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A guide to the use of lead for radiation shielding

FOREWORD

Lead has long been recognized as a highly effective material in providing protection from various sources of radiation, and as such, has become a standard in the design of radiation protection systems.

Lead for Radiation Protection has been written to familiarize architects, designers, specifiers, users and engineering students with the radiation shielding properties, design, and fabrication information on lead and lead based products. No shielding systems should be undertaken without consulting with a qualified radiation consultant or certified radiation physicist.

The scope of this publication is limited to the application of lead as part of a protective shield or barrier imposed between the energy source and the person or object to be protected.

Section I provides background information on the sources and characteristics of radiation, and shielding from radiation. Section II provides some basic information on lead as a shield material, and its comparison to other materials; while Section III outlines some of the basic applications of lead for radiation shielding.

The information provided in Section IV is based upon the currently used construction materials and techniques of applying lead as part of a radiation shielding system. The illustrated methods of lead constructions are intended as a guide only. Again the services of a qualified radiologist should be obtained before the design of any shielding system is considered.

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A GUIDE TO THE USE OF LEAD FOR RADIATION SHIELDING

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RADIATION SHIELDING

Introduction

Radiation is energy propagated through space, and, in the context considered here, encompasses two kinds of phenomena: 1) electromagnetic waves, e.g., x-rays, gamma-rays, and 2) particle emulsions, e.g., alpha and beta-particles from a radioactive substance or neutrons from a nuclear reactor.

The universe is flooded with radiation of various energy levels, but the earth's atmosphere shields us from most of the harmful radiation. Without such shielding, human life would not be possible as we know it today. With the advent of man's ability to directly convert matter into energy, in what we call the atomic or nuclear process, and the increased usage of machine produced forms of radiation and radioactive isotopes, we have introduced the possibility of excessive radioactivity into our immediate environment.

Sources of Radiation

A disturbance of the internal structure of the atom, such as occurs in the production of x-rays or in nuclear fission, is followed by an action toward stability within the atom. This action may be accompanied by the emission of particles, called particle radiation, and/or by electromagnetic radiation. Thus the harnessing of atomic energy and increased industrial and medical use of x-rays have brought about the problem of controlling the powerful radiation emitted.

Types and Characteristics of Radiation

The various types of radiation - alpha, beta, gamma, neutron, and x-rays - differ chiefly in their ability to penetrate and ionize matter. It is the latter characteristic which injures living tissue and which must be guarded against. The alpha particle is a positively charged helium nucleus which is completely stopped by 3 or 4 inches of air or a piece of paper. Beta particles are high speed electrons of varying energies. In general, they produce less ionization in matter than alpha particles but are more penetrating. Most common substances such as 1 inch of wood will completely absorb beta rays.

Gamma radiation is emitted in all directions from its source as an expanding spherical front of energy, with great powers of penetration. High energy gamma radiation will not be wholly blocked by a foot of lead, while lower energy levels can be safely blocked by 3/16 inch or less of lead.

Neutrons emitted by the atomic pile are uncharged particles which will also ionize certain material indirectly. Neutrons are classified according to their energy levels as very fast, fast, slow and thermal, the last having the lowest energy level.

X-ray's are produced by accelerating electrons in a high voltage field to impact a target material, causing the emission of radiation in all directions. Shielding against x-rays can be designed knowing the accelerating voltage.

The comparative energy of a particular form of radiation can be depicted on the electromagnetic spectrum. The most familiar form of radiation, that of visible light, falls roughly at the center of the scale. Radio waves occupy the lower energy end of the scale. Gamma and neutron radiation lie near the higher energy extreme, with energies greater than x-ray and just below that of cosmic rays.

Although there are many forms and types of radiation which may be injurious to health, the primary ones of concern are gamma rays, x-rays, and neutron particles. It is widely accepted that if adequate shielding is provided for these forms, the effects from the others can be considered negligible. This protection can be accomplished by barrier shielding with a material that will induce sufficient attenuation of the radiation intensity caused by a particular installation to a tolerable level.

Characteristics of Shielding

Radiation shielding is considered in two general classifications of thermal and biological, which are defined as:

Thermal Shielding is used to dissipate excessive heat from high absorption of radiation energy, and

Biological Shielding is needed to reduce radiation, e.g., gamma or neutron radiation, to a safe level for humans and animals.

In providing a system of biological shielding, the danger of exposure to radiation is classified into two separate categories: internal and external.

The former is primarily a hygiene and medical problem, and does not involve shielding as such. External radiation comes from a source outside the human body, such as an x-ray tube, cyclotron, nuclear reactor, or radioactive materials such as radium. Protection against external radiation is fundamentally a question of providing a sufficient distance from the radiation source, limiting the time of exposure to the radiation, and imposing a protective shield between the source and the body to be protected. The design of a radiation protective shield will depend, in addition on such factors as the type and characteristics of the radiation source, type of installation, and the properties of the shield material.

Criteria for the Selection of A Shield Material

Theoretically, all materials could be used for radiation shielding if employed in a thickness sufficient to attenuate the radiation to safe limits; however, due to certain characteristics, discussed below, lead and concrete are among the most commonly used materials. The choice of the shield material is dependent upon many varied factors such as: final desired attenuated radiation levels, ease of heat dissipation, resistance to radiation damage, required thickness and weight, multiple use considerations (e.g., shield and/or structural), uniformity of shielding capability, permanence of shielding and availability. The following is a generalization of the more important criteria and the required properties of the shield material:

Attenuation

Neutrons The attenuation of neutrons is dependent upon the effective cross section of the shield, a measure of the probability that an incident neutron will undergo a nuclear reaction reducing the neutron's energy. Usually a hydrogen containing material such as water is used for thinness. During attenuation of incident radiation, it is important to recognize that secondary radiation, i.e., that produced by an irradiated shield material, can be emitted. For example gamma rays produced within a shield material by neutron absorption are a potential source of secondary radiation. Such phenomena require a shielding material that will not become radioactive.

Gamma Rays and X-Rays Their attenuation is dependent upon the density of the shielding material; it can be shown that a dense shield material with a higher atomic number is a better attenuator of x-rays.

Thermal - Heat Removal

As it is often necessary to remove heat from the inner layer of the shield, the shield material should have good heat conductivity.

Radiation Damage Resistance

It is an essential requirement that the radiation which is attenuated does not have a significantly deleterious effect on the mechanical or physical properties of the shield material.

