the two skins for panels not square cut to size: +/- 5 mm;
Length and width for panels square cut to size: +/- 1 mm;
Misalignment between the two skins square cut to size: +/- 0.05 mm;
Standard thickness: +/-0,5 mm;
Panel thickness (if clearly requested in order) +/-0,2 mm;

Lead protected wall

General requirement of lead in wall with respect to x-ray generated by the machine

X-rays generated by peak voltages below	Minimum thickness of lead	X-rays generated by peak voltages below	Minimum thickness of lead
75 kV	1.0 mm	225 kV	5.0 mm
100 kV	1.5 mm	300 kV	9.0 mm
125 kV	2.0 mm	400 kV	15.0 mm
150 kV	2.5 mm	500 kV	22.0 mm
175 kV	3.0 mm	600 kV	34.0 mm
200 kV	4.0 mm	900 kV	51.0 mm

Analysis for Honeycomb wall panel with required lead

Mechanical Properties of Aluminum

Young modulus: 70GPa
Poisson’s Ratio: 0.35
Mass density: 3.67gcm^{-3}

Mechanical Properties of Lead

Young modulus: 16GPa
Poisson’s Ratio: 0.44
Mass density: 11.34gcm^{-3}

Mechanical Properties of Corian

Young modulus: 10.34GPa
Poisson’s Ratio: 0.37
Mass density: 1.7gcm^{-3}

Mechanical Properties of Steel
(Fe P03 UNI EN 10130)
Young modulus: 200GPa
Poisson’s Ratio: 0.29
Mass density: 1.43gcm^{-3}
Yield Stress: 240 MPa

1mm leaded wall

Wall dimension: 600mm × 2900 mm
Weight of the Wall: 38.2 kg
Number of safe key: 14

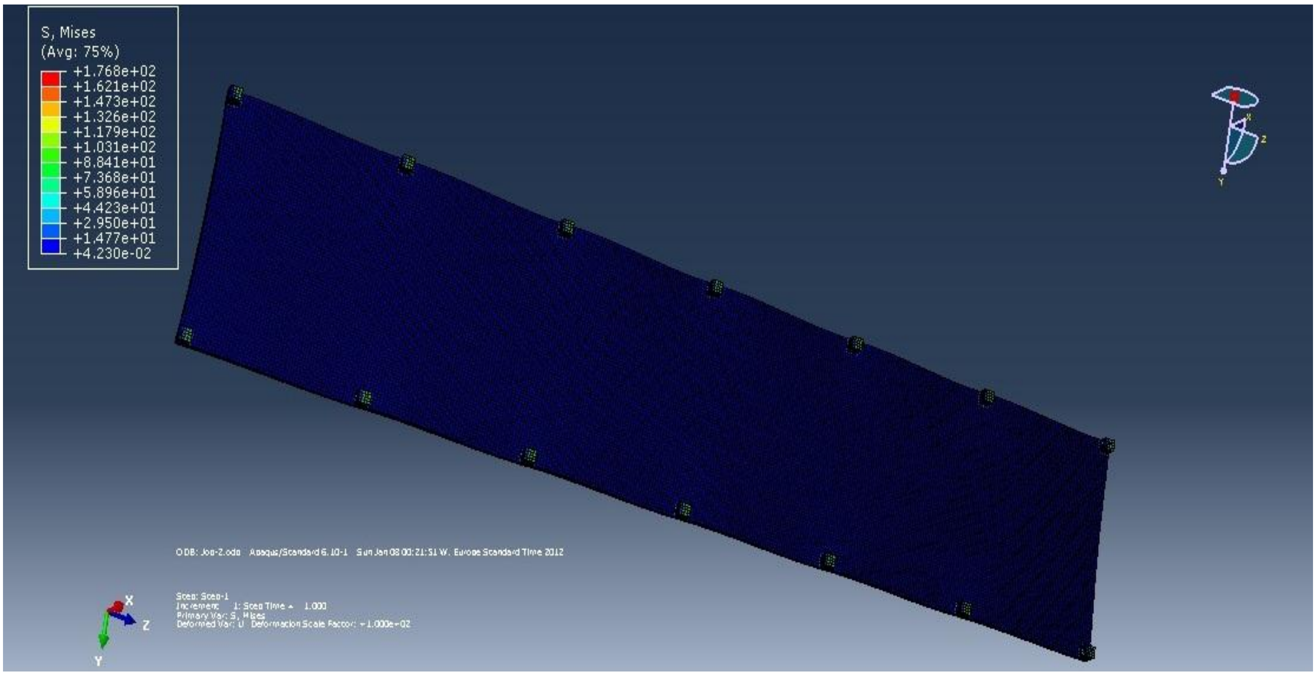


Fig 2.10: Wall panel with 1 mm lead

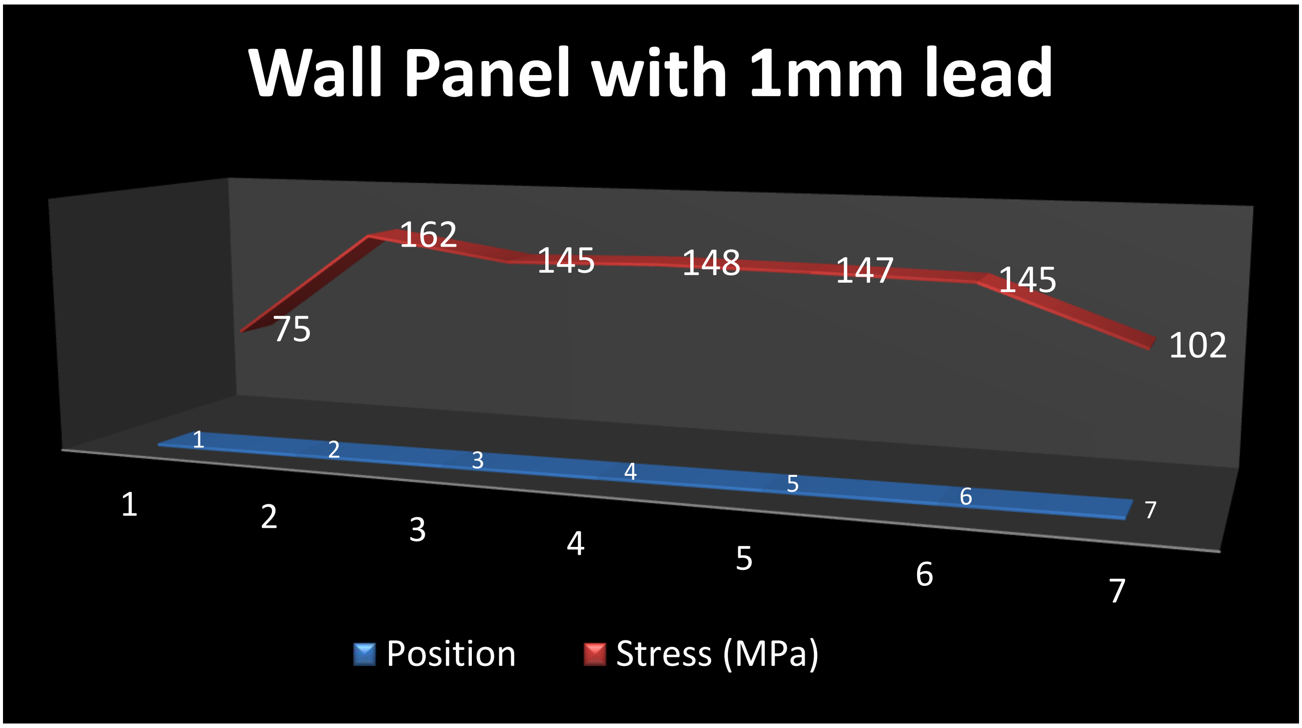


Fig 2.11: estimated Stress on key position

1.5mm leaded wall

Wall dimension: 600mm × 2900 mm
Weight of the Wall: 48.1 kg
Number of safe key: 16

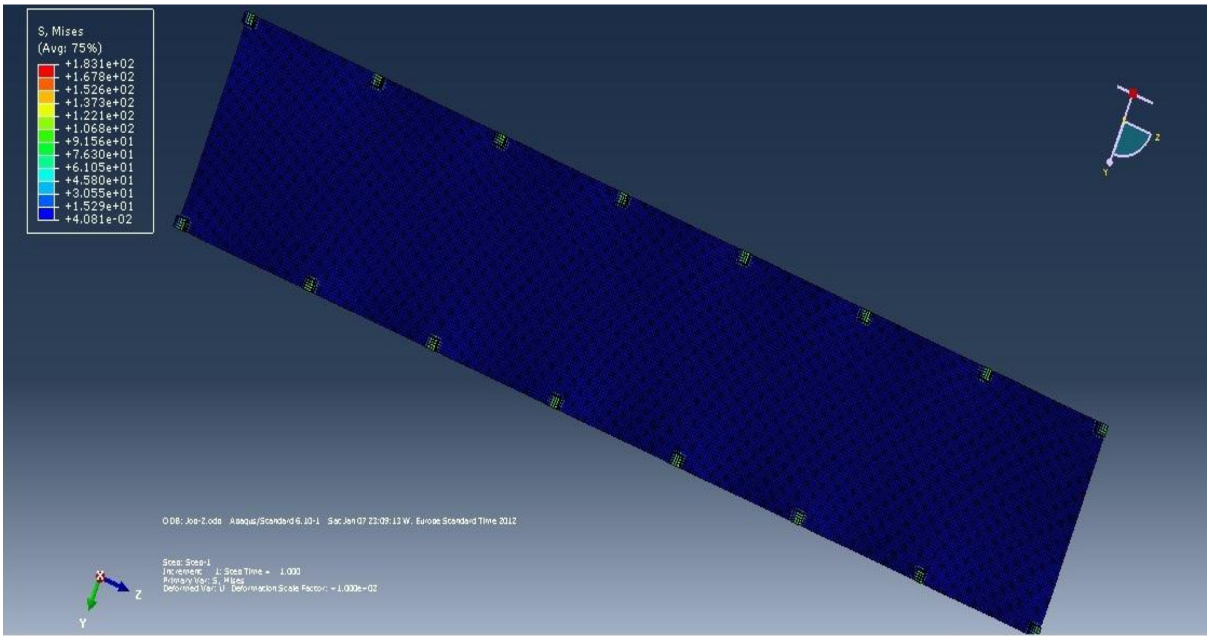


Fig 2.12: Wall panel with 1.5 mm lead

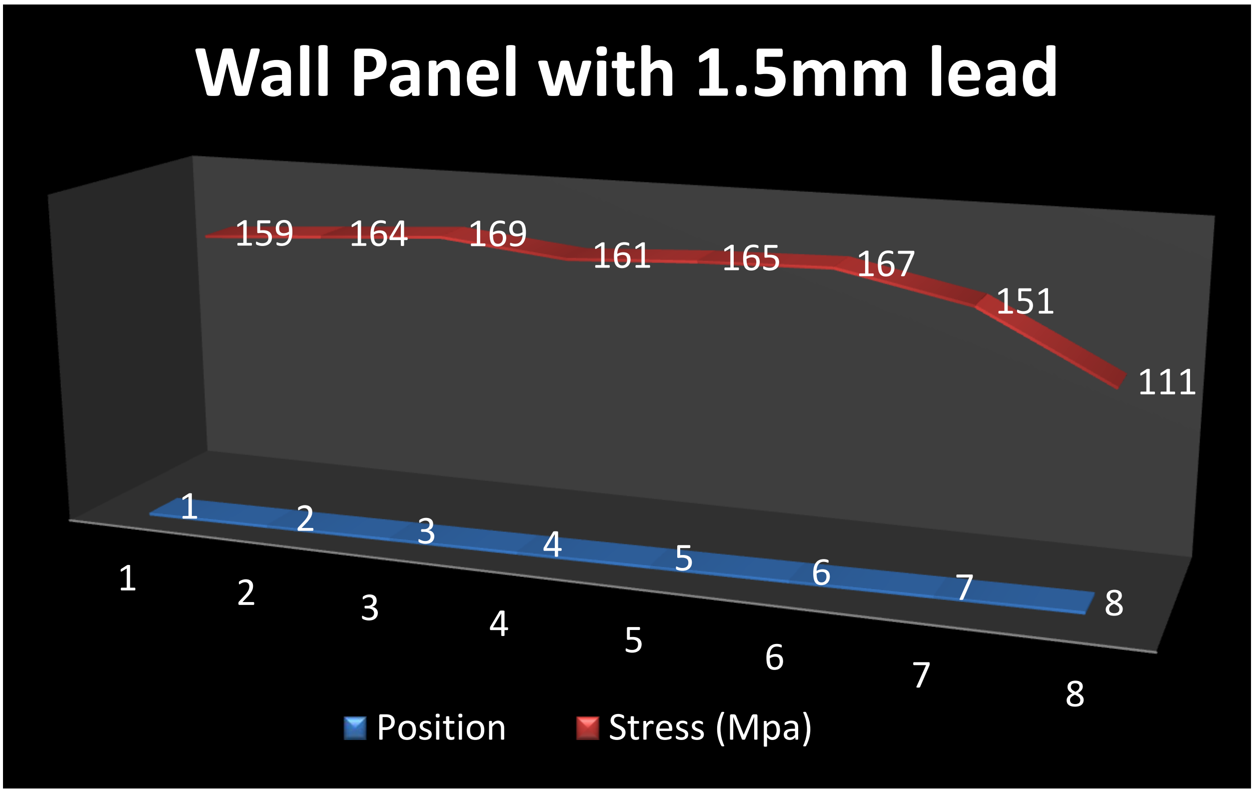


Fig 2.13: estimated Stress on key position

2mm leaded wall

Wall dimension: 600mm × 2900 mm
Weight of the Wall: 58 kg
Number of safe key: 16

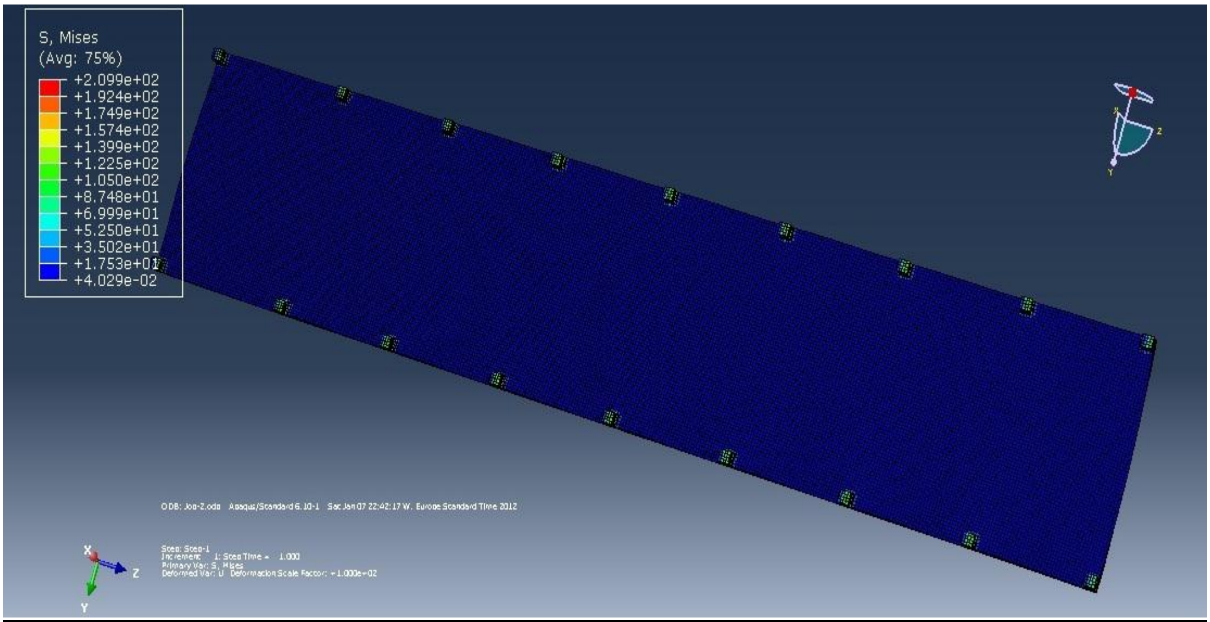


Fig 2.14: Wall panel with 2 mm lead

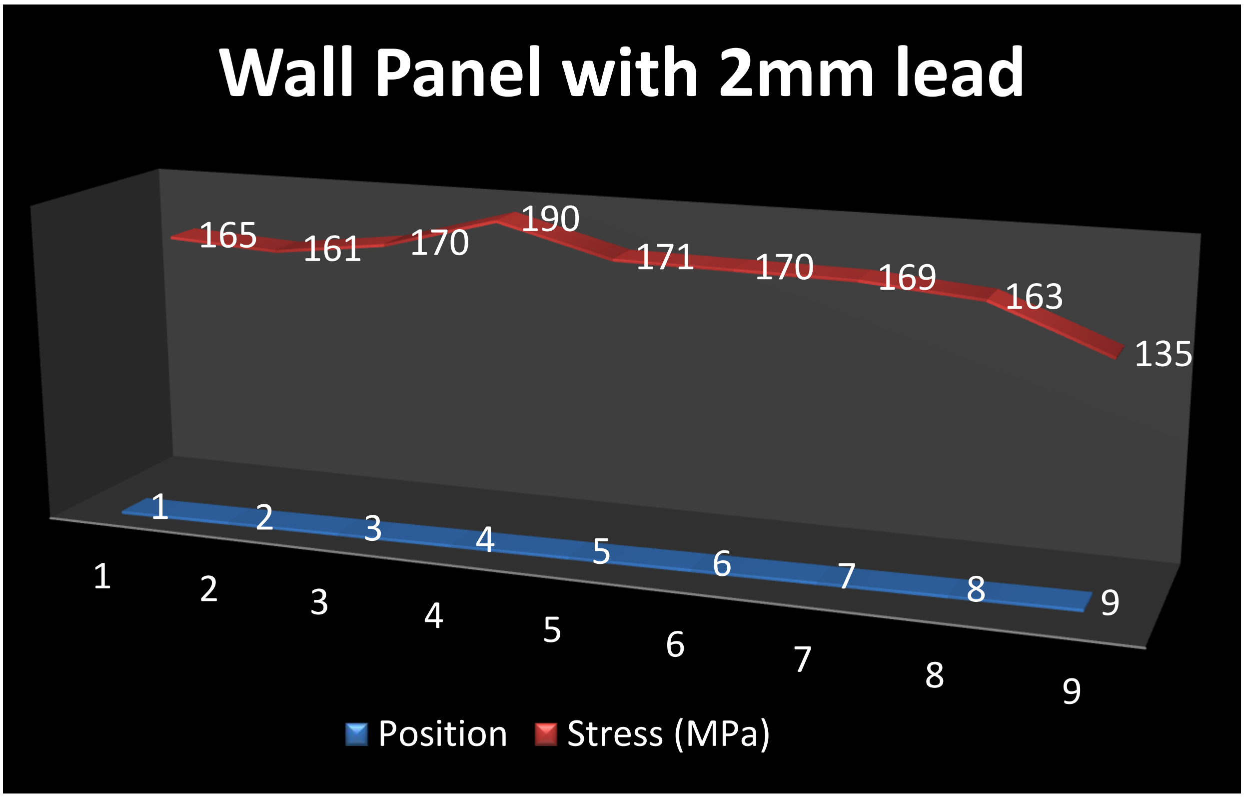


Fig 2.15: estimated Stress on key position

Summary

Wall panel with Lead	Weight of wall panel (kg)	Safe number of key to hang
1 mm	38.2	14
1.5 mm	48.1	16
2 mm	58	18

2.2 Structure

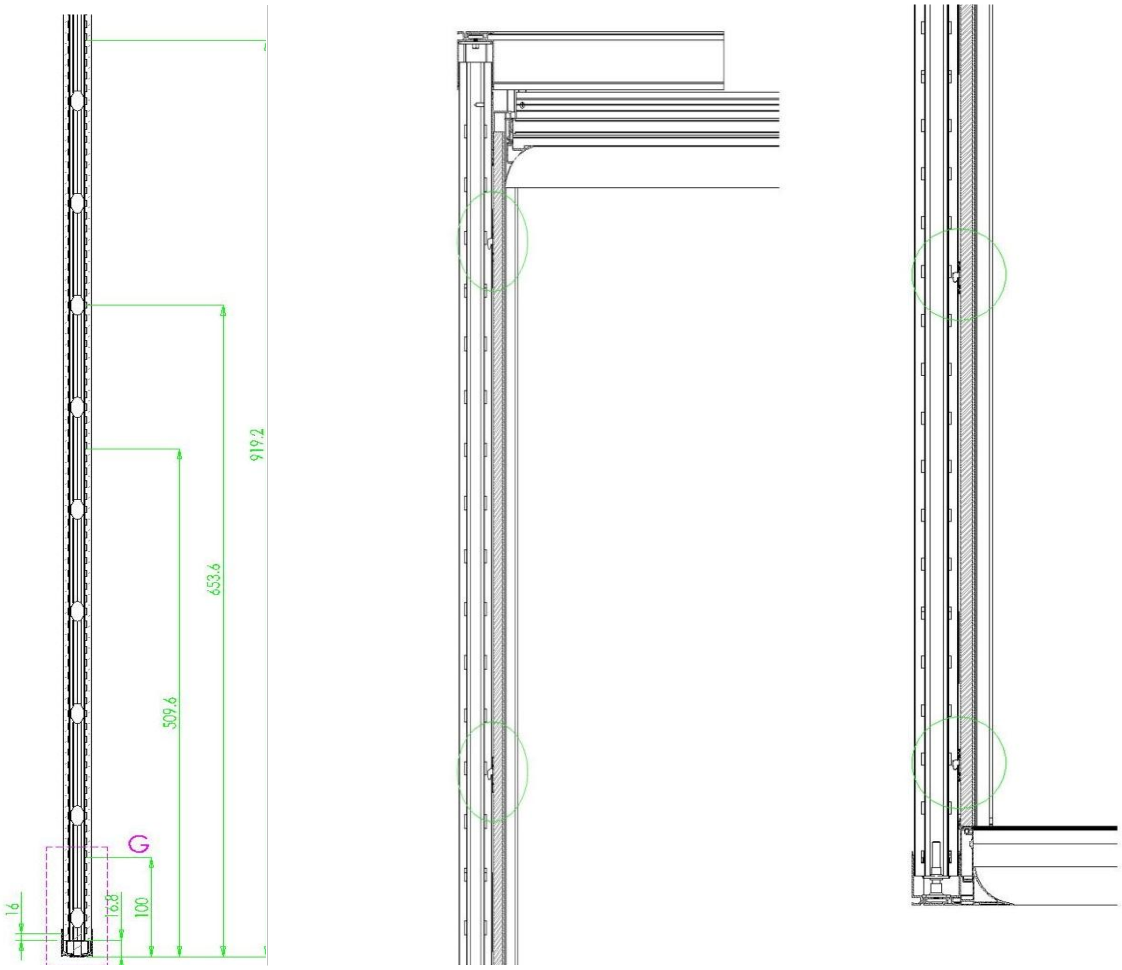


Fig 2.16: Details of stucture and way to linked with wall panel,ceiling and floor

MOUNTING SYSTEMS
For fastening the panels to the posts, the hooks are used W 1 and W 2 right- the left. The panel will be mounted to the structure will be pre-drilled first and then will be mounted hooks W 1 - W 2 with the appropriate screws .It is very important to maintain between the panels (both horizontally and vertically) the escape of 6 mm. This is the minimum that will allow the attachment or release of the panel and the panel. Should be mounted at least 4 hooks per panel (two right and two left) and for cm heights above. 80 hooks mounted every 60 cm. So for a 2.70 m high panel will be mounted four hooks and four 1 W W 2 hooks. Do not mount the recommended amount could not join the panel the column throughout its length, giving rise to belly flops, deformation and vibration. It is recommended that after mounting the panel, insert one or more self-tapping screws in flight near the street or to the full height panels conduit This will prevent the release of the panel.

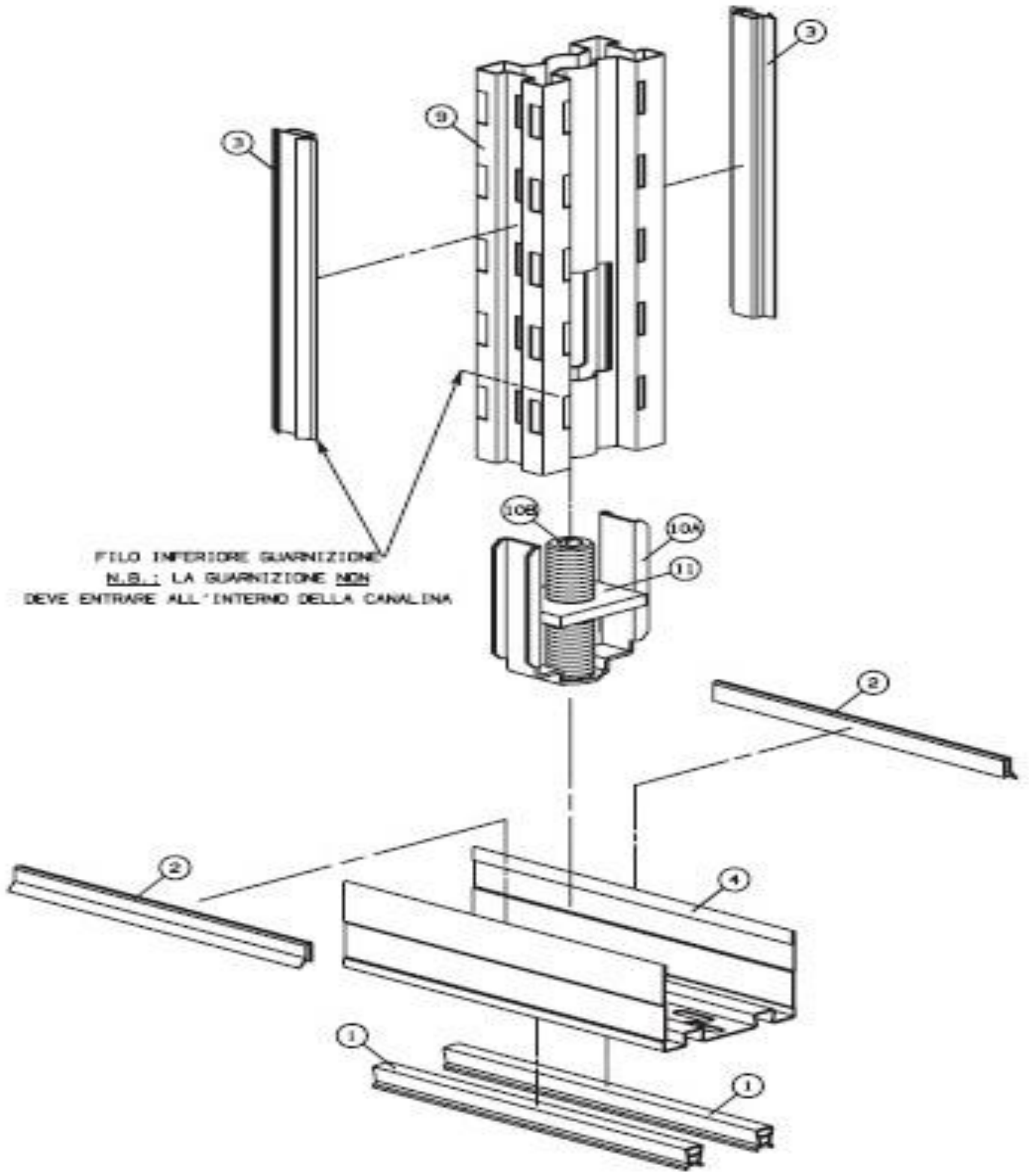


Fig 2.17: Connection of structure and frame with floor

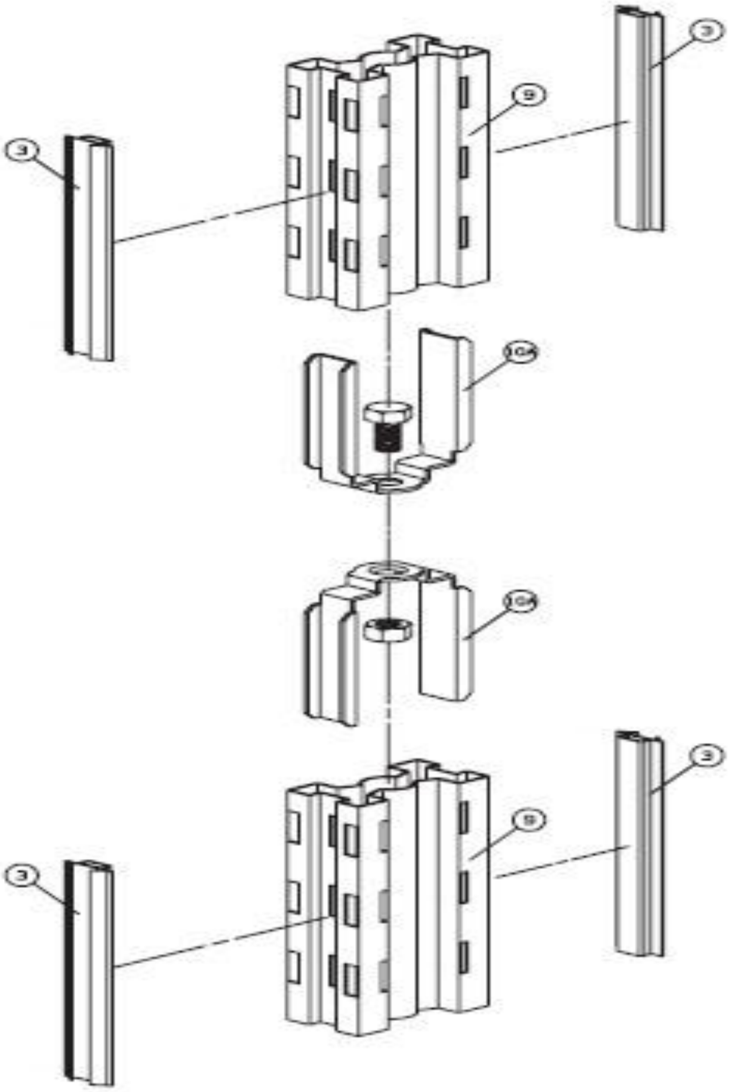


Fig 2.18: Connection of structure and frame to fixed

EXTENSIONS TO CEILING

1) When we are in a position of having to mount the wall in a where there is a ceiling you should proceed as follows: place conduit to the ground and screwing on the ceiling properly. Put posts and link them with at least three when we cross themodule out of the panel, two blocks when there is a windows. At the fourth pillar of the subsequent placement will not push controsofitto but on the slab is the conduit through the ceiling.

2) There is a possible solution because if too long, mounted carried out, there are any obvious oscillatory phenomena in the two uprights together.

2.3 Ceilings:

Ceiling

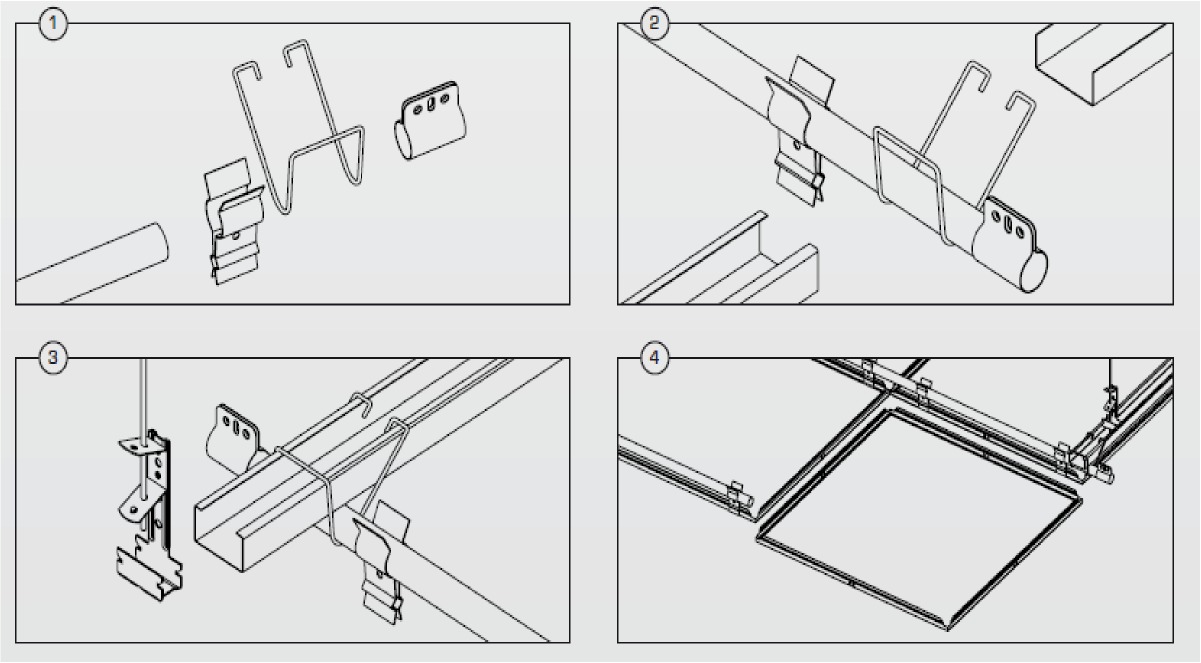


Fig 2.19: Enigma air tight ceiling

DESCRIPTION
The application of the ceiling structure hidden Matrox Enigma Air Tight, is especially used in environments where it is necessary to insert a compact system not only from an aesthetic point of view but especially from the construction point of view: the use of the tube carrier mobility as part of 'it remarkable stability and robustness to the system without compromising in any way the final effect. In addition to it the tiles are equipped with special air tight rubber gaskets in order to make the room ermetic.

FEATURES

- tubular diameter 22 mm and spring harness
- Panel with air tight gaskets, available in version 45 ° bevel
- Total access to the air
- Available in aluminum and steel pre-and post varnished
- Wide range of perimeter solution
- Warping cross and parallel
- Ease of installation
- Wide range of drilling (for filters)
- Right edge (where nt air tight)
- Smooth ceiling
- Available in pre-painted or powder coated version.
- Wide choice of perimeter solutions
- Total accessibility to the interspace
- Easy laying

STANDARD DIMENSIONS : 600 X 600 mm
MATERIALS : STEEL 5 / 10 and 6 / 10
ALUMINIUM : 5 / 10 to 7 / 10

2.4 Filters

FILTER PANELS USED AS HEPA FILTERS

HEPA filters: Main or final filters used for the most critical requirements of air purity and sterility in areas such as industry, research, medicine, pharmaceuticals, and nuclear engineering.
Separation of suspended particles or aerosols, toxic dusts, viruses, bacteria etc. from the supply and extract air in ventilation systems with large volume flow rates and long filter life.

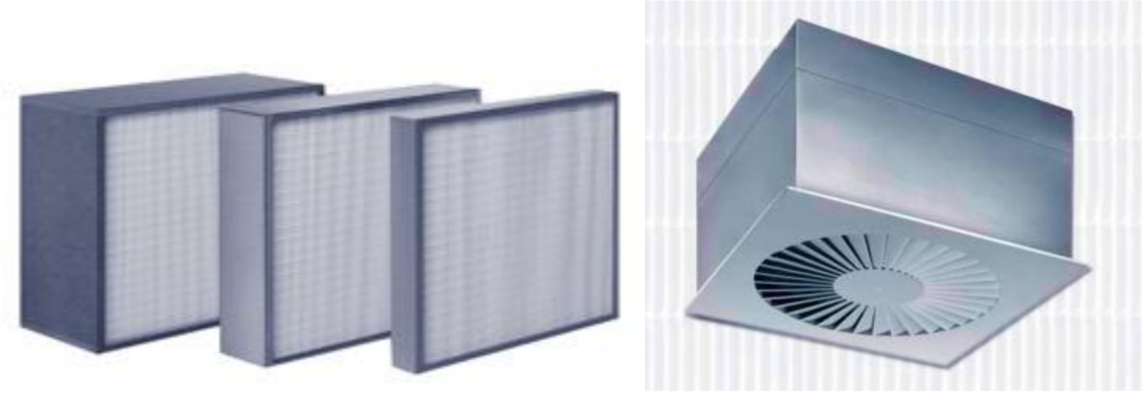


Fig 2.20 HEPA filters

Technical characteristics:

- 1 filter F781W46 terminal F648V1C;
- volume flow rate 684 m3/h;
- cat. H13;
- dim.600x600mm,;
- round diffuser plate.