In designing a radiation shielding system, a balance should be made between the cost, availability, and ease of fabrication of the shield material and the effect of the shield size, weight and configuration on the total installation. The designer should also be aware of the material's transportation costs, wastage and its scrap value, and the flexibility of the materials to be used in various portions of the installation.

Properties of Lead for Radiation Shielding

The properties of lead which make it an excellent shielding material are its density, high atomic number, high level of stability, ease of fabrication, high degree of flexibility in application, and its availability. The following is a discussion of these properties as related to the criteria of selecting a shield material.

Attenuation of Neutron particles

As discussed above, in shielding against neutron particles it is necessary to provide a protective shield that will attenuate both the neutron particles and the secondary gamma radiation.

When applied as part of a neutron particle shielding system, lead has an extremely low level of neutron absorption and hence practically no secondary gamma radiation.

If the shield material has a high rate of neutron capture, it will in time become radioactive, sharply reducing its effectiveness as a shield material.

Lead itself cannot become radioactive under bombardment by neutrons. Therefore lead shielding, even after long periods of neutron exposure, emits only insignificant amounts of radiation due to activation.

Attenuation of Gamma Radiation and X-Ray

In the design of a protective shielding system, one of the key factors is preventing the penetration of the rays. As stated earlier, the property of the shield material of the most significance in preventing this penetration is its density. Lead enjoys the advantage of being the densest of any commonly available material. Where space is at a premium and radiation protection is important lead is often prescribed. It is recognized that lead is not the most dense element (i.e., tantalum, tungsten, and thorium are higher on the density scale), but lead is readily available, easily fabricated and the lowest cost of the higher density materials.

Other Factors

Being a metal, lead has an advantage over various aggregate materials such as concrete; being more uniform in density throughout. In addition, because commonly used forms of lead exhibit smooth surfaces lead is less likely to become contaminated with dirt or other material which, in turn, may become radioactive.

Regarding its re-use, lead contains only small quantities of other elements which can be adversely effected by exposure to radiation, and therefore, it is immediately available for re-use, adaptation, or for sale as scrap. Currently, the price of scrap lead may be as high as 80% of the prevailing price of virgin lead.

In addition to the significant physical properties, lead's versatility, ease of fabrication, and availability in a variety of forms lend itself to a great many installation applications.

To meet the varied applications and installations of radiation shielding systems, lead can be fabricated easily into countless designs with weights varying anywhere from ounces to many tons.

Comparison of Shield Materials

Lead is heavier than roughly 80 per cent of the periodic table. It could be assumed therefore that shield constructions making use of lead will tend to be heavier than constructions making use of lighter elements. This concept may be true in static shielding structures where weight and volume restrictions are of lesser importance, and concrete and water are often used. In mobile shielding systems however, where weight and volume reductions are at a premium, the selection of the lighter materials would have quite the opposite effect on reducing radiation to that intended.

The remaining elements which are heavier than lead could contribute to even greater weight savings, although the use of such materials as depleted uranium and tungsten is usually prohibitive in cost.

The traditional concept of lead being heavy must be re-evaluated in terms of providing a highly effective shield structure, with the lowest volume and weight of the commonly available material.

Choice of Shield Materials

Using a method of computation from one of the many excellent radiological handbooks, it can be readily determined that lead is an excellent choice as a material for construction of a radiation protective shield barrier. One such source is NCRP Report No. 34 - Medical X-Ray and Gamma-Ray Protection for Energies up to 10 MeV - Structural Shielding Design and Evaluation. This publication is available from National Council on Radiation Protection and Measurements, Washington, D.C. 20008. Although other building materials can be used for either a new or existing structure, their weight and volume will be far greater than that of the required thickness of lead necessary to provide the required level of protection.

The following section outlines the various forms of lead available for radiation shielding applications, which are summarized in Table 1.

When lead is specified for a radiation shielding application, regardless of its form or shape, the purity of the selected grade is related to the nature of the radiation source. In some instances the common impurities that might be found in lead could become secondary radiation emitters.

Forms of Lead Available for Radiation Shielding Sheet, Plates and Foil

Normal sheet lead is available in thicknesses from 0.002 inches, up to many inches. Any thickness under

Table I FORMS OF LEAD USED FOR RADIATION SHIELDING

FORM	USE
Lead Sheet, Slab and Plate	Permanent shield installations
Lead Shot	Where solid lead is impractical, due to location, shape, and accessibility
Lead Wool	Filling deep cracks in a radiation barrier
Lead Epoxy	In-the-field crack filling patching
Lead Putty	Non-hardening, temporary seal or patch
Lead Brick	Convenient, easily handled; may be moved and re-used
Lead Pipe	Shielding of radioactive liquids
Lead-clad Tubing	Shielding of radioactive liquids
Lead-lined/Lead-clad Pipe	Shielding of radioactive liquids
Lead sleeves	Shielding of duct and pipes carrying radioactive materials
Lead Powder	Dispersed in rubber or plastic for flexible shielding; also mixed with concrete and asbestos cement
Lead Glass	Transparent Shielding
Lead-Polyethylene-Boron	Combined gamma, neutron, and thermal neutron barrier material

1/32 inches is referred to as foil, and above 1/2 inch as plate. Table 2 lists the commercially available lead sheets. This form of lead shielding is extensively used in hospitals, laboratories and industrial facilities for installations that often encompass a large area. Lead sheet requires adequate support when applied to any vertical surface.

Lead Laminates

Sheet lead that is bonded to other materials such as wood, steel, wallboard, plastic, and aluminum for the manufacture of panels, doors, cabinets, portable screens, etc., is known as lead laminate. It is frequently used because of its self-supporting nature and greater ease in erecting and handling. Lead laminates can be produced in any practical size to comply with the user's requirements. They are especially suitable for the erection of rooms or sections in industrial plants or other buildings as they can be easily assembled by normal construction methods.