2.5 Junctios

There are some junctions, they are developed for wall panel and structures to make

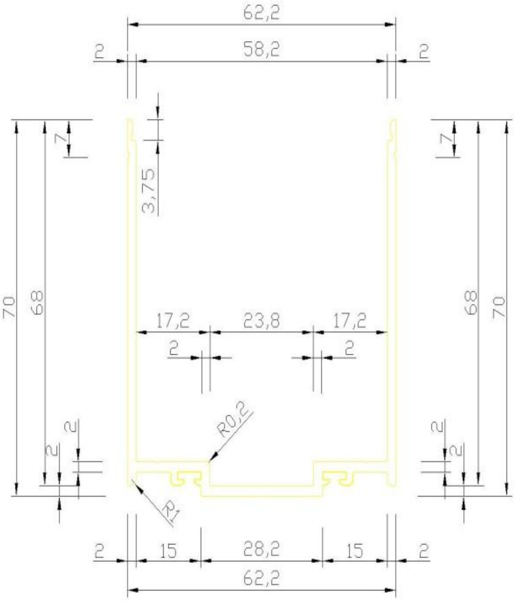


Fig 2.21: Junction 1

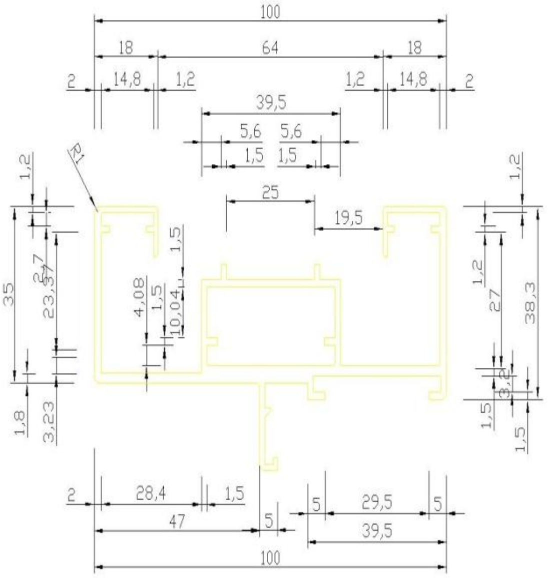


Fig 2.22: Junction 2

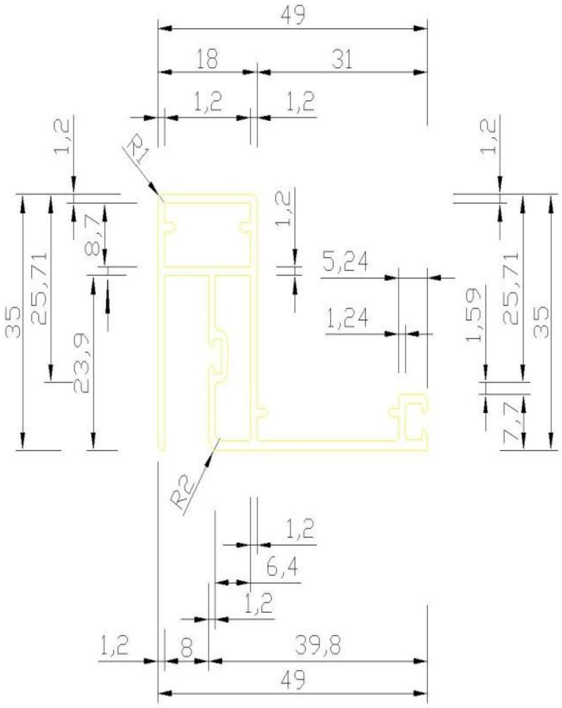


Fig 2.23: Junction 3

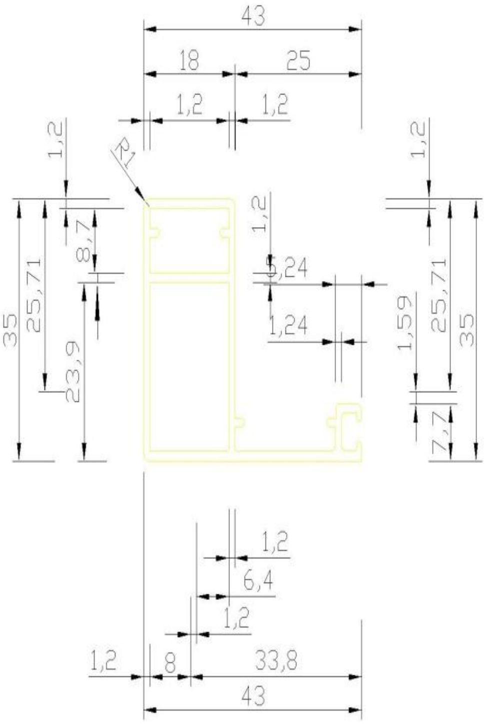


Fig 2.24: Junction 4

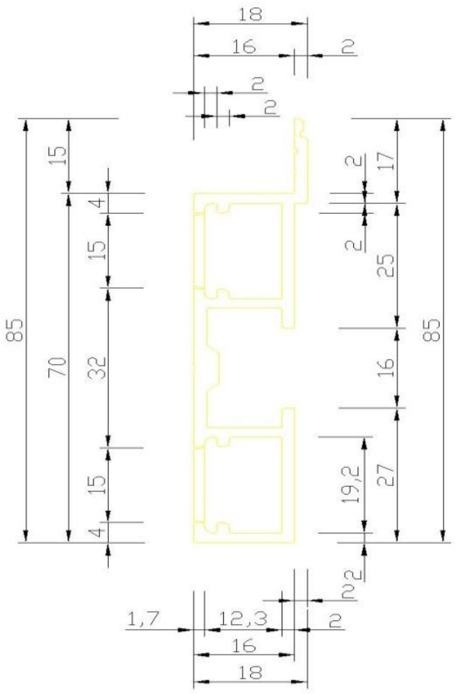


Fig 2.25: Junction 5

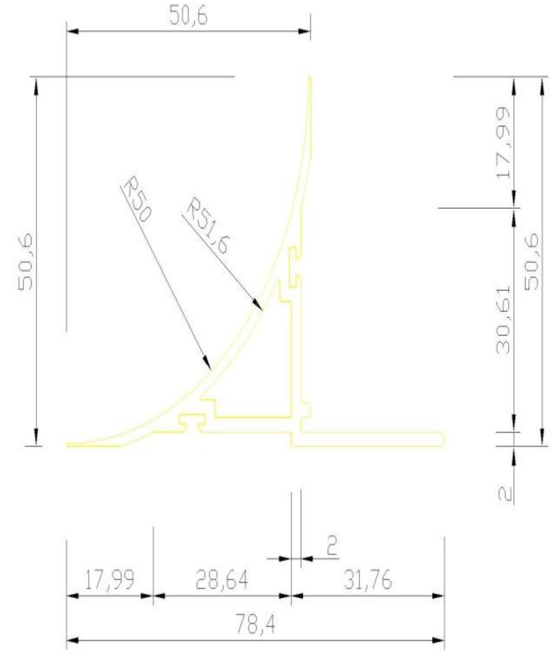


Fig 2.26: Junction 6

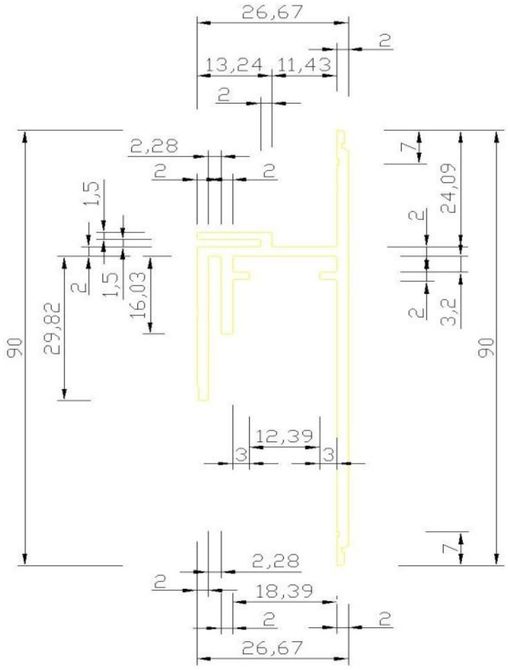


Fig 2.27: Junction 7

Junctions will be used to link with each component of wall panel and structure with other accessories.

Here is some model to use this type of junctions with the structure

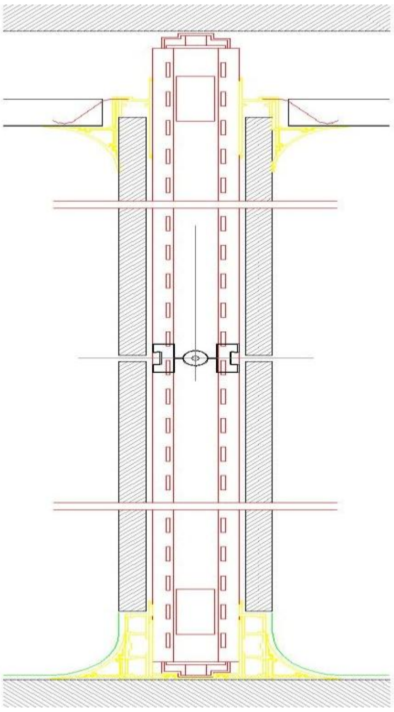


Fig 2.28: Junctions for false ceiling and Floor with the structure

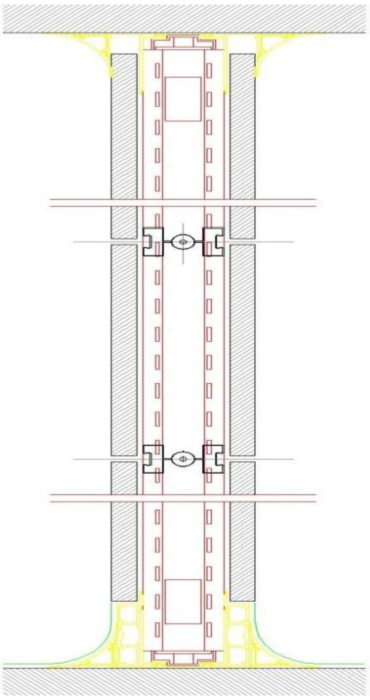


Fig 2.29: Junctions for ceiling and Floor with the structure

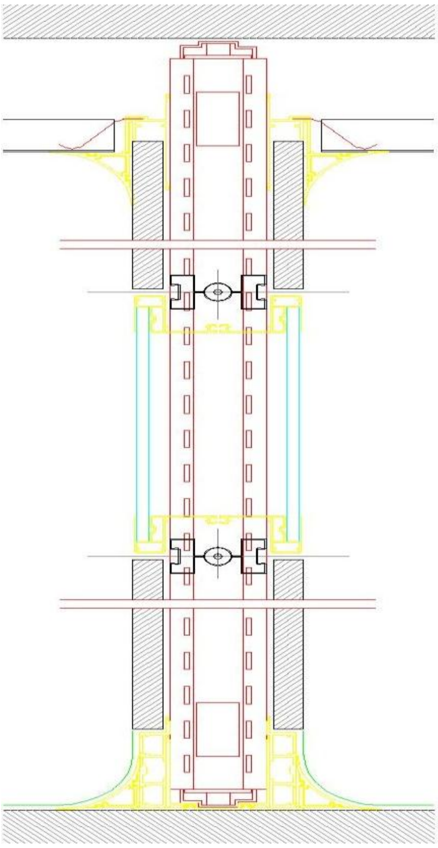


Fig 2.30: Junctions for two layers glass window with the structure

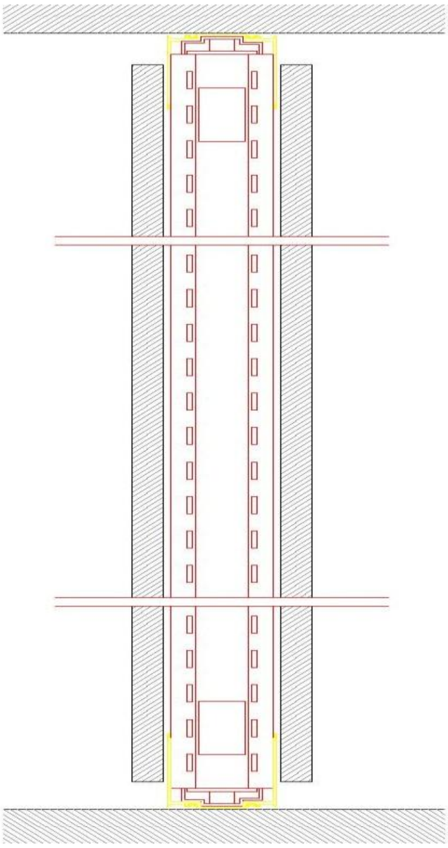


Fig 2.31: Junctions for wall panel with Floor and ceiling with the structure

Fig 2.32: Junctions for two layers glass for window with structure and wall panel