Table 2 - Commercial lead sheets

Thickness Inches	Millimeter equivalent	Weight in Pounds for a 1 Square Foot Section	
		Nominal Weight	Actual Weight
1/64	0.40	1	0.92
3/128	0.60	1 1/2	1.38
1/32	0.79	2	1.85
5/128	1.00	2 1/2	2.31
3/64	1.19	3	2.76
7/128	1.39	3 1/2	3.22
—	1.50	—	3.48
1/16	1.58	4	3.69
5/64	1.98	5	4.60
3/32	2.38	6	5.53
—	2.5	—	5.80
—	3.0	—	6.98
1/8	3.17	8	7.38
5/32	3.97	10	9.22
3/16	4.76	12	11.06
7/32	5.55	14	12.9
1/4	6.35	16	14.75
1/3	8.47	20	19.66
2/5	10.76	24	23.60
1/2	12.70	30	29.50
2/3	16.93	40	39.33
1	25.40	60	59.00

Notes:

1. The density of commercially rolled lead is 11.36 g/cm³.
2. The commercial tolerances are +−0.005 inches for lead up to 7/128 and +−1/32 for heavier sheets.

Lead Plastic Composites

With minor variations, lead plastic composites are available in the following forms:

Sheet Material A lead powder and plastic mixture core between two sheets of plastic. This material is suitable for protective aprons and is available in a variety of thicknesses for various energy levels.

Solid Material A mixture of lead powder dispersed in polyethylene, the proportions of which are variable within very wide limits according to the application. A typical proportion is 5 parts lead to 1 part polyethylene by weight. Material is suitable for small and complicated components in nuclear power equipment, where shielding may be required for gamma radiation as well as neutron particles.

The material can be accurately machined and individual parts may be welded by using filler rods of the same material.

Bulk Material A mixture of lead powder and a thermo-setting resin containing approximately 94% by weight of lead in the finished component. The material is supplied in an unfinished form and can be used in the manufacture of castings or mouldings where a relatively high degree of protection with considerable mechanical strength and hardness is required.

Lead Bricks

Lead bricks are produced in a wide range of sizes in the plain and the interlocking styles, and are normally produced from 4 per cent antimonial lead alloy, which is harder than pure lead, and more resistant to damage. Lead bricks are also more resistant to damage than, e.g., concrete.

The unique design of the interlocking type permits mating surfaces to interlock, thus preventing the leakage of radiation. Any rays that penetrate the first angle of the interlocking joint will actually strike an equal or greater depth of lead than the straight thickness of the wall.

Lead bricks are manufactured to extremely accurate tolerances, and as a result of recent production improvements, can be obtained with the almost complete absence of porosity.

The smooth surfaces of lead bricks allow for easier decontamination of the shield from radioactive dust.

Typical standard sizes of interlocking brick are 3 to 13 inches long, 3 to 5 inches thick, and 2 inches high. The standard size of plain brick (non-interlocking) is usually 2 x 4 x 8 inches. However, both types are manufactured in an ample range of special sizes to meet any requirements.

Concrete or Cinder Block

Another form of space shielding construction is a concrete or cinder block with an unperforated sheet of lead anchored at its center. The two halves of the block are approximately 2" smaller in both directions than the sheet lead. Thus the sheet lead extends past the outer edges of the block on all sides. When a wall is constructed of these blocks the lead in each block overlaps that in all adjoining blocks by 1" providing a continuous lead lining.

Lead Shielded Doors and Door Frames

Lead laminated doors are available for both new and existing structures. The standard door is constructed utilizing a single layer of sheet lead in the center equal in thickness to that in the wall in which the door is to be installed. The sheet lead extends to the edges of the door. Solid wood cores on either side of the sheet lead are held together utilizing poured lead dowels 1 1/2" from all edges and 8" on center. Lead lined doors can be provided in any face veneer desired.

When designing the shield system for the door, it will also be necessary to plan for shielding continuity at the door frame. The method selected to shield the door frame will depend upon the method of wall shielding installed, that is whether the lead was applied to the wall surface or used internally in the wall during construction.

It is important to remember that the lead in the door frame must overlap the lead in the wall and be continuous on one side to the door stop surface to achieve effective shielding.

Lead Glass

To provide viewing of the patient in the x-ray room while providing protection to the operator, lead glass viewing windows can be furnished in the barrier. It is produced 1/4 inch thickness which is equivalent to 1.5 mm sheet lead.

Lead glass can be installed in multiple layers so as to provide a lead equivalency to the lead in the wall in which it is installed.

Lead-Filled Acrylic Sheet

Another material available for viewing windows in radiation barriers is a lead-filled acrylic sheet. Adding up to 30 per cent by weight of lead to acrylic resin does not affect the resins mechanical properties or transparency after long exposure to gamma radiation levels. The product can be easily fabricated with only slight modifications of the thermoforming and machining methods used for conventional acrylics.

APPLICATIONS OF LEAD FOR RADIATION SHIELDING SYSTEMS

X-Ray Protection

One of the most important events in modern physics occurred on December 28, 1895, when Wilhelm Conrad Roentgen submitted a paper outlining his discovery of what eventually came to be known as "x-rays". He had chosen the term x-ray because they were then of unknown origin, and "x" is a scientific symbol for the unknown.

Even though x-rays were known before the time of Roentgen, (in 1784 Ben Franklin had witnessed x-rays produced experimentally,) none had recognized any real significance in the production of this electrical phenomenon. Once the milestone marked by Roentgen had been passed, however, many came to grasp the significance of x-rays, among them Thomas Alva Edison who was one of the first to have intentionally produced an x-ray. He was also one of the first to broaden the scope of research and examine other means of using these rays, such as in fluoroscopy.

Not all of these discoveries were complete blessings however. Research in fluoroscopy, for example, led to an early case of radiation damage to one of Edison's assistants and the fluoroscopes themselves caused the removal of the skin from the hands of a good many purchasers. Predictions were being made that science would develop a means of photographing the contents of secret documents through letter boxes. This prompted one knowing wag to predict a potential market for lead mail boxes. It was a combination of these essentially unrelated items which spurred the research for means of protection against these rays. The research of other materials did little to inhibit the advancement of sheet lead as an effective means of protection and it was not long before lead was established as a standard against which other materials were measured.

Protection Against X-Rays Continuous x-rays are produced in commercial machines when a high energy electron is deflected in the coulomb field of a nucleus.

The x-rays produced are widely used both by the medical profession and by industry. These rays can cause physical damage to persons exposed to them so it is necessary to enclose or shield the x-ray generating units with a material which resists x-ray penetration. Since the impermeability of the shielding material is a function of its density, lead is usually the most economical material for such shielding applications.

A major factor in the design of a x-ray protective shield is the intensity of the rays, which is a function of the voltage impressed on the x-ray tube. It is customary therefore to use voltage as a primary guide in selecting the proper thickness of the shielding material. Lead is primarily used as radiation shield for

x-rays produced at potentials below 300 KV, whereas concrete is used above 300 KV, as well as for gamma beam installations.

Medical X-Ray The healing arts have benefitted immeasurably from the use of x-ray as a tool for diagnosis and therapy. In recent years the increased use of x-ray itself has become something of a hazard. Operating personnel, as well as occupants of nearby premises, may unknowingly be exposed to dangerous amounts of radiation unless adequate shielding is used. Since liability insurance usually covers only the patient, it does not protect the user of the equipment against injured parties outside his practice. The doctor's responsibility towards these occupants or personnel, therefore, become a major consideration when x-ray equipment is installed. *No shielding systems should be undertaken without consulting a qualified radiation consultant or certified radiation physicist.* In addition, effective liaison should be established with the office of radiation control of the municipality having jurisdiction over the installation, where a list of qualified radiation consultants can be obtained.

Industrial X-Ray Certain types of industrial x-ray machines intended for production line operation are self-contained in lead lined cabinets, interlocked to prevent access to the enclosure while the x-ray generating unit is energized. However, a general x-ray department usually requires the provision of a lead lined room. This type of installation of x-ray equipment is comparable to that used in hospitals and other medical facilities. Such a room must be carefully planned and constructed with lead lining of sufficient thickness to keep the exposure of persons in its vicinity below safe tolerance limits. The principal factor in determining this proper thickness of lead to be used is the intensity of the x-rays to be generated. However, consideration must also be given to such factors as cumulative time of operation, the distance of the operator and persons outside the room from the x-ray tube, and the generation of scattered or secondary radiation given off by objects in the path of the useful beam.

Portable Space Shielding Systems

With the increased usage of radioactive materials in medicine and industry, hospitals, factories and laboratories require a movable barrier for local applications which will effectively shield the operating personnel. Since these barriers may only be used for relatively short periods - perhaps for one simple operation - and then re-built for an entirely different purpose, it is important that the system can be handled by unskilled workers, with a minimum of mechanical assistance.

Flexibility of design is an important factor because of the frequent alterations. Therefore, the majority of the components of the system must be freely interchangeable. Those components which serve specific or special purposes should be as versatile as possible.

The efficiency of protection of a portable shield is largely dependent upon the accuracy of the design of the component parts, as well as the quality of manufacture of each of the parts. In addition, the components of the system should be limited in weight, and size, and not easily damaged by repeated handling.

The currently used portable shield materials containing lead are:

- Lead Bricks
- Leaded Glass, Sheet and Bricks
- Leaded Plastics
- Lead Clad Building Material
- Lead Laminated Panels
- Lead Shot
- Lead Sheet and Foil

The following sections provide some additional information on the more important lead shield materials.

In *lead brick* shield systems, most of the shield is built from standard interchangeable wall units, with special units available for the installation of tools and implements for remote handling.

Leaded glass bricks can also be made part of the system so that work being conducted may be viewed directly without any loss in overall shielding efficiency.

Mobile Lead Screen Lead sheet and various lead laminates may be used in some applications of portable shielding where the erection of a lead brick wall is not the most convenient method. Such specially designed shields are used in medical and industrial applications of radioactive isotopes.

A typical mobile shield would consist of an unpierced lead sheet, laminated with a resilient adhesive between two plywood panels and covered with a variety of surfaces, finishes, such as wood veneer, mylar or plastic. Usually the screen is provided with a metal trim on all edges, in addition to the normally supplied mobile mounts and casters.

If required, mobile lead screens can be furnished with a view window of lead glass of equal shielding capacity as the screen panel.

Lead Blankets In order to permit maintenance and inspection of a nuclear installation, it is necessary to provide a barrier that will reduce the gamma radiation to an acceptable level. Even though the reactor is not operating when a nuclear plant is shut down, a significant amount of gamma radiation remains in the components of the cooling system. One way to permit the maintenance personnel to reach the necessary

locations is by the use of a flexible lead blanket or pad that can be placed over the pipes and other sources of the gamma radiation. In addition to being flexible and rugged, the blankets must contain enough shielding material to be an effective gamma radiation barrier, while light enough to be easily carried.

Lead is unique for this application due to its high density. The flexible lead blankets are fabricated from a layer of leaded vinyl sheet sandwiched between two sheets of flexible plastic. Another form of a lead blanket is made from lead wool evenly distributed between two layers of material, which is then quilted.

Protective Clothing

Special clothing should be worn when there is a possibility of contamination with hazardous amounts of radionuclides. The degree of protection required is a function of the quantity, type, and nature of the radiation, as well as the design of the available facilities.

For low and medium level work, coveralls, caps, gloves and either special shoes or shoe covers are suggested.

For close or contact work with radioactive materials emitting radiation of low penetrating power, shielded clothing such as leather, eye protection or leaded gloves and aprons may be used to increase allowable exposure time. Leather and rubber are effective against most beta radiation, while fabrics loaded with a high atomic number material such as lead are used for shielding against scattered x-rays in fluoroscopy. At the higher energy levels, the great increase in weight and the loss in flexibility which would be necessary to shield against gamma rays rule out the use of shielded garments.

Gamma Ray Shielding in Laboratories

Values prepared by the National Bureau of Standards may be used to determine the required thicknesses for shielding from gamma ray sources in the laboratory. In practice such calculations should be made only under the direction of a qualified expert; the resulting installation may subsequently require measurements of actual radiation levels obtained.

DESIGN AND CONSTRUCTION

OF X-RAY PROTECTIVE SPACE SHIELDING SYSTEMS

Introduction

Commonly used building materials in walls, ceilings, and floors may provide an adequate level of x-ray protective shielding in a great many installations. When these materials do not furnish the necessary level of protection however, the protective barrier must be increased by either additional thickness of these materials, or by adding a suitable thickness of a shield material such as lead, concrete or steel.

In reviewing the previous section on shield materials, it is clearly evident that the use of lead in a protective shield installation will result in an effective, light-weight, low-volume attenuation barrier. These factors, combined with its versatility, makes lead an ideal choice for x-ray shielding applications.

There are a number of methods of applying lead for x-ray protection, including sheet lead, lead laminated to common building materials, lead brick, lead lined block, leaded glass and a variety of leaded vinyls.

It cannot be stressed too strongly that before a radiation protection shielding system is considered, contact should be made with the radiation control officer of the local municipality having jurisdiction, as well as a registered specialist in the field of radiological shielding.