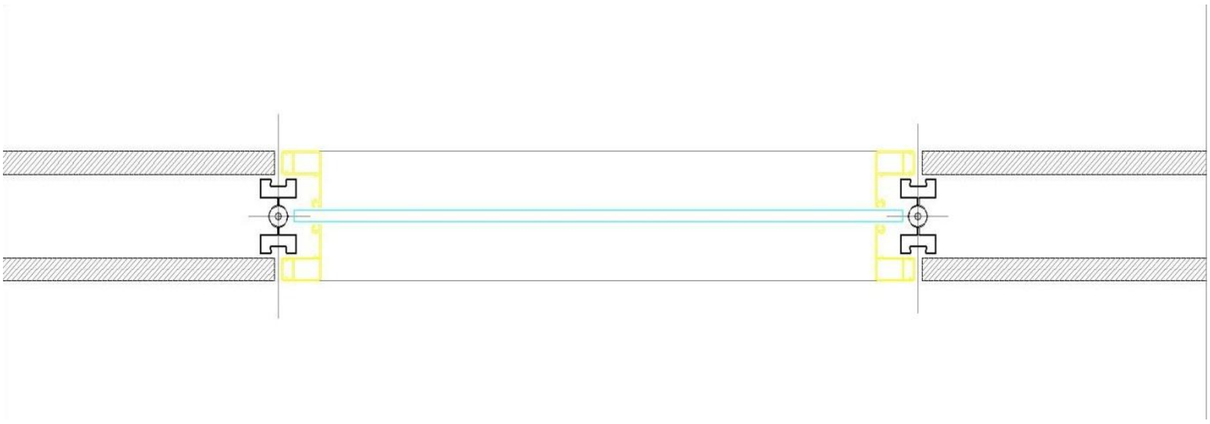


Fig 2.33: Junctions for one layer glass for window with structure and wall panel

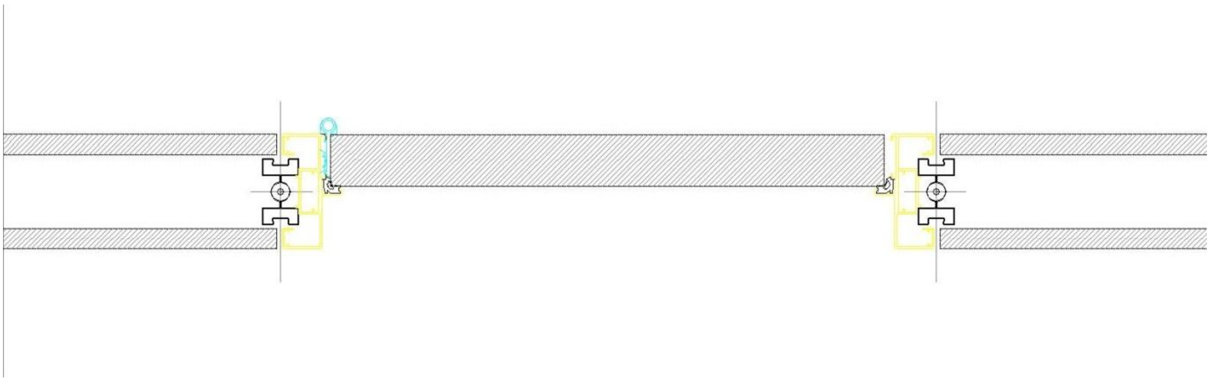


Fig 2.34: Junctions for door with structure and wall panel

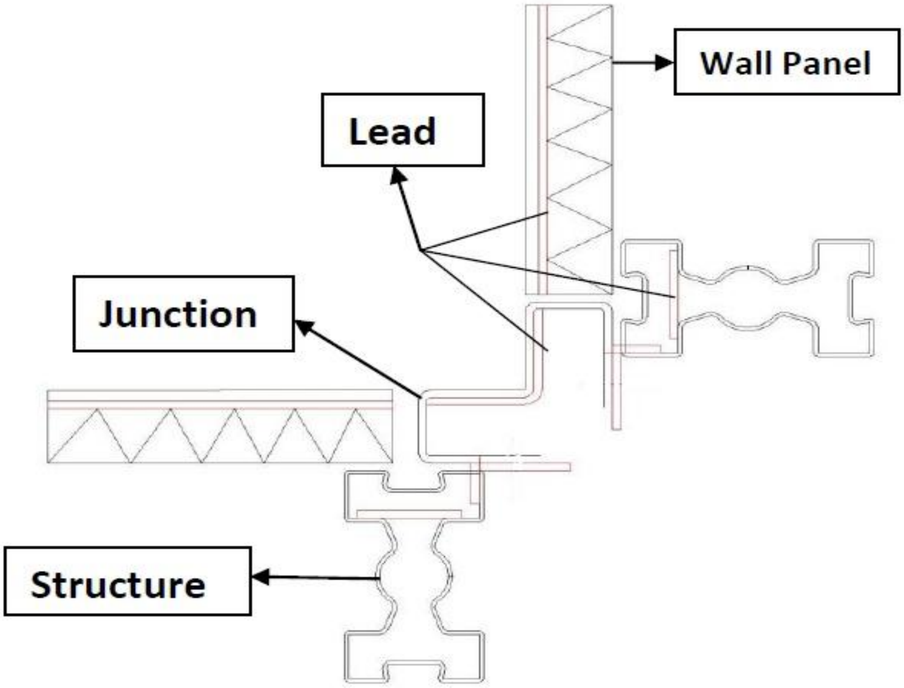


Fig 2.35: Junction for 90^0 angle wall panel at corner in room

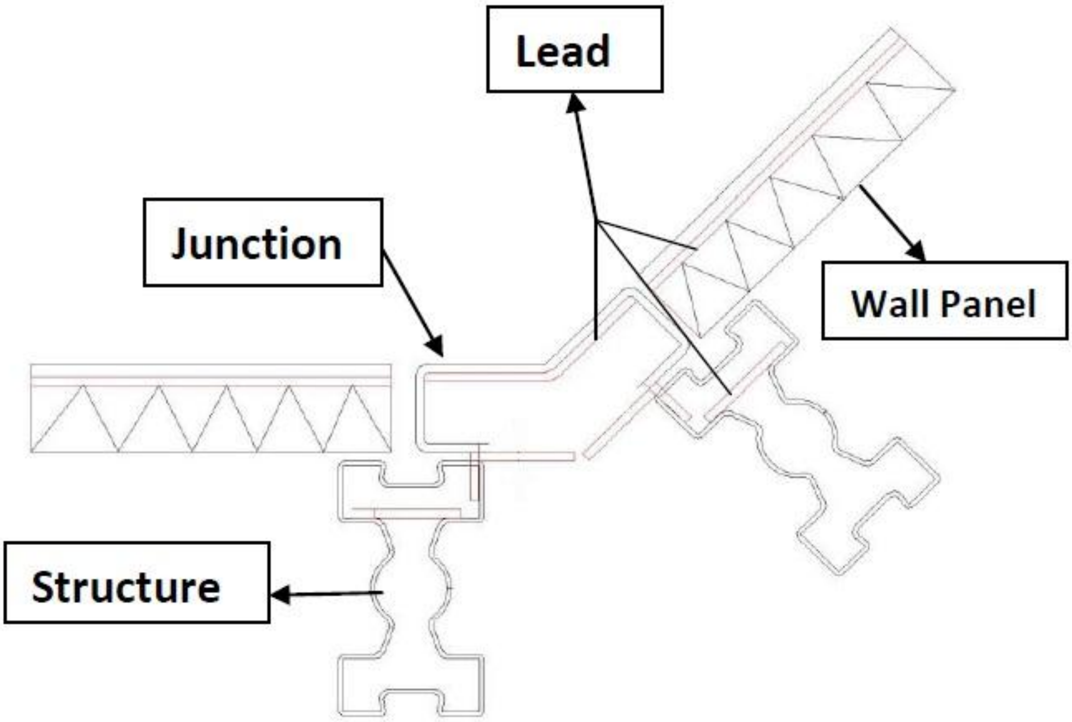


Fig 2.36: Junction for 135^0 angle wall panel at corner in room

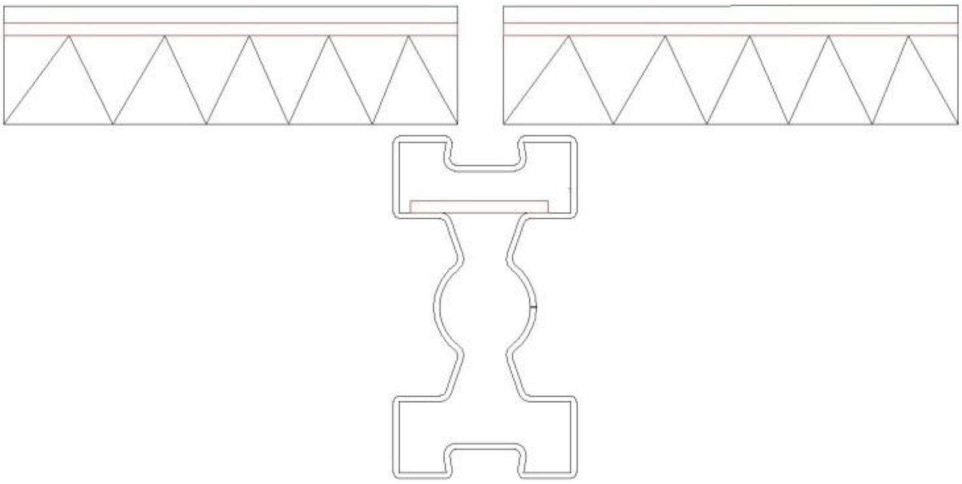


Fig 2.37: Two wall panels hanging on structure

2. 6 Seal material

Fig 2.38: Seal Material

Mapei Mapesil AC (Sealant) is solvent-free, acetic-crosslinking mildew resistant silicone sealant, available in a range of 26 colors and has a transparent appearance. Mapei Mapesil AC seals interior and exterior expansion joints accommodating up to 20% expansion of the initial size. In interior and exterior ceramic tile, walls and floors in bathrooms, showers and swimming pools.

Mapesil AC can also be used to create perfectly flexible gaskets between construction elements in building, mechanical engineering, ship-building, automobile manufacturing etc. N.B. Mapesil AC perfectly adheres to glass, ceramic and anodised aluminium. When first treating with Primer FD, Mapesil AC adheres well also on concrete, metal, wood, painted surfaces, plastic, rubber, etc.

2.7 Floors

CONDUCTIVE PVC FLOORS FOR OPERATING THEATRE AND INTENSIVE CARE UNITIS

DLW Vinyl homogeneous vinyl floor covering.

The DLW collection of homogeneous vinyl floor covering includes a wide selection of chip designs, marbled and directional patterns, and colors. Thanks to its versatility and many benefits, it can be used in almost any application. Homogeneous vinyl floor covering offers many convincing benefits:

The DLW collection of homogeneous vinyl floor covering also includes several conductive floor covering (ESD and Conductive), which can also be optimally combined with matching non-conductive floor covering and finally, homogeneous vinyl floor covering is an environmentally compatible material: it requires less energy consumption in production, reduced chemicals use in maintenance and it can be recycled at the end of its service life.

Vinyl Homogeneous Pastel Conductive

Fig 2.39: Vinyl Homogeneous Pastel Conductive

Product attributes the perfect high- performance complement. As a conductive floor covering, Pastell Conductive’s pure, bright colours combine perfectly with the Favorite floor covering with its fine chip pattern. Pastell Conductive is ideal for use in the health care sector for combinations of conductive and non-conductive areas. It is now available in16graduations of color.

TECHNICAL DETAILS FLOOR –WALL –CEILING

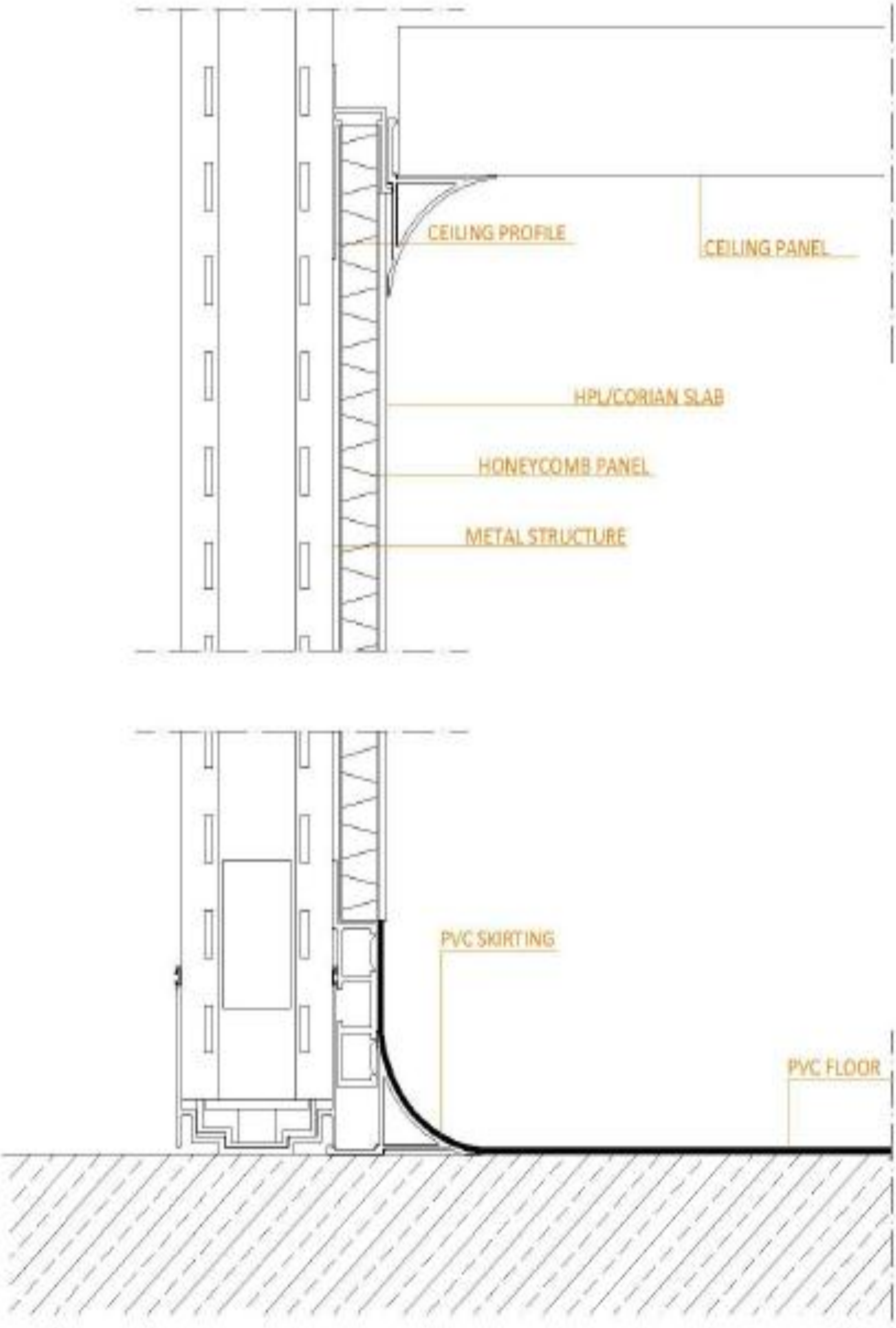


Fig 2.40: FLOOR –WALL –CEILING with partition wall

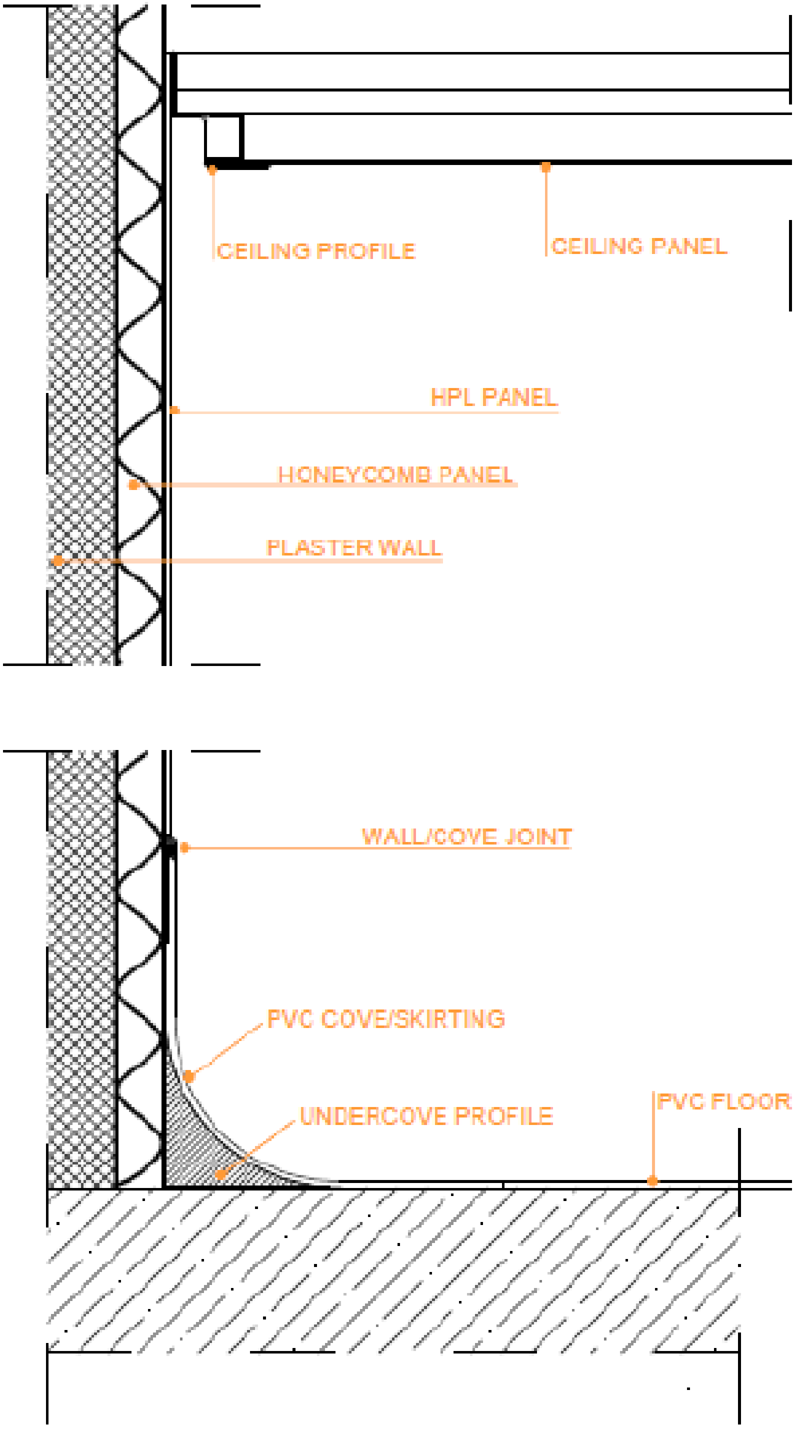


Fig 2.41: FLOOR –WALL –CEILING with traditional wall

2.8 Lights:

Luminaire complete with Planirex glass diffuser and Dark 60° louvre - Direct light emission Fitting for modular 600x600 recessed series panels or monolithic plasterboard with IP65 total protection.

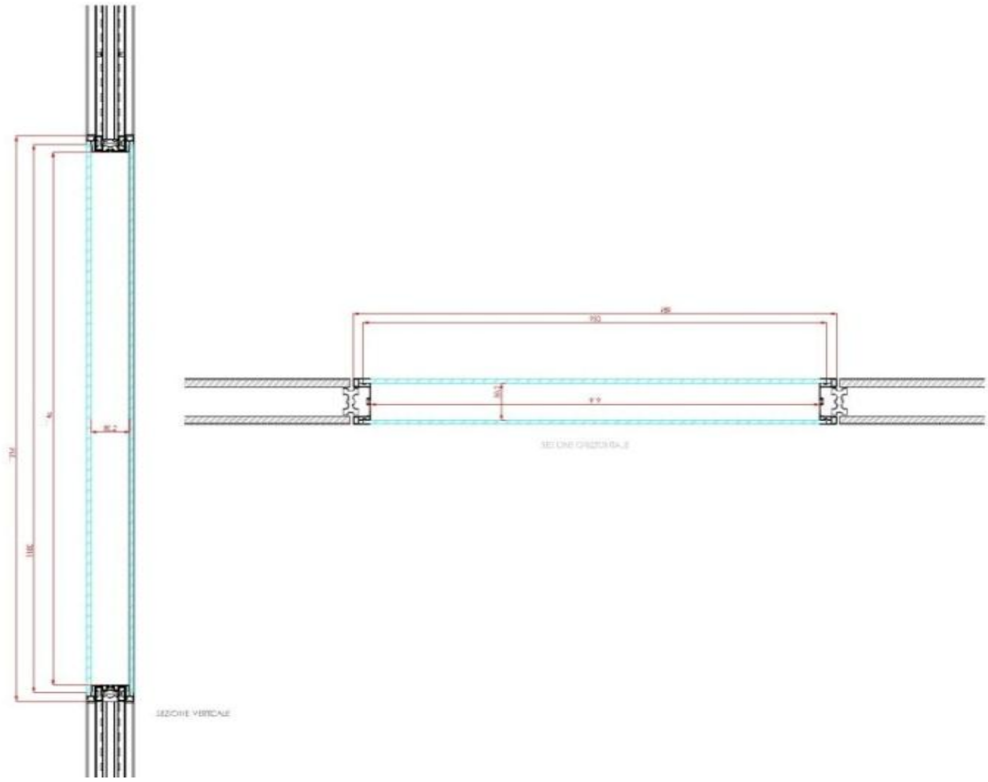
Fig 2.42: lighting system

HOUSING - Version for sealed false-ceilings. Housing made of brake-formed electrically welded steel plate 0.7 mm approx. thick, surface-treated and powder-coated. The external part is specifically bent to be coupled to metal panels (or plasterboard) where sealing between the false-ceiling module and luminaire must be obtained.

DIFFUSERS AVAILABLE - VD Planirex diffuser made of a 3 mm thick transparent tempered glass pane. Frame made of extruded aluminium diffuser natural anodised. Fixed with no-loss nickel steel pins to be rotated by 90°. No-fall chains made of galvanised electrically welded steel rings, with terminal hooks. Complete with pin seat covers, perfectly co-planar to the frame, made of oxidised anodised extruded aluminium and fitted with no-fall tie-rods that guarantee safety during routine maintenance.

Equipped with Dark 60° symmetrical louvre with direct light distribution, made of double-parabolic longitudinal elements and louvre closed in the upper part and made of very pure (99.99% Al content) mirror-finish high-bright oxidised (2 µm) aluminium with PVD (Physical Vapour Deposition) treatment. Average direct luminance both lengthwise and crosswise lower than 1000 cd/m2, for observation angles exceeding 65° from the vertical. Fixed to the housing with galvanised stee wire springs. Steel wire fasteners and no-fall down devices. Suitable for installation in areas where VDU terminals are used.