Design Requirements

The primary factors to be considered in the design and construction of a x-ray protective space shielding system are:

- Energy of the radiation source, expressed in KV.
- Orientation and projected field size of the useful beam.
- Distance from source to point where protection is required.
- Size and location of openings in the barrier.
- Geometrical relationship between the source of radiation, openings, and the position of the person or object to be protected.
- Maximum allowable dose rate.
- Machine utilization factors and amount of leakage radiation.

The protective shield is classified as either a primary barrier for x-ray beam attenuation, or as a secondary barrier for shielding against leakage and scattered radiation. The barrier material thickness is based upon the above factors, but the mathematical computations to determine the required thickness can be found in radiological engineering publications and handbooks.

One such publication is the National Council on Radiation Protection and Measurements (NCRP) Report No. 49 entitled Structural Shielding Design and Evaluation for Medical Use of X-rays and Gamma Rays of Energies Up to 10 MeV.

An additional factor to consider in the design of a medical x-ray installation is that the occupancy factor in any area adjacent to the radiation source is generally zero for any space more than 7 feet above the floor. This is based on the fact that most individuals are less than seven feet tall, and therefore it is usually possible to reduce the shielding thickness above this height. However, consideration must be given to the height of the radiation source (must be below 7 feet) and the possibility of the radiation scattering from ceiling of the adjacent area toward the occupant, in order to provide sufficient shielding.

In reviewing these factors, a significant consideration unique to dental x-ray installations is the extreme flexibility of the useful beam orientation, and its effect on the shield thickness requirements. It is good engineering practice therefore, to apply the calculated maximum material thickness to both classes of protective barriers.

Construction of A Space Shielding System

The construction of an x-ray protective barrier shall be such that the radiation protection is not impaired by any area being left unshielded. Any openings in the protective barrier, whether nail, screw, or bolt holes, penetrations for pipes, ducts, conduit, electric service devices, or louvers, doors, windows, etc., must be so protected as not to impair the overall attenuation of the rays.

All larger openings, such as doors, observation windows, etc., should be located in the secondary barrier whenever possible (this is principally an economic decision, as shielding these openings frequently involves the use of more expensive materials, i.e., lead glass, lead lined doors, etc.).

The basic protective barrier involves the use of sheet lead for the protection of the general area (i.e., walls, ceilings, and floors). However, since sheet lead has very little inherent structural strength; most installations require that the sheet lead be supported in some fashion, or that the sheet lead be laminated to some more rigid building material.

Where lead is to be used in the shielding of new structures, careful consideration of the construction methods to be used will result in maximum space saving.

When a sheet lead lining is specified for a new structure, the installation is much simpler as many of the corners between surfaces can be shielded as they are built. However, the addition of sheet lead to an existing structure involves no significant design problems, except that special care is required at all corners, openings, and at any point of shield discontinuity. Therefore, the addition of lead rather than the common building materials presents no particular problem and will result in a considerable saving of the available floor space.

The use of lightweight partitions, where feasible, with the lead shielding built in, should always be considered. For this reason, lead laminates are eminently suitable for use in the erection of new structures, and may be used without any other material except a stud frame to produce shielded partition walls and ceilings. In such a situation it is often necessary to provide a lead mat under the partition so that excessive radiation is not scattered under it.

Advantage may also be taken of the different forms of laminate available to achieve a hygienic and pleasing finish without any additional treatment or decoration. To achieve the maximum all-round benefit, it is most important that the architect consult a certified radiation physicist or radiologist and the shielding installation contractor at the design stage. Only in this way will it be possible to incorporate the required shielding into the building at minimum cost and without unnecessary waste of valuable floor space.

Sheet Lead Lining

In the construction of a sheet lead lining for an x-ray protective shielding system, the support of the sheet lead is very important.

This needed support is accomplished in a variety of ways, and in such a manner as to prevent sag, cold flow, mechanical damage, and to maintain the continuity and integrity of the barrier. All of these methods are satisfactory and the choice of which may depend upon the type of construction and other installation conditions. Some of the more common methods of construction are described in the following section.

The sheet lead is positioned against the wall surface, or partition studs, with the longer dimension of the sheet running vertically. The width of the sheet should not exceed 48 in. for ease of handling, with all joints occurring over a vertical support. All joints should be lap joints with an overlap of 1/2 in., or twice the sheet thickness, whichever is greater.

It is recommended that the sheets be installed by continuous attaching along the upper edge of the supporting structure, supplemented by additional attaching points at intervals of not more than 30 inches in either direction. The top of the sheet should turn out at least 2 inches over the horizontal support.

At each joint and at 16 in. intervals, studs of either wood, steel angles or channels are placed running from floor to ceiling, and secured at both top and bottom. Additional securing at intermediate points is required, the spacing of which depends on the weight of the sheet lead, but in no case should this vertical spacing be greater than 4 ft. The lead sheet is secured by fastening through the lead to the supporting studs. The selected type of fastener should be used in conjunction with a hard washer for stress relieving at the point of concentration.

There are several methods of fastening the sheet lead to a wall surface, three of which are shown in Figure 2.

The screw-capping method of Figure 2-A requires a lead-patch burned to the sheet lead over each fastener. These patches should extend several inches in each direction beyond the point of fastening so that the rays striking at an angle cannot penetrate the fastener hole. Patches should be of the same thickness of lead as the sheets to eliminate any possibility of radiation leakage.

The lead plug method of Figure 2-B does not require the addition of lead patches.

An alternate method, Figure 2-C, to be considered is to employ boards attached horizontally across the studs. The lowest boards are applied first to a height of

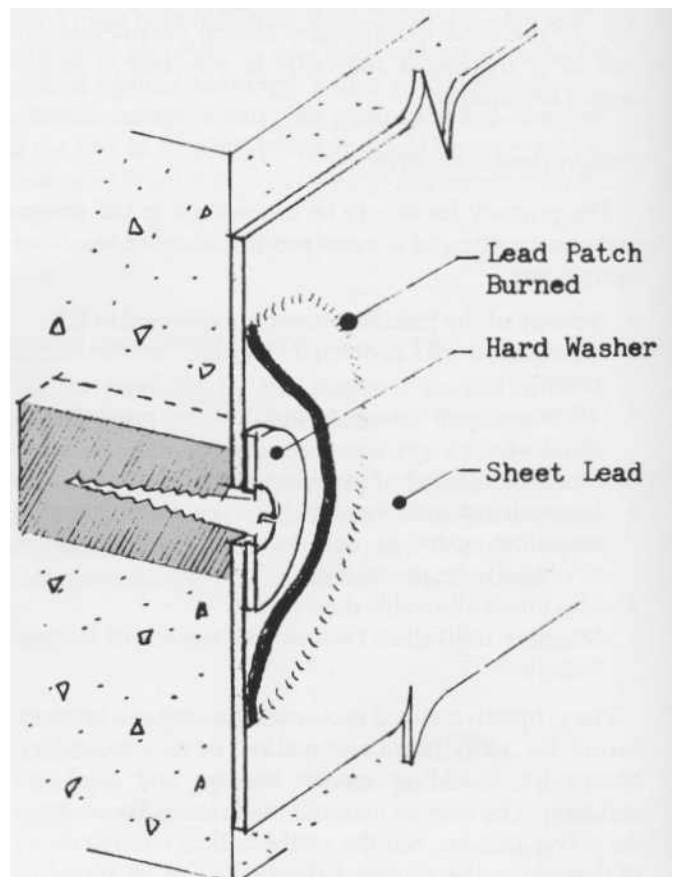


Figure 2-A Screw Capping Method

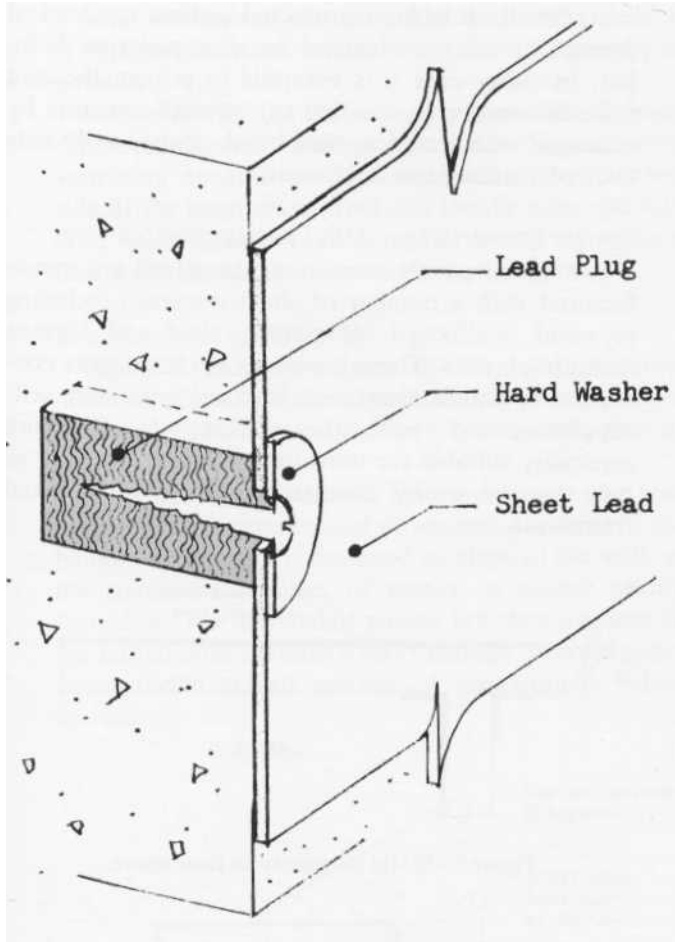


Figure 2-B Lead Plug Method

about 18 inches, and then covered with sheet lead, which is turned back over the upper edge of the top board, and then turned upward about 1 in. and fastened against the studs. Another 18 inch tier is applied in the same manner, fitted down over the set-back of the first sheet of lead, and covered with lead. The joints between the lead sheets are then burned or soldered.

For the joints at the floors and ceilings, the sheet should be extended around the corners, and burned or soldered to the sheet on the adjoining surface to form a continuous shield. The lead lining should extend around the door frame so that it will overlap the lead lining of door when the door is closed. In addition, the door frames within the protective barrier may require a lead threshold to complete the protective shielding.

All joints between the lead sheet lining and other materials must be constructed to prevent a reduction in the required level of protection.

Protection of the ceiling is most easily accomplished by laying lead, with overlapped joints, on the floor above or over a drop ceiling. Figure 3 shows the installation of sheet lead on the floor above. The ceiling lining should be extended sufficiently to prevent the passage of the rays through a gap existing between the

lead sheet on the walls and that applied for ceiling protection. This precaution is required as the rays travel in a straight line at an angle to the walls and ceiling.

Soldered or burned seams are permissible providing that the lead equivalent of the joint is not less than the barrier thickness required; and that the lap joint is one-half inch or twice the sheet thickness, whichever is greater.

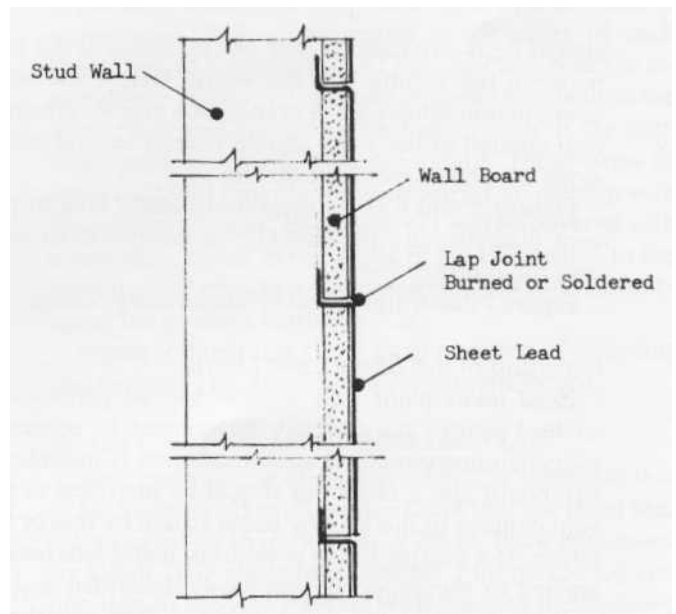
Sheet Lead Lining In Existing Structures

When installing a sheet lead lining in an existing structure, the following points should be especially noted.

When the floor is covered with sheet lead, it should extend up each wall a minimum of 2 in. with the wall shield overlapping it down to the floor level, as shown in Figure 4. It is not good practice to have the floor sheet lead overlapping the wall sheets.