2.9 Window



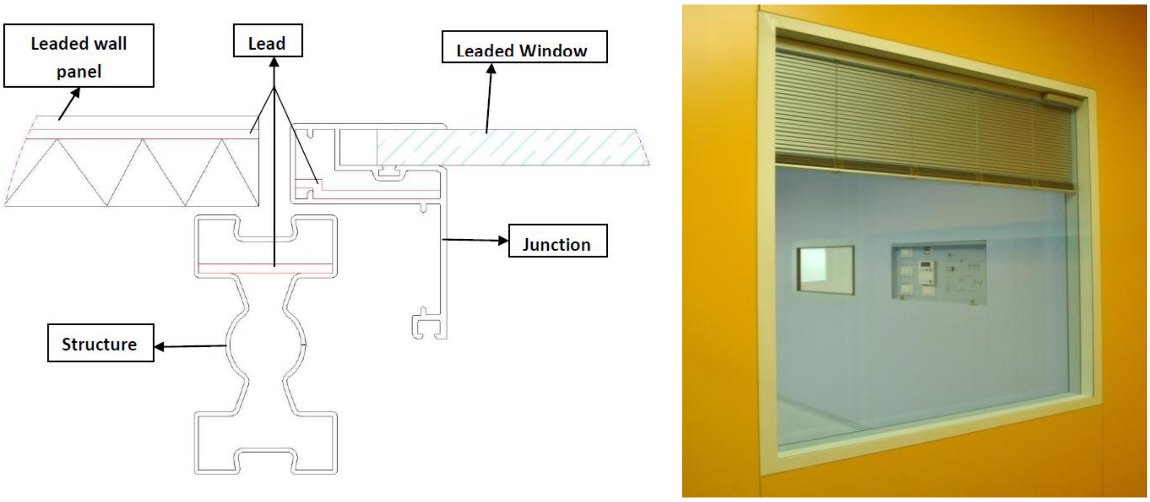
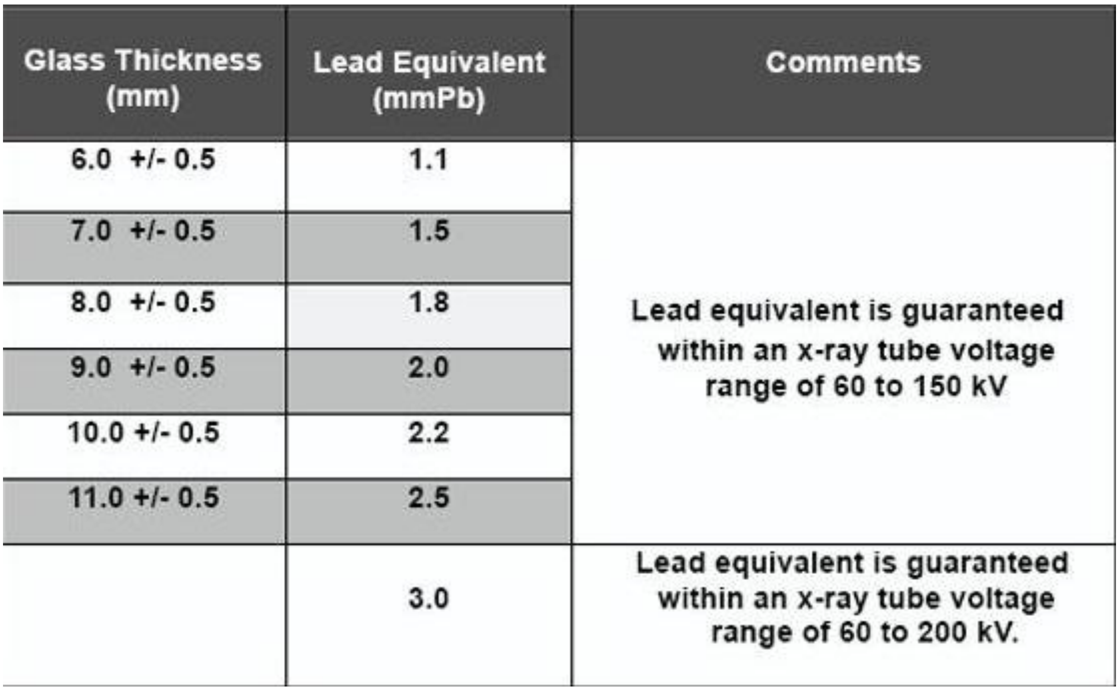


Fig 2.43: Leaded Window

Window for internal wall dim.1180x950mm with double tempered leaded glass. However this is often no longer the case, given the high density of modern developments, the increased workloads possible with new technology and the present dose constraints. The issue of shielding of X‑ray room windows must be referred to the RPA as the majority of these windows may require shielding. For general rooms, the lead equivalence of the window required may be 2 mm at 150 kV depending on the workload, the occupancy outside, and the distance to the nearest occupied area, although windows of 3‑4 mm lead equivalence at 150 kV or more may be required for multi-slice CT and angiographic installations. In all cases the actual amount of shielding required should be based on the RPA’s advice. If windows are required in X‑ray rooms, they may be shielded by lead glass or lead acrylic. These should be provided in the form of double-glazing, with plate glass on the outside as lead glass and lead acrylic may be easily damaged and lead glass must be kept dry. Window frames must also be shielded with sufficient overlap provided between the window and window frame and between the window frame and wall. Windows should be marked with the lead equivalent thickness. Alternatively, windows may be shielded by lead blinds or shutters. A range of lead blinds is available including electronically operated vertical blinds. The blinds should also be marked with the lead equivalent thickness. The primary beam should not be routinely directed towards a window.

X-ray shielding glass can be supplied with lead equivalences ranging from 1mm to 3.5mm. If additional x-ray protection is required then the sheet glass can be layered to any lead equivalence. Radiation shielding glass standard sizes of 800mm and 1000mm are available with widths up to 2000mm. Most standard sizes are available from stock and can usually be delivered within five to ten working days. Please call for availability. Larger lead glass sizes can be ordered up to 1100mm by 2400mm. Radial vision panels can be cut to suit various applications. X-ray shielding glass can be supplied double glazed in a sealed unit with various other specialist glasses to achieve properties such as FR30, FR60, Scratch resistant, Impact resistant etc. Lead glass can also be supplied laminated for extra durability or vinyl finished for one-way viewing in use as a privacy window.



Glass Thickness (mm)	Lead Equivalent (mmPb)	Comments
6.0 +/- 0.5	1.1	Lead equivalent is guaranteed within an x-ray tube voltage range of 60 to 150 kV
7.0 +/- 0.5	1.5	
8.0 +/- 0.5	1.8	
9.0 +/- 0.5	2.0	
10.0 +/- 0.5	2.2	
11.0 +/- 0.5	2.5	
	3.0	Lead equivalent is guaranteed within an x-ray tube voltage range of 60 to 200 kV.

2.10 Door

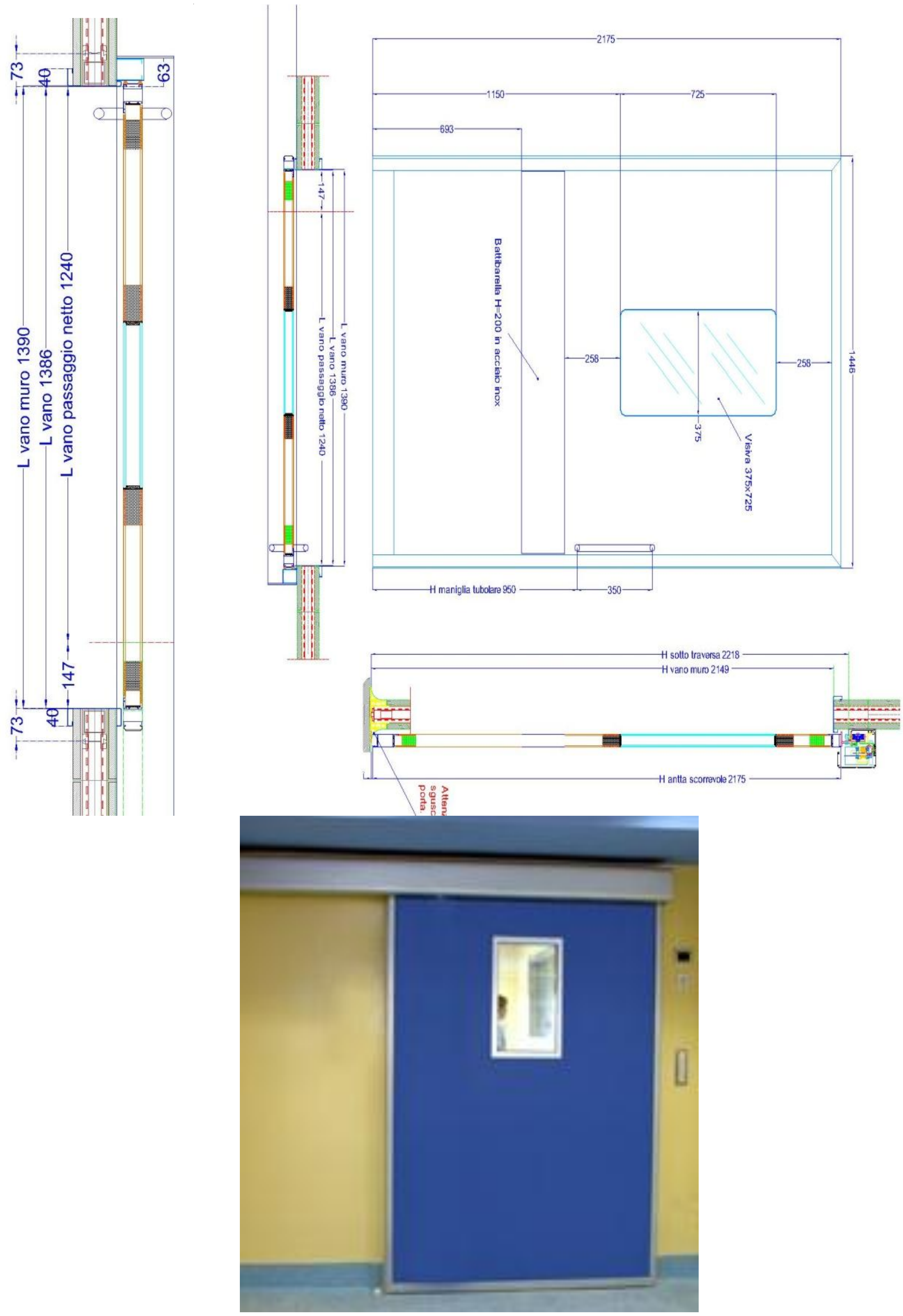


Fig 2.44: Door

Automatic sliding doors, single leaf - with X-ray protection. With window double glazed 500x500mm flush with door surface, equivalent to 2mmPB.

Canopy: Over the full length of the track coated aluminum plate finished in RAL 9006
Rail construction: Aluminum profile, Metaflex system, 2 mm. deep indentations.
Door blade: 60mm thick PU-core, 2x MDF with hard pressured laminate Formica. The Formica laminate will have a flush vertical joint. The above panel will be framed in anodized aluminum profiles.
Gasket: On all 4 sides of the door blade a special rubber gasket
Opener: Aluminum or stainless steel lever handles both sides
X-Ray protection: 2mm lead insert
Frame: aluminum profile type L
Operation: automation SDA-04L 230V 50/60 Hz on the rail construction
Switches: 2 pieces push button ES1
Safety: One photocell in the aluminum frame and deceleration measuring. Sliding direction: Right or Left opening

2.11 Diaphanoscope

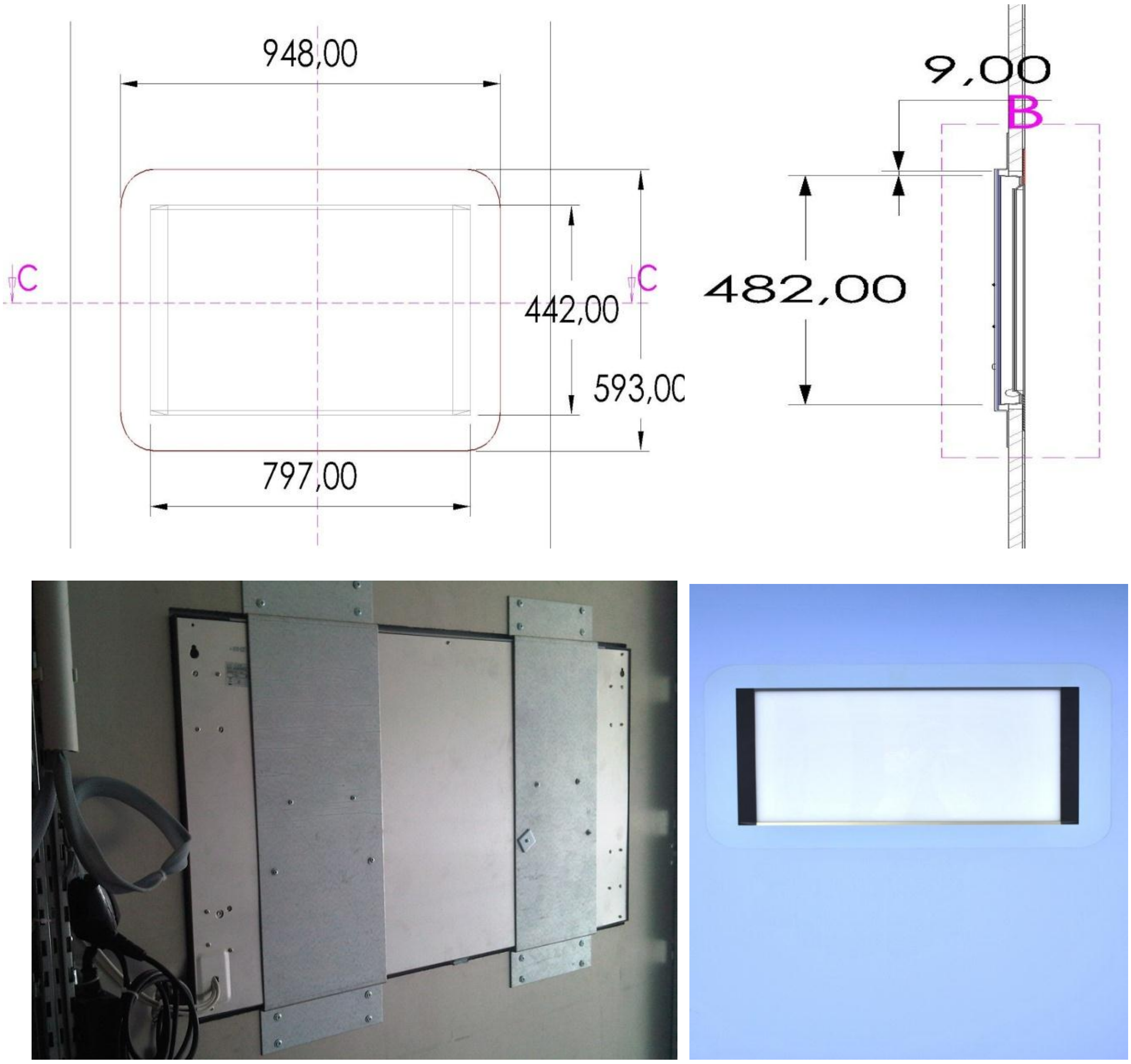


Fig 2.45: Diaphanoscope

TECHNICAL DATA

Steel plate thickness 8 / 10 with a baked enamel finish paint epoxy textured white (RAL 9003) thick stainless steel sheet 8 / 10 (AISI 430) satin Speaker cast opal white methacrylate 3mm Reggilastre aluminum profile containing rolls of grip at the top and side clips in polycarbonate, the profile also has the function of frame Electrical Components

- socket with fuse 10A 250V
- bipolar switch 16A 250V fluorescent light
- black cable with plug 2m Italian model 3x0, 75mm ² 10A 250V
- Day-light fluorescent lamps G13 6000 ° K
- Fuse 5x20 fast glass
- Supply Voltage 230V 50Hz
- Adjusting the brightness
- models with ignition starter, from 100% to 60%
- models at high frequency, from 100% to 10%
- Protection IP 5X
- Insulation class 1
- Aluminum flanges
- Leaded cover on the back by suitable lead plate.

2.12 Control Panel

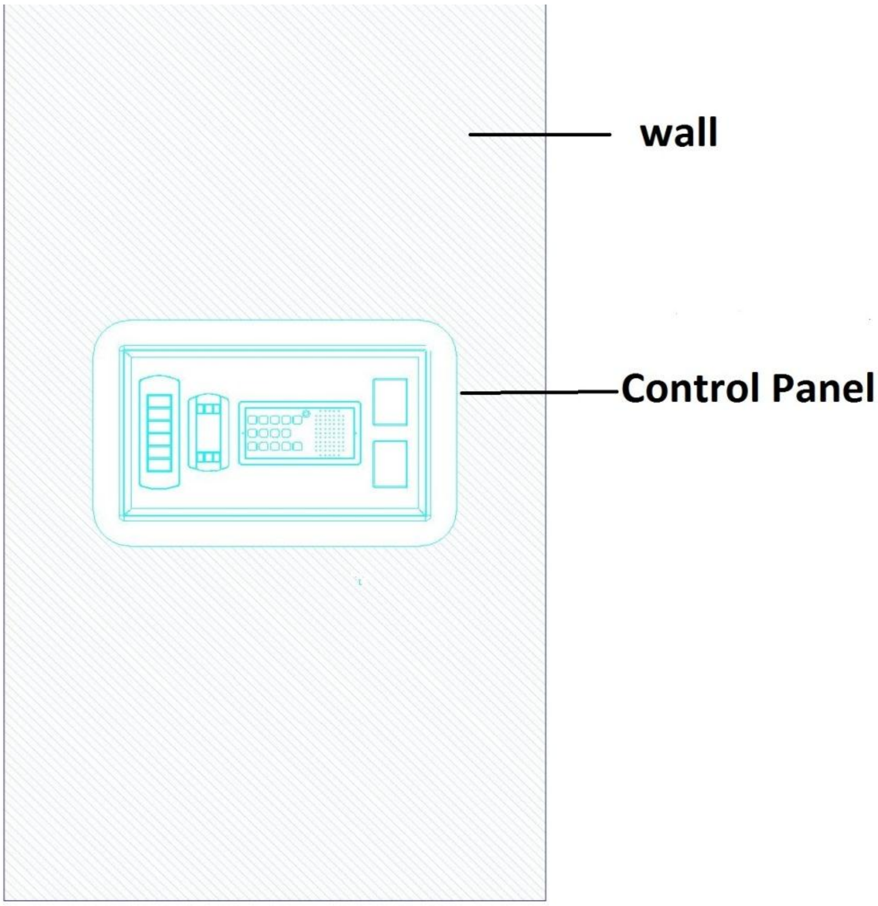


Fig 2.47: CONTROL PANEL

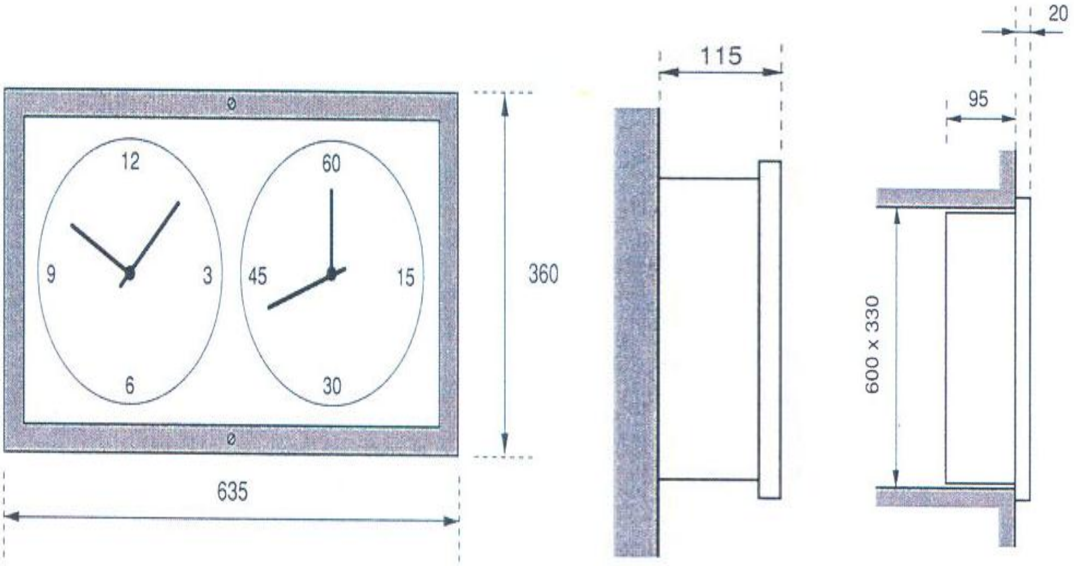
Control panel for the operating room, flush mounted on the perimeter of the operating room, with no protruding parts, edges or sharp corners, to avoid dust facilitate the cleaning and disinfection., made of aluminum honeycomb panels 10mm thickness, reinforced and sealed doors . 1 module timer and clock module, dim. mm. 1150 h.