Wall corners should be similarly treated, with one sheet extending around the corner for a minimum of 2 in. and underneath the sheet ending at the corner. This practice will reduce the possibility of the top sheet being accidentally raised, and the Shield effectiveness reduced.

The installation of sheet lead to an existing ceiling requires greater care to prevent a discontinuity of shield. In normal construction practices, the sheet lead is laid on the floor above. In existing buildings this will



**Figure 2-C
Horizontal Boarding Method**

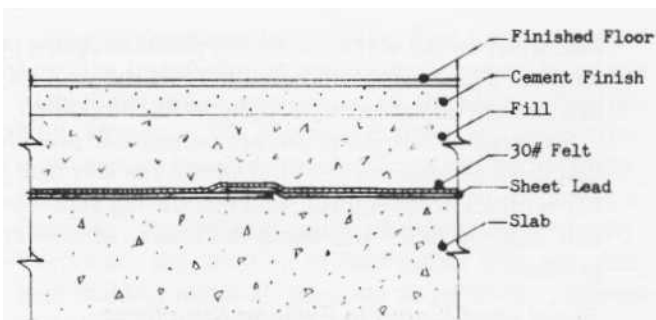


Figure 3
Sheet lead on floor covered with building paper and concrete.

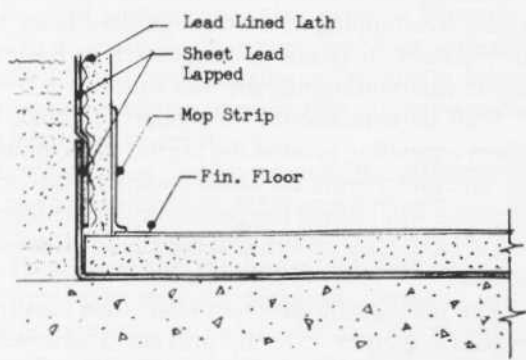


Figure 4
Floor to Wall shield continuity.

almost certainly cause a lack of continuity at the joint between the ceiling and the walls. Unless the room construction allows for a continuous shield, the sheet lead applied to the walls should extend several inches along the underside of the ceiling.

Figures 5 and 6 show diagrammatically how to prevent discontinuity of shielding in floor-over or adjacent room protection.

Figure 7 illustrates a lead insulated hung ceiling.

Finishing of the Sheet Lead Lining

Lead takes paint well without special preparation, so lead linings may simply be painted to present a pleasing appearance. If such treatment is intended, a baseboard and a chair rail should be provided to prevent damage to the lead by being struck by feet or furniture. If a plaster finish is desired, metal lath may be applied to the supports previously described and the wall plastered in the usual manner. Wall board may also be applied to these supports. Wood floors to be laid over lead linings either in the x-ray room or in rooms overhead should be laid on floating sleepers, care being taken that no nails penetrate the lead. Cement floors may also be laid over lead linings but if the lead is left exposed without immediately pouring the

concrete, it should be protected against mechanical damage by a layer of heavy building paper or 30-lb. felt. In either case it is essential to protect the lead from the corrosive reaction of "green" concrete by coating it with a cold applied brush coat 12 to 15 mils thick of a bituminous compound.

Barrier Construction With Lead Laminates

Laminated panels containing sheet lead are manufactured with a number of sheet materials including plywood, wallboard, aluminum, steel and various forms of plastics. These laminates are often more convenient to handle than sheet lead since they are self-supporting and require fewer fasteners. They are especially suitable for temporary barrier structures as they can be easily constructed on a simple stud framework.

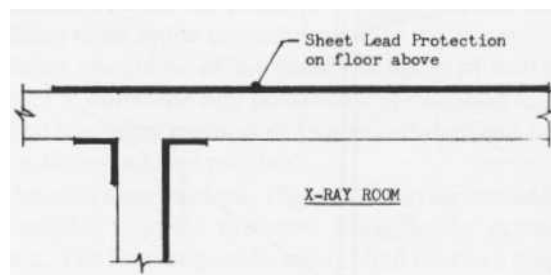


Figure 5 - Shield continuity on floor above.

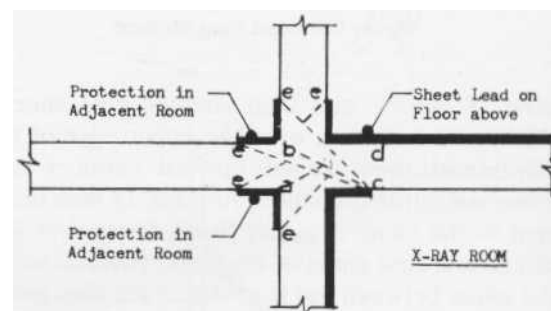


Figure 6 - Shield continuity for adjacent rooms.

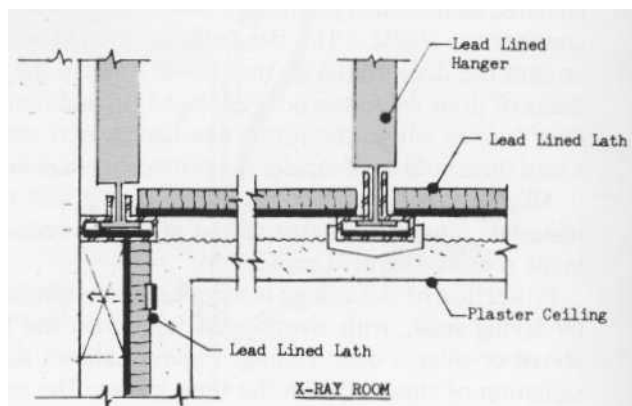


Figure 7 - Lead insulated hung ceiling.

In all methods of installation of laminated panels, it is important that the laminates be butted as closely as possible.

It should be noted that a variety of surface finishes can be provided as an integral part of the lamination by veneering decorative sheet materials to the finished side of the lamination. This can also be accomplished after installation by adhering a variety of surface finishes to the laminated panels.

Lead Laminated Plywood

Figure 8 illustrates three of the more common methods of installing lead laminated plywood panels to ensure continuity of protection at joints and points of fastening.

In Figure 8A, a batten is fastened on top of a lead strip, which is then turned up around the sides of the batten. The batten is fastened to plugs in the wall, at the minimum number of points to ensure secure fastening. The laminated panels are then secured to the batten with fasteners short enough to avoid penetrating the sheet lead, and spaced apart from the batten fasteners.