- 1 module diaphanoscope dim. mm. 600 h
- 1 module dim. 300mm. equipped with gas and electrical outlets predisposition (electric and gas plugs and included)
- 1 cabinet with two reinforced doors, dim. mm. 850 h.No. 01 socket, dim. mm. 100 h.

  Glass front door (visarm) on aluminum hinges and magnet lock (or square key). Seals made of rubber along the entire perimeter.   Size mm. 650L.x150P.x600H.

- Leaded cover on the back by suitable lead plate.

2.13 Clock



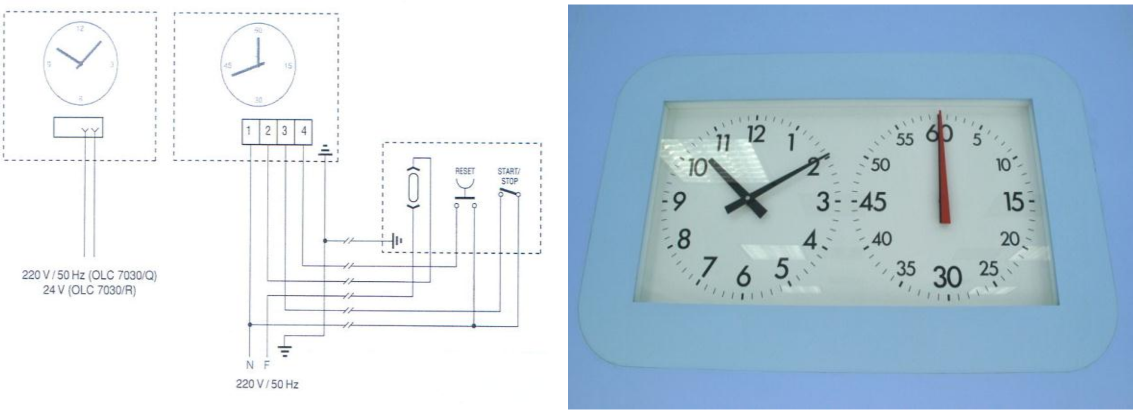


Fig 2.48: Wall Clock

Analogue "seconds counter" clock is for Operation theatre, industrial and laboratory use.
It is composed of two independent parts: clock and stopwatch. It can be supplied in the following models:

- OLC7030/Q, provided with an electric quartz movement clock, powered from 220V mains and a Ni-Cd buffered battery that assures six month operation in case of power failure.
- OLC7030/R provided with a slave movement at 24V polarized impulses every 60s.

The stopwatch is provided with a synchronous movement powered from 220V/50Hz mains. Then indication of the seconds of the minutes is given by means of a red and a black hand respectively.
The stopwatch is operated from a remote control unit, available upon request that gives start, stop and reset facilities. The clock can be mounted or installed in a rack. Leaded cover on the back by suitable lead plate.

Technical characteristics:

- Steel housing with epoxy resin finish
- Dial glass protection
- Stainless steel front frame
- Weight 13.2 kg

2.14 Gas plate

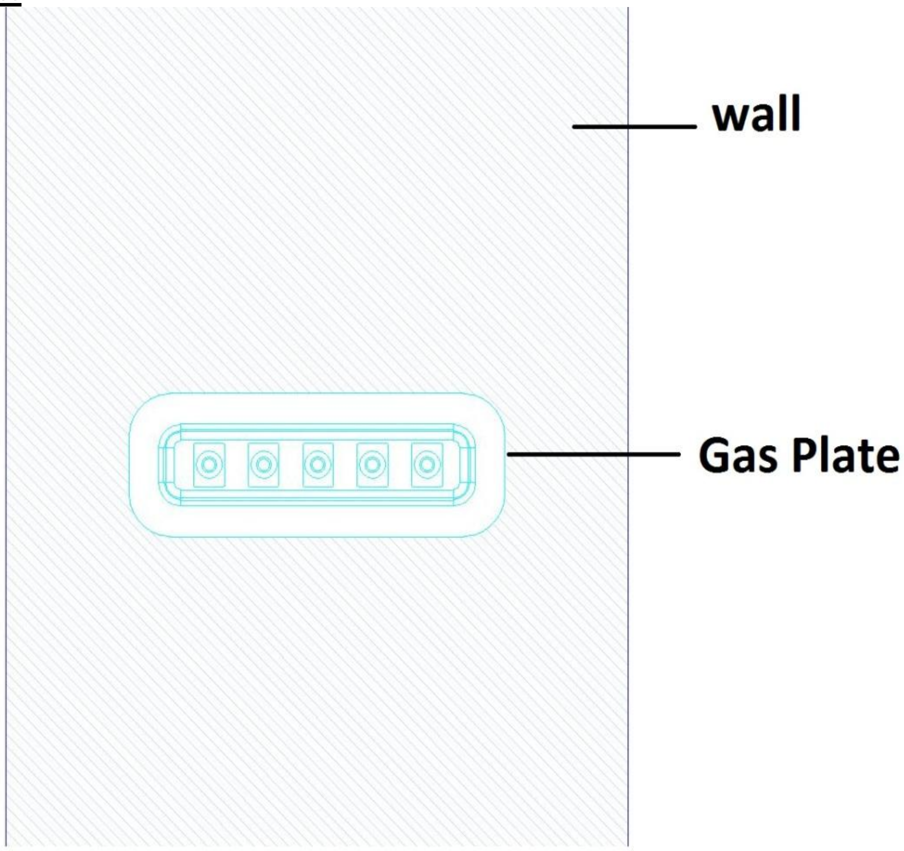
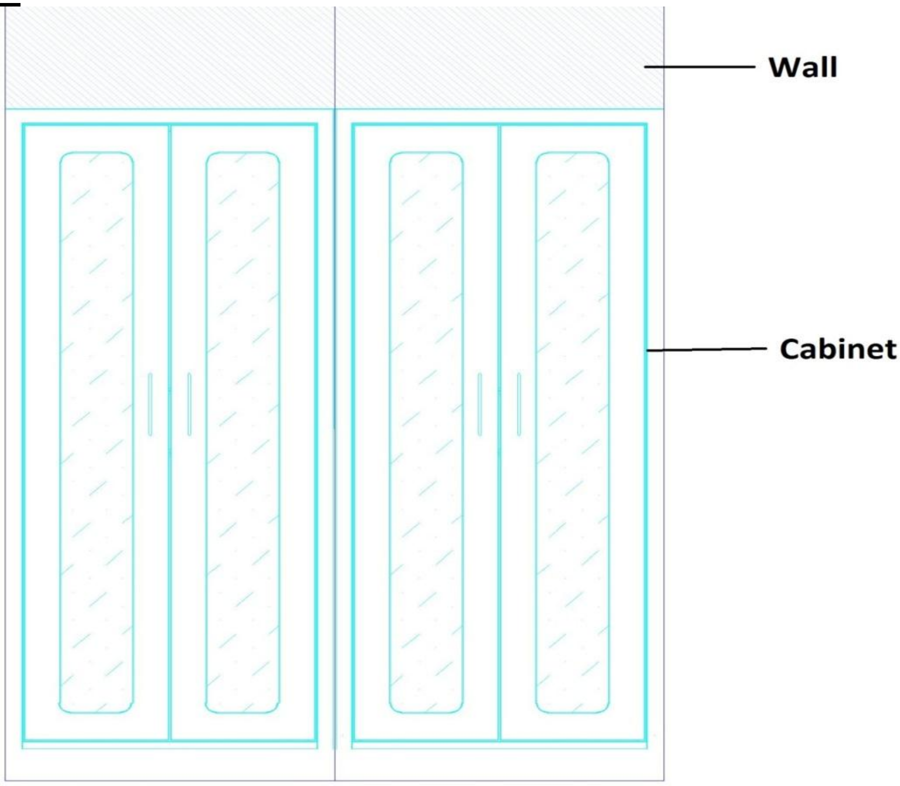


Fig 2.49: Gas Plate

Rounded plate recessed and flush with the wall, with gas plugs (oxygen, nitrous oxide, air, vacuum and extraction) made of casted corian. Leaded cover on the back by suitable lead plate.

2.15 Cabinet



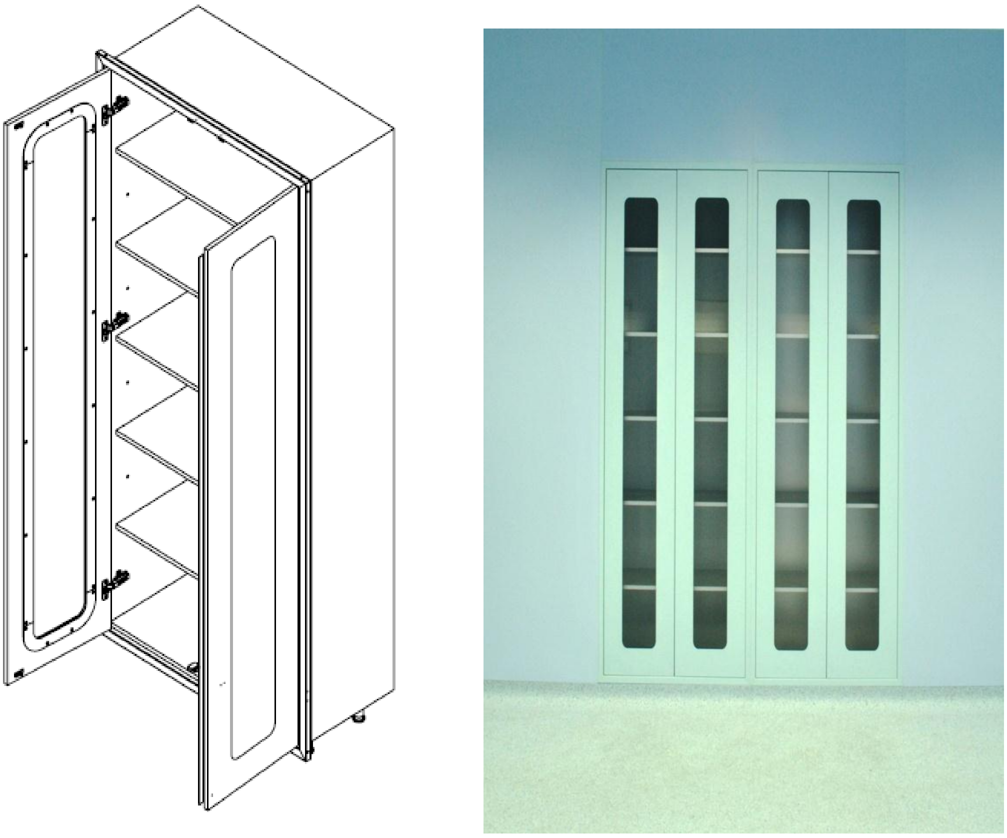


Fig 2.50: Cabinet

Air tight cabinets, made of honeycomb aluminum panel, recessed and flush to wall, with push to open opening x-ray shielded on the back .Dim: 2100x950x420mm. Leaded cover on the back by suitable lead plate.

2.16 PC Case

Fig 2.51: PC case

Pc case made of Corian, steel and aluminum. Dim. 1350x750mm. Aluminum frame sp.15/10. Two types of opening: sliding and push to open. Leaded cover on the back by suitable lead plate.

2.17 Crashrails corridors

Acrovyn

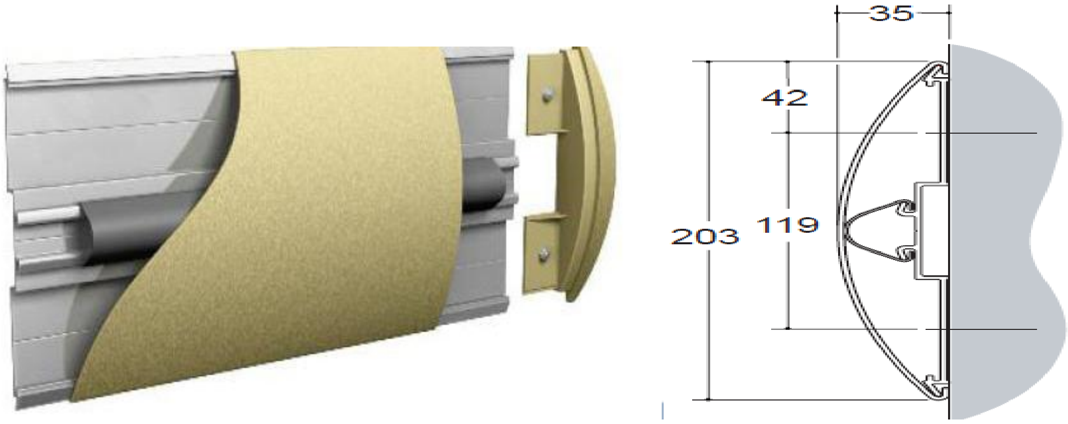


Fig 2.52: Acrovyn crashrail

Features:

- Acrovyn cover over continuous aluminum retainer
- Free-floating design flexes on impact
- Continuous Acrovyn regrind shock-absorbing bumper
- Four mounting options for varying stand-offs
- Accessories: Acrovyn end caps, external corners and return to wall end caps for extended option

Handrail

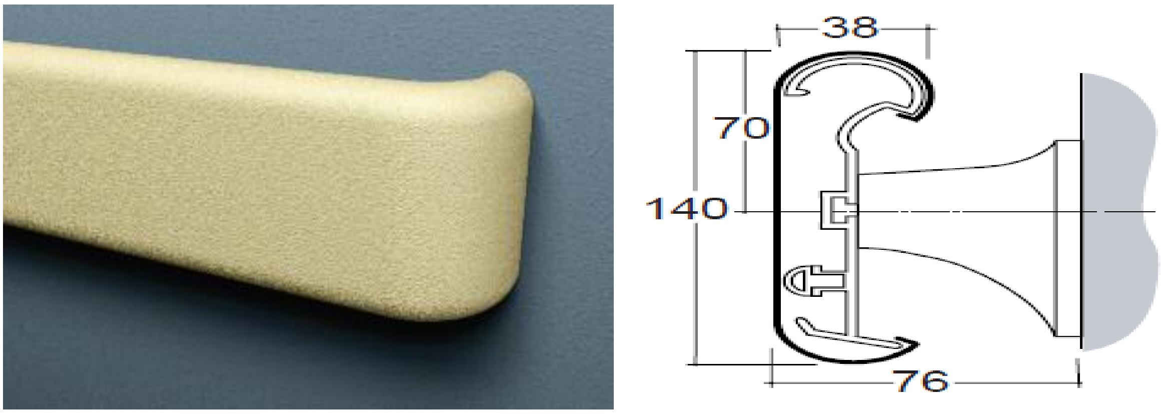


Fig 2.53: handrail crashrail

Features:

- Single piece- Acrovyn cover over aluminium retailner
- Free-floating design flexes on impact
- Shock-absorbing bumper cushion for increased impact protection
- Rapid fix brackets in two stand-off options for easy installation
- HRB4C(AL)- anti-ligatureoption featuring continous bracket
- Accessories: Acrovyn end caps, external and internal corners
- Available in all Acrovyn profile colors

2.18 Scrub

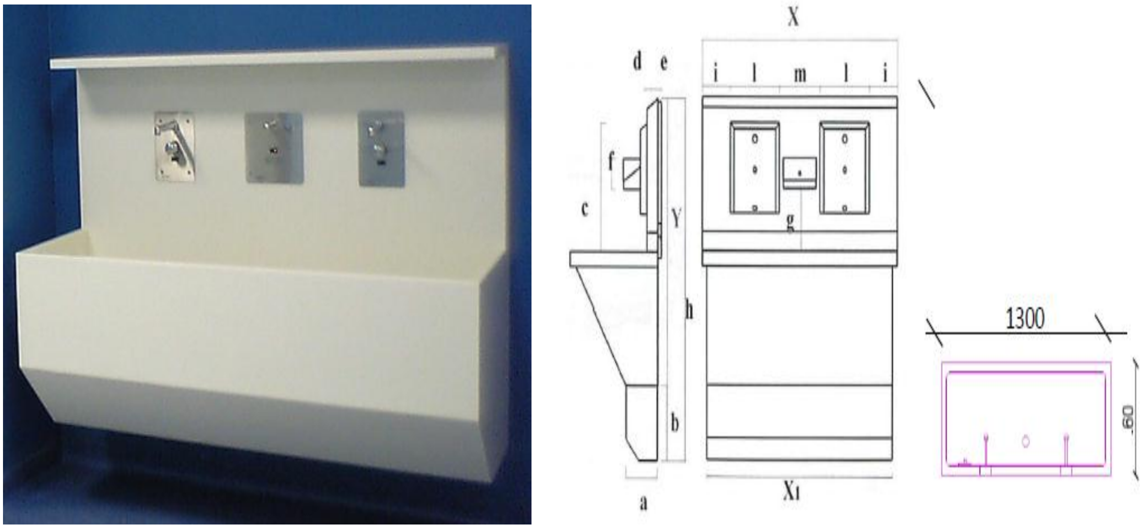


Fig 2.54: Srcub

Scrub made of Corian complete with electronic tap. Two seats dim. 1300x580x1100mm.Electronic soap dispenser completed with inbox shell 223x156x116mm included.

2.19 Eletric Plate

Fig 2.55: Electric Plate

Rounded plate recessed and flushes with the wall, with electrical plugs: 6 Schuko plugs (with cap) and 6 equipotential plugs (earthling on floor). X-ray shielded on the back please show shielded part and earthling solution as per photocopy

2.20 Air handle unit

Fig 2.56: Air handle unit

Intake (ac extraction) operating theatre ventilation air grid, including all color painted flanges solutions with metal and lead. In the air handle unit, we designed 60^0 angled leaded blade to protect radiation shielding in the operation theater.

Chapter-3: Model of a x-ray proof Operation Theater with innovative materials

General Notes

1. Any room remodeling and construction- floor ceiling and walls must be finished before equipment installation can begin.
2. Installation of proper specified power.
3. Installation of load centers, branch panels, wire trough, circuit breakers, junction boxes and conduit as specified.
4. Interconnecting wire and cable as specified.
5. Installation of wall and ceiling support and suspension frame work as specified.
6. For the most part convenience outlets are to be specified by others. Required outlets will be depicted. For ease in service, locate at least one outlet on each wall with in close proximity to the control console and x-ray control cabinet.
7. Any ceiling mounted light fixtures, diffusers, vents, smoke/fire detectors, sprinkler heads; nozzles etc. shall not extend more than ½” below the finished ceiling.
8. Any plumbing requirements
9. Installation of warning lights and/or interlock switches at main door of exam room to be coordinated with equipment representatives.
10. Any air conditioning requirements. (Heating, ventilation, air conditioning and humidification)
11. Any ancillary and accessory items such as : film processors, tanks, dryers, sliver collection system, film loading bins, cassette transfer cabinets, safe-lights, illuminators etc.
12. Radiation protection requirements- these must be specified by a qualified radiation physicist.

3.1 The room layout

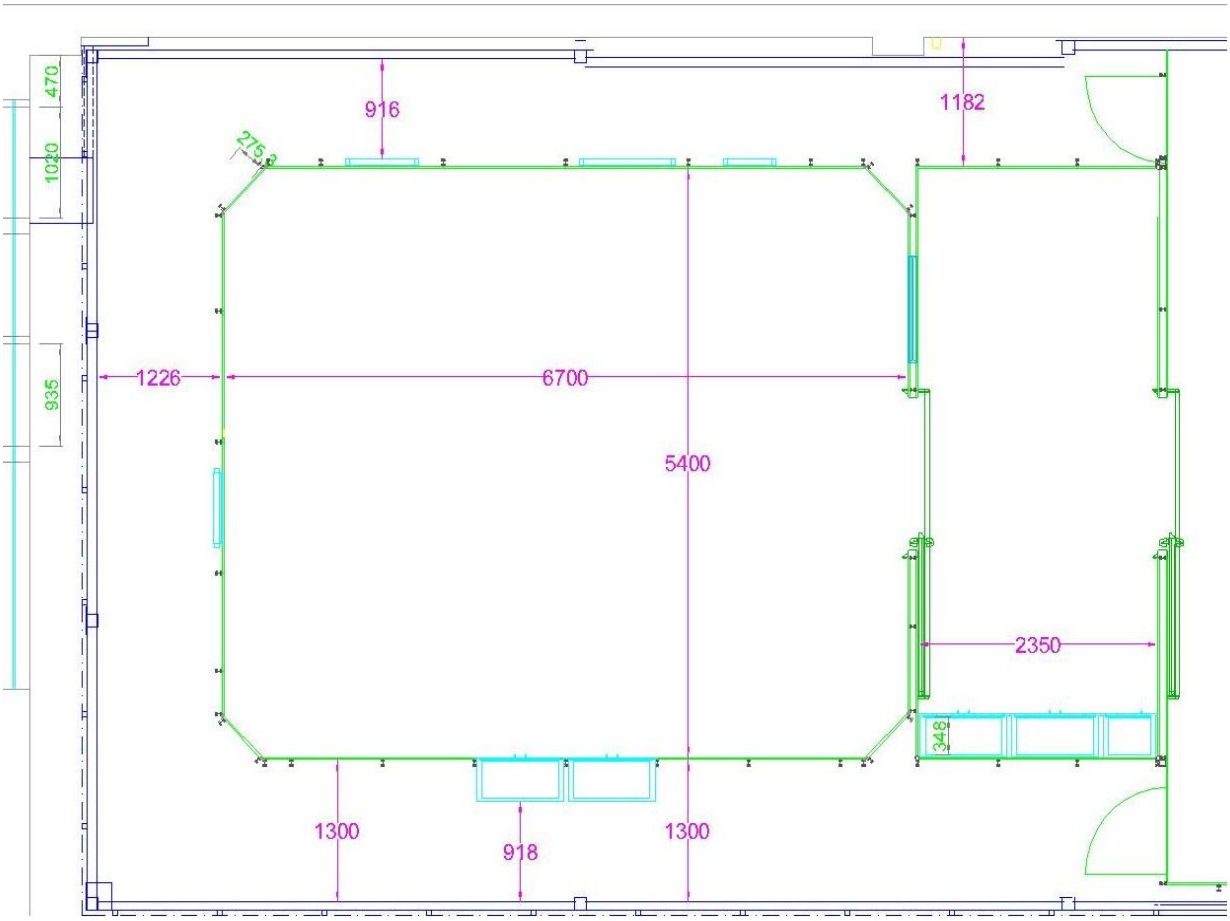


Fig 3.1: X-ray Room floor layout

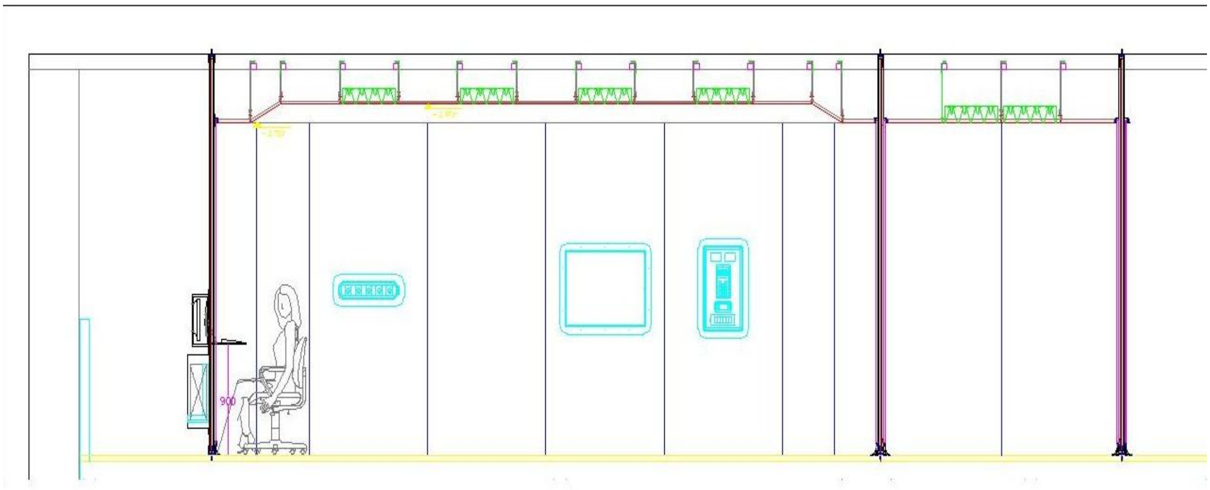


Fig 3.2: X-ray room side view layout

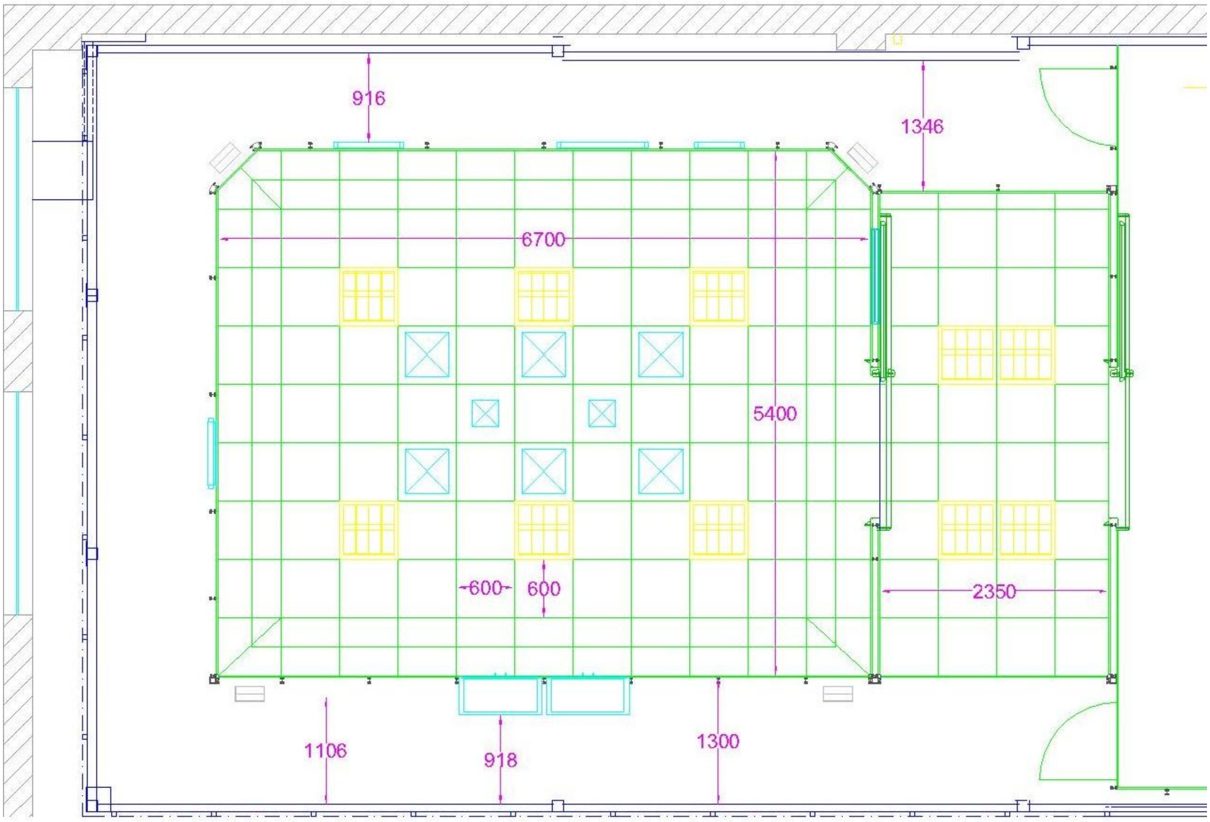


Fig 3.3: X-Ray room ceiling layout

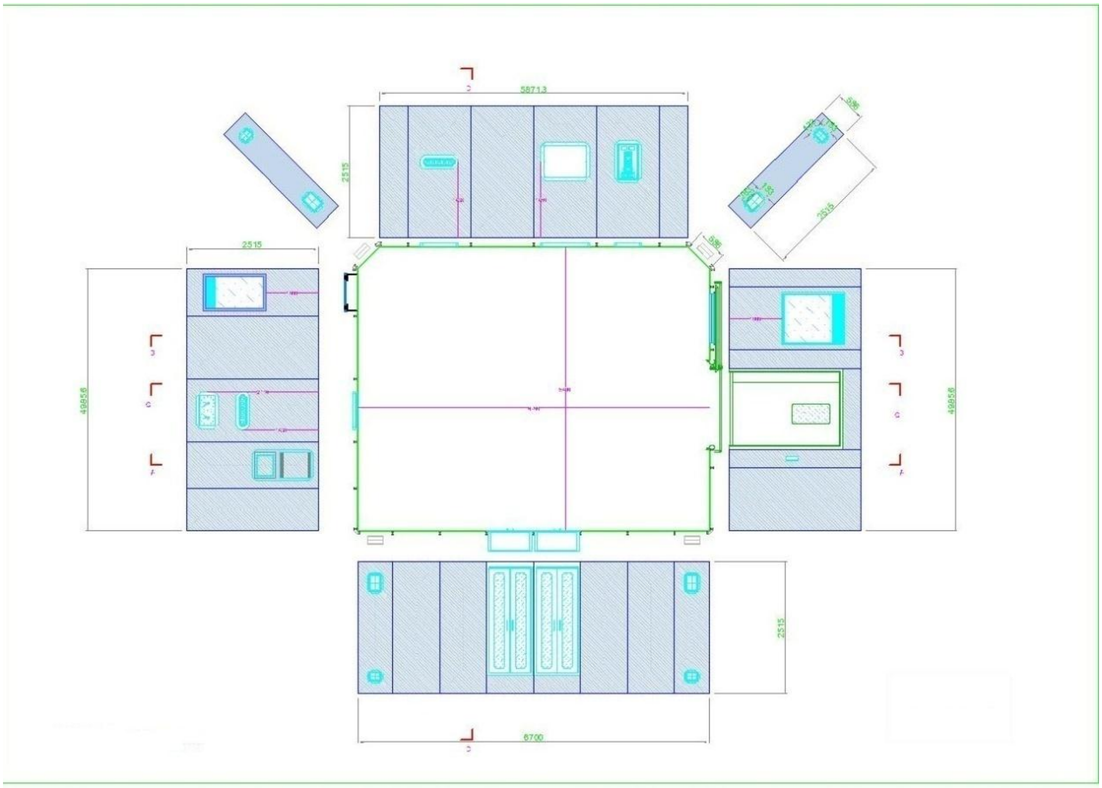


Fig 3.4: Wall layout

Fig: 3.5

3.2 Electrical systems

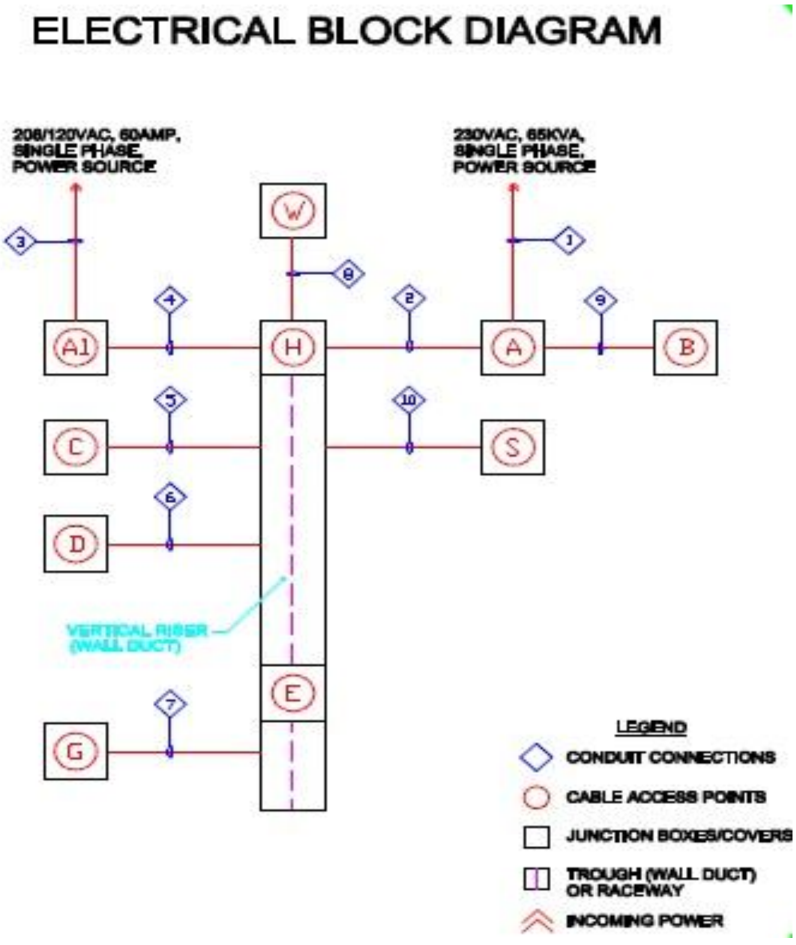


Fig: 3.6 Electrical layout

The length and size of incoming wire with the assumption that the power source has the required capacity, the voltage regulation under load variation is calculated to be within ±5%.

Power to main disconnect <A>: 230VAC, Single phase, 65KVA
Main circuit breaker <A>: 120amp, 2-pole
X-ray generator: CMP-200 40KW high frequncy generator

Important Power notes

Power lines for equipment listed shall be dedicated lines run directly from nearest facility power source. Under no circumstances shall any other electrical equipment be connected to these power lines now or in the future.

Line requirements

A. No transients (impulses from 0.5 to 800 microseconds) that exceed 30% of nominal peak line voltage, as measured by a power line analyzer, with the system in standby shall occur.
B. Transients equal to or greater than 30% of nominal peak line voltage.
    - Shall not occur more than once per hour.
    - Shall not exceed more than 12 impulses per 24-hour period.

Voltage regulation

A. 230VAC, single phase, 65KVA incoming line to main disconnect with 5% voltage regulation under intermittent no load to full load conditions is required, 60Hz ± 5%

3.3 Patient safety grounding

Patient safety grounding consideration:

A special grounding system is required in all diagnostic rooms by some state and local codes. This ground system strongly recommended in areas where electrically susceptible patients might be examined or treated under present, future or emergency conditions. Consult with the governing electrical codes and confer with appropriate hospital administrative personnel and consulting engineers to determine the areas requiring the grounding system. If such a grounding system is required, the responsible construction participants shall design and install grounding system to include all metal objects and fixtures.

Chapter -4: Discussion

Advances in technology, alongside the diversity and growth of hospitals, have led to the need for more specialized healthcare settings and furnishings, thus new and insightful architecture and design of healthcare facilities. Today, healthcare architects are taking into account these needs when developing designs that are conducive to patient-centered care. At the same time, however, the needs of the staff should also be considered; therefore their participation in the architectural design team, the design evaluation, building and commissioning process is crucial. We analyzed the contributions on various levels, which we referred to as fields. Within each field, we highlighted the most important trends and we illustrated important concepts through the citation of key references. Since each discussion is accompanied by a detailed table, which provides even more information than is addressed in the text, readers may easily identify manuscripts that have specific features in common. They furthermore allow tracking specific contributions over the different fields and visually indicate what area of research is well addressed or should be subject to future research.

In operation theater, there may have light radiated X-ray machine, so there should have X-ray proof wall system. The partition wall is one kind of modern wall system and this report discussed the complete room solution of X-ray proof operation theater. For X-ray scaterring, we used lead layer to protect the radiation, but lead is high weighted material. If we consider a wall dimesion of 600mm×2900mm without lead, it's self weight is 18.5kg and including 1mm lead layer weight will be 38.2 kg. Upto 2mm lead layer in back of wall is safe for wall panel and structure. If we need to design more than 2mm lead layer, then we can't hang the wall panel with the structure, then we have to keep the wall panel in the ground or we have to in the traditional way like adding cheap board or paster board on wall. Finally it may noted that, X-ray proof partition wall system is for light radiation protection. For the heavy radiation we have to consider traditioally wall system.

The wall system also includes all the technical elements for completion which can be placed flush with wall and located inside the wall and the ceiling hollow spaces and this co-planar system offers an easy to clean surface (no corners, no reliefs, no slots) and guarantees a perfect aseptic surface. The false ceiling system consists of a metal substructure for suspension and painted stainless steel panels integrated with lights. In the operating theatres the ceilings, always in coplanar position and sealed, are equipped with air tight systems and filters. Here, this report shows the economical X-ray proof solution for the junctions in wall system like wall system with floor, ceiling, window, door, ventilation system, control panel and so on.

References

1. Handbooks of U.S. Department of Commerce, National Bureau of Standards, USA.
2. Report on Shielding and x ray room design, International Atomic Energy Agency (IAEA), Austria.
3. Report on Radiation Shielding and Room Design, St. James's Hospital, Ireland.
4. Report on Radiation shielding design assessment and verification requirements, Department of Environment, Climate Change and Water NSW, Sydney.
5. Radiation Health Branch, Department of Health, Western Australia.
6. Report on Radiation safety for X-ray diffraction and fluorescence analysis equipment, National Institute of Standards and Technology, Technology Administration, U.S. Department of Commerce.
7. Structural Shielding Design for Medical X-Ray Imaging Facilities, National Council on Radiation Protection and Measurements.

Glossary

Absorbed dose (D): The energy imparted by ionizing radiation to matter per unit mass of irradiated material at the point of interest. In the Systeme Internationale (SI), the unit is joule per kilogram (J kg–1), given the special name gray (Gy). 1 Gy = 1 J kg^{-1}.

Air kerma (K): (see kerma). Kerma in air. In this Report, the symbol K always refers to the quantity air kerma (in place of the usual symbol Ka), followed by an appropriate subscript to further describe the quantity (e.g., KP is air kerma from primary radiation).

Ampere (A): Unit of electric current. One ampere is produced by one volt acting through a resistance of 1 ohm.

As low as reasonably achievable (ALARA): A principle of radiation protection philosophy that requires that exposures to ionizing radiation be kept as low as reasonably achievable, economic and social factors being taken into account. The protection from radiation exposure is ALARA when the expenditure of further resources would be unwarranted by the reduction in exposure that would be achieved.

Attenuation: The reduction of air-kerma or exposure rate upon passage of radiation through matter. This Report is concerned with broad-beam attenuation (i.e., that occurring when the field area is large at the barrier and the point of measurement is near the exit surface).

Computed tomography (CT): An imaging procedure that uses multiple x-ray transmission measurements and a computer program to generate tomographic images of the patient.

computed tomography dose index (CTDI): A dose index quantity obtained by integrating over the dose profile resulting from a single computed tomography axial rotation. When obtained using a 10 cm (100 mm) long ionization chamber, it is designated CTDI100. When normalized per milliampere-second (mAs), it is designated nCTDI100.

Concrete equivalence: The thickness of standard-weight concrete [2.4 g cm–3 (147 lb foot 3)] affording the same attenuation, under specified conditions, as the material in question.

Controlled area: A limited-access area in which the occupational exposure of personnel to radiation is under the supervision of an individual in charge of radiation protection. This implies that access, occupancy and working conditions are controlled for radiation protection purposes.

Dose: Often used generically when not referring to a specific quantity, such as absorbed or effective dose.

dose-length product (DLP): A dose index quantity obtained using the following formula:
$DLP = L/P\ (1/3\ CTDI_{100,center} + 2/3\ CTDI_{100,periphery})$,
where L is the length of patient scanned, p is the pitch, and
$CTDI_{100,center}$ and $CTDI_{100,periphery}$ are CTDI100 values determined at the center and periphery of a standardized phantom (see pitch and computed tomography dose index).

Dose-line integral (DLI): The infinite line integral along a given phantom axis of the accumulated absorbed dose D(z) for a CT scan series, where z is the distance along the axis of rotation.

Dose limit: A limit on radiation dose that is applied for exposure to individuals in order to prevent the occurrence of radiation-induced deterministic effects or to limit the probability of radiation-related stochastic effects to an acceptable level.

Effective dose (E): The sum of the weighted equivalent doses for the radiosensitive tissues and organs of the body. It is given by the expression:

$$E = \sum w_T H_T,$$

where H_T is the equivalent dose in tissue or organ T and w_T is the tissue weighting factor for tissue or organ T.

Equivalent dose (HT): The mean absorbed dose in a tissue or organ modified by the radiation weighting factor (wR) for the type and energy of radiation. The equivalent dose in tissue or organ T is given by the expression:

$$H_T = \sum w_R (D_{T,R}),$$

where $D_{T,R}$ is the mean absorbed dose in the tissue or organ T due to radiation type R. The SI unit of equivalent dose is the joule per kilogram (J kg $^{-1}$) with the special name sievert (Sv). 1 Sv = 1 J kg^{-1}.

Exposure: In this Report, exposure is used most often in its general sense. When used as a defined radiation quantity, exposure is a measure of the ionization produced in air by x or gamma radiation. The unit of exposure is coulomb per kilogram (C kg –1). The special name for exposure is roentgen (R), where 1 R = 2.58 × 10–4 C kg –1. Air kerma is often used in place of exposure. An exposure of 1 R corresponds to an air kerma of 8.76 mGy.

Fluoroscopy: The process of producing a real-time image using x rays. The machine used for visualization, in which the dynamic image appears in real time on a display screen (usually video) is a fluoroscope. The fluoroscope can also produce a static record of an image formed on the output phosphor of an image intensifier. The image intensifier is an x-ray image receptor that increases the brightness of a fluoroscopic image by electronic amplification and image modification.

Gray (Gy): The special name given to the SI unit of absorbed dose and kerma.1Gy =1J kg–1.

Half-value layer (HVL): The thickness of a specified substance that, when introduced into the path of a given beam of ionizing radiation, reduces the air-kerma rate (or exposure rate) by one-half.

ionization chamber: A device for detection of ionizing radiation or for measurement of exposure, air kerma, or absorbed dose, and exposure, air-kerma, or absorbed-dose rate.

kerma (K) (kinetic energy released per unit mass): The sum of the initial kinetic energies of all the charged particles liberated by uncharged particles per unit mass of a specified material. The SI unit for kerma is J kg –1, with the special name gray (Gy). 1 Gy = 1 J kg –1. Kerma can be quoted for any specified material at a point in free space or in an absorbing medium (e.g., air kerma).

Kilovolt (kV): A unit of electrical potential difference equal to 1,000 volts. Kilovolt peak.

(kVp): The crest value in kilovolts of the potential difference of a pulsating potential generator. When only one-half of the voltage wave cycle is used, the value refers to the useful half of the cycle.

Lead equivalence: The thickness of lead affording the same attenuation, under specified conditions, as the material in question.

Leakage radiation: All radiation coming from within the source assembly except for the useful beam. Leakage radiation includes the portion of the radiation coming directly from the source and not absorbed by the source assembly, as well as the scattered radiation produced within the source assembly.

Leakage radiation technique factors: Technique factors specified for x-ray source assemblies at which leakage radiation is measured.

Milliampere (mA): 10–3 ampere. In radiography, the current flow from the cathode to the anode that, in turn, regulates the intensity of radiation emitted by the x-ray tube.

Milliampere-minutes (mA min): The product of the x-ray tube operating current and exposure time in minutes.

Milliampere-seconds (mAs): The product of the x-ray tube operating current and exposure time in seconds.

Occupancy factor (T): The factor by which the workload should be multiplied to correct for the degree of occupancy (by any one person) of the area in question while the source is in the “ON” condition and emitting radiation.

Occupational exposure: Exposures to individuals that are incurred in the workplace as a result of situations that can reasonably be regarded as being the responsibility of management (exposures associated with medical diagnosis or treatment for the individual are excluded).

Occupied area: Any room or other space, indoors or outdoors, that is likely to be occupied by any person, either regularly or periodically during the course of the person’s work, habitation or recreation and in which an ionizing radiation field exists because of radiation sources in the vicinity.

Operating potential: The potential difference between the anode and cathode of an x-ray tube.

Optically-stimulated luminescent dosimeter: A dosimeter containing a crystalline solid for measuring radiation dose, plus filters (absorbers) to help characterize the types of radiation encountered. When irradiated with intense light, optically-stimulated luminescent crystals that have been exposed to ionizing radiation give off light proportional to the energy they received from the radiation. The intense illuminating light needs to be of a different wavelength than the emitted light.

Phantom: As used in this Report, for radiation protection purposes, a volume of tissue-equivalent material used to simulate the absorption and scattering characteristics of the patient's body or of a portion thereof.

Pitch (p): In computed tomography (CT), the ratio of the patient translation per gantry rotation to the nominal beam width for the CT scan.

Primary protective barrier: A barrier sufficient to attenuate the useful beam to the required degree.

Primary beam (useful beam): Radiation that passes through the window, aperture, cone or other collimating device of the source housing.

Primary radiation: In this Report, radiation emitted directly from the x-ray tube that is used for patient imaging.

Protective barrier: A barrier of radiation attenuating material(s) used to reduce radiation exposure.

Radiation protection survey: An evaluation of the radiation protection in and around an installation that includes radiation measurements, inspections, evaluations and recommendations.

Radiation weighting factor (wR): The factor by which the absorbed dose in a tissue or organ is modified to account for the type and energy of radiation in determining the probability of stochastic effects. For the x rays used in medical imaging, the radiation weighting factor is assigned the value of one.

Radiography: The production of images on film or other record by the action of x rays transmitted through the patient.

Roentgen (R): The special name for exposure, which is a specific quantity of ionization (charge) produced by the absorption of x- or gamma radiation energy in a specified mass of air under standard conditions. 1 R = 2.58 × 10–4 C kg –1 (coulombs per kilogram).

Scattered radiation: Radiation that, during interaction with matter, is changed in direction and the change is usually accompanied by a decrease in energy. For purposes of radiation protection in medical x-ray imaging, scattered radiation is assumed to come primarily from interactions of primary radiation with tissues of the patient.

Secondary protective barrier: A barrier sufficient to attenuate scattered and leakage radiations to the required degree.

Secondary radiation: The sum of leakage and scattered radiations.

shielding design goals (P): Practical values, for a single medical x-ray imaging source or set of sources, that are evaluated at a reference point beyond a protective barrier. When used in conjunction with the conservatively safe assumptions recommended in this Report, the shielding design goals will ensure that the respective annual values for effective dose recommended in this Report for controlled and uncontrolled areas are not exceeded. For low linear-energy transfer radiation, the quantity air kerma is used. P can be expressed as a weekly or annual value (e.g., mGy week–1 or mGy y –1 air kerma), but is most often expressed as weekly values since the workload for a medical x-ray imaging source has traditionally utilized a weekly format. sievert (Sv): The special name for the SI unit of equivalent dose (HT) and effective dose (E). 1 Sv = 1 J kg–1.

Source: In this Report, the target (i.e., the focal spot) of the x-ray tube. target: The part of an x-ray tube anode assembly impacted by the electron beam to produce the useful x-ray beam.

Tissue weighting factor (w_T): The factor by which the equivalent dose in tissue or organ T is weighted, and which represents the relative contribution of that organ or tissue to the total detriment due to stochastic effects resulting from uniform irradiation of the whole body.

Uncontrolled (non-controlled) area: Any space not meeting the definition of controlled area.

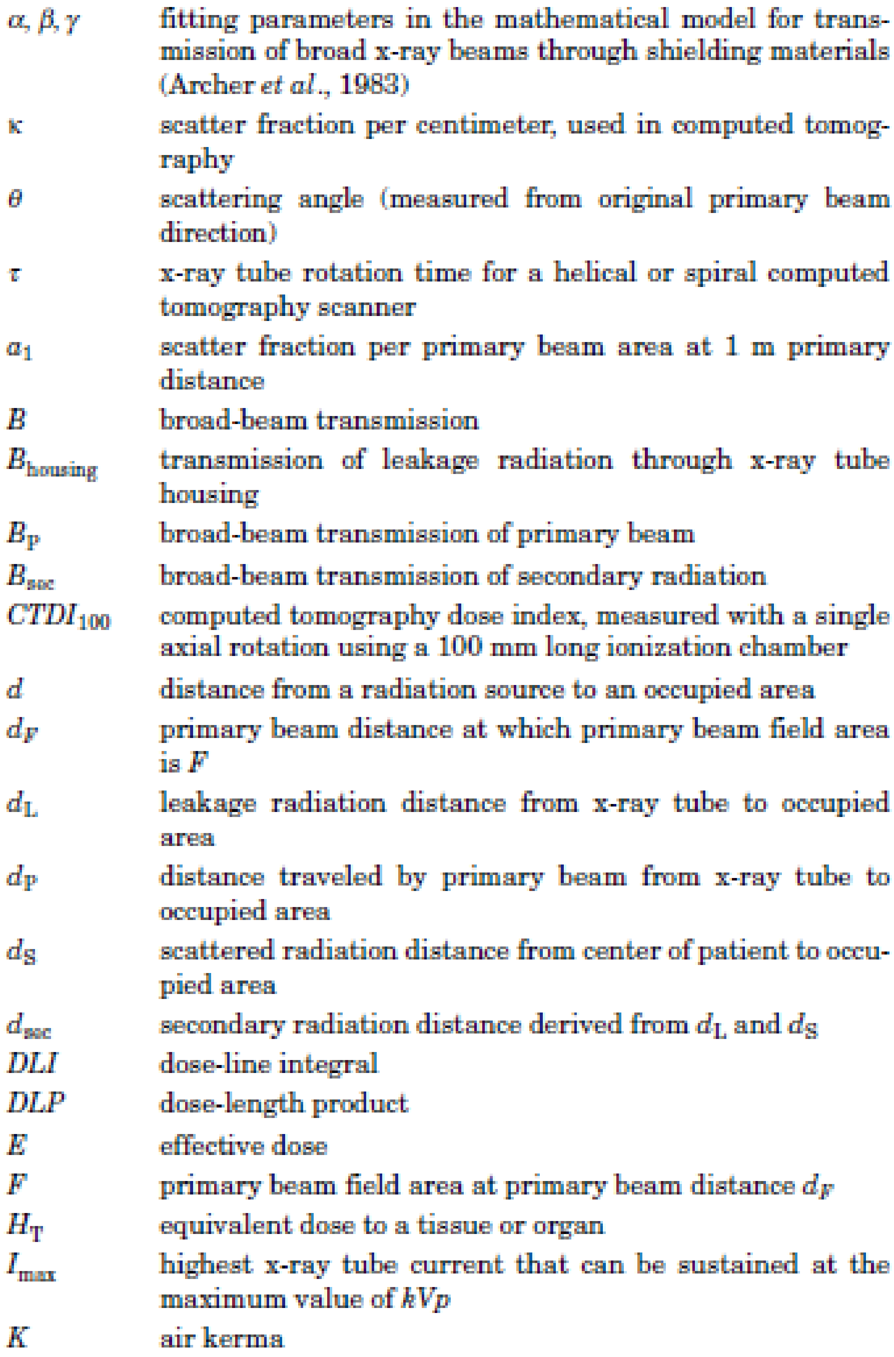
Use factor (U): Fraction of the workload during which the useful beam is directed at the barrier under consideration.

Workload (W): The degree of use of an x-ray source. In this Report, the workload of a medical imaging x-ray tube is the time integral of the x-ray tube current and is given in units of milliampere-minutes (mA min). The total workload per week (Wtot) is the total workload over a specified period and in this Report is expressed in mA min week–1.

X-rays: Electromagnetic radiation typically produced by high-energy electrons impinging on a metal target.

X-ray tube housing: An enclosure constructed so that leakage radiation does not exceed specified limits. In this Report, an x-ray tube housing so constructed that the leakage radiation measured at a distance of 1 m from the source cannot exceed 0.876 mGy air kerma (100 mR exposure) in 1 h when the x-ray tube is operated at its maximum continuous rated current for the maximum rated tube potential.

Symbols



α, β, γ	fitting parameters in the mathematical model for transmission of broad x-ray beams through shielding materials (Archer *et al.*, 1983)
κ	scatter fraction per centimeter, used in computed tomography
θ	scattering angle (measured from original primary beam direction)
τ	x-ray tube rotation time for a helical or spiral computed tomography scanner
a_1	scatter fraction per primary beam area at 1 m primary distance
B	broad-beam transmission
B_{housing}	transmission of leakage radiation through x-ray tube housing
B_{P}	broad-beam transmission of primary beam
B_{sec}	broad-beam transmission of secondary radiation
$CTDI_{100}$	computed tomography dose index, measured with a single axial rotation using a 100 mm long ionization chamber
d	distance from a radiation source to an occupied area
d_F	primary beam distance at which primary beam field area is F
d_{L}	leakage radiation distance from x-ray tube to occupied area
d_{P}	distance traveled by primary beam from x-ray tube to occupied area
d_{S}	scattered radiation distance from center of patient to occupied area
d_{sec}	secondary radiation distance derived from d_{L} and d_{S}
DLI	dose-line integral
DLP	dose-length product
E	effective dose
F	primary beam field area at primary beam distance d_F
H_{T}	equivalent dose to a tissue or organ
I_{max}	highest x-ray tube current that can be sustained at the maximum value of kVp
K	air kerma

K_{L}	air kerma in an occupied area due to leakage radiation
$\dot{K}_{L}$	leakage air-kerma rate at 1 m from source
$\dot{K}_{lim}$	maximum permitted leakage air-kerma rate at 1 m when x-ray tube is operated at its maximum leakage radiation technique factors for kVp and mA
K_{P}	air kerma in an occupied area due to primary radiation
$K_{P}(0)$	unshielded primary air kerma at d_{P} due to N patients examined per week
K_{P}^{1}	unshielded primary air kerma per patient at 1 m calculated for a workload distribution of total workload per patient W_{norm}
K_{S}	air kerma in an occupied area due to scattered radiation
K_{sec}	air kerma in an occupied area due to total secondary radiations
$K_{sec}(0)$	unshielded secondary air kerma at d_{sec} due to N patients examined per week
K_{sec}^{1}	unshielded secondary air kerma per patient at 1 m calculated for a workload distribution of total workload per patient W_{norm}
K_{W}^{1}	air kerma at 1 m per unit workload due to primary beam
kVp	x-ray tube operating potential in kilovolt peak
kVp_{max}	maximum x-ray tube operating potential (maximum kVp) at which continuous operation is possible
L	length of patient scanned (or scan length) in computed tomography examination
mAs	current-time product in milliampere (mA) second (s)
N	number of patients per week undergoing x-ray procedures in a given x-ray room
${}_{n}CTDI_{100}$	$CTDI_{100}$ normalized per milliampere second
N_{R}	total number of rotations in an axial or helical computed tomography scan series
p	pitch, the ratio of the patient translation per gantry rotation to the nominal beam width for a computed tomography scan
P	shielding design goal (mGy week^{-1} air kerma)
T	occupancy factor
T_{b}	nominal width of a computed tomography x-ray fan beam along the axis of rotation
U	use factor
W	x-ray tube workload (mA min)

W_{norm}	average workload per patient (mA min patient^{-1}) (Simpkin, 1996a)
w_R	radiation weighting factor
W_{site}	site-specific average workload per patient at the installation under evaluation (mA min patient^{-1})
w_T	tissue weighting factor
W_{tot}	total workload per week (mA min week^{-1})
$x_{1/2}$	half-value layer (HVL) for an x-ray beam
$x_{barrier}$	thickness of barrier material that decreases air kerma in occupied area to the appropriate shielding design goal
x_{est}	estimated barrier thickness that decreases the sum of transmitted air kerma contributions to P/T; used in the iteration method of determining the barrier thickness
x_{pre}	thickness of "preshielding" material that intercepts the primary beam
z	distance along the axis of rotation of a computed tomography scanner