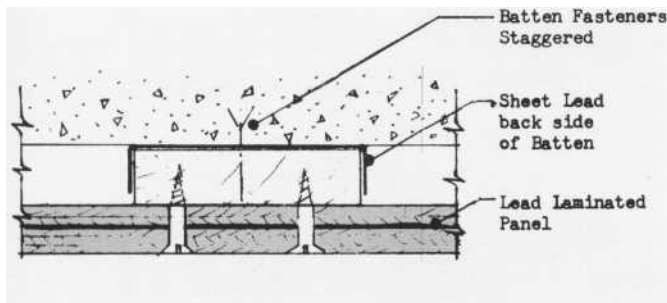


Figure 8-A

In Figure 8B, the laminated panels are directly fastened to plugs in the wall, with the joints and fasteners covered by a batten, made from the laminate material, which is glued into place.

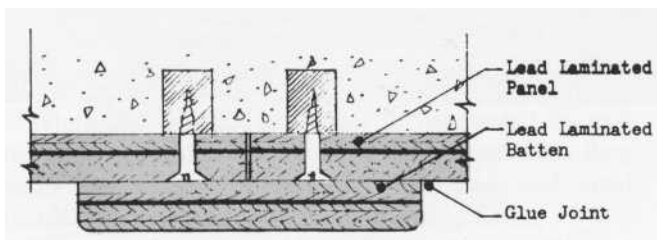


Figure 8-B

Figure 8C, illustrates a third method where a wooden batten is placed over the joints and fasteners, and is then fastened through the laminated panels into plugs in the wall. The wooden batten is then covered with a strip of sheet lead, which is fastened along its edges to complete the shielding.

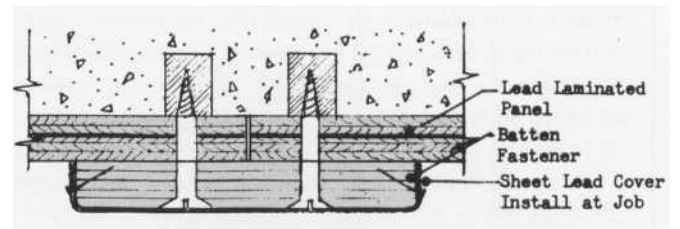


Figure 8-C

Lead Laminated Gypsum Wallboard

Lead laminated gypsum wallboard consists of a single unpierced sheet of lead laminated to either 1/2 in. or 5/8 in. thick wallboard. The bonding is accomplished with a continuous layer of mastic adhesive.

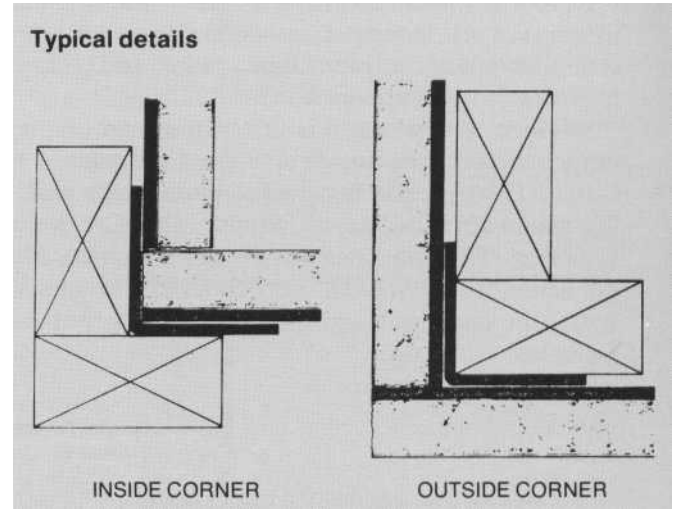
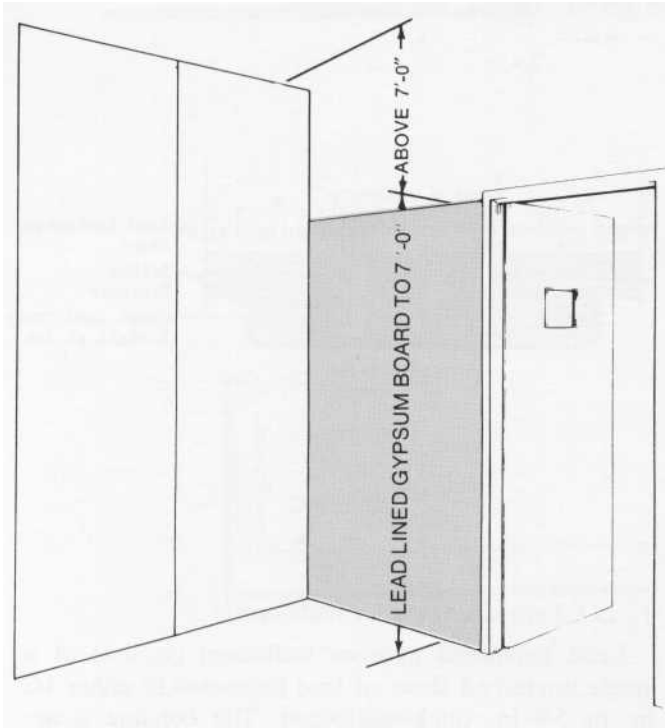
The lead laminated wallboard should be fastened at a minimum of 8 in. on center at the edges of each sheet, and at a minimum of 12 in. on centers at the intermediate studs. A 2 in. wide strip of sheet lead of the same thickness should be applied to each of the joint studs prior to installing the wallboard. These strips of sheet lead will provide the necessary 1 in. overlap with the adjoining sheet. Each fastener will be covered with a lead disc, equal in thickness to lead laminated to the wallboard to eliminate the possibility of radiation leakage at the point of fastening.

Figure 9 illustrates the typical methods of installing and fastening lead laminated gypsum wallboard.

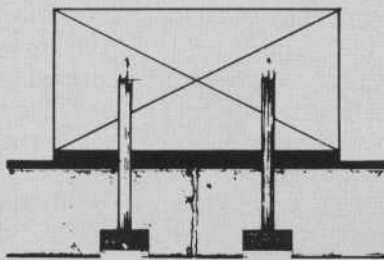
Barrier Construction with Lead-Lined Lath.

The construction of lead-lined lath is similar to that of lead laminated wallboard, except that the sheet lead is laminated to 16 in. x 48 in. x 3/8 in. thick perforated rock lath. The sheet lead extends 1 in. on the top and one side to provide overlap with the lead on adjoining sheets.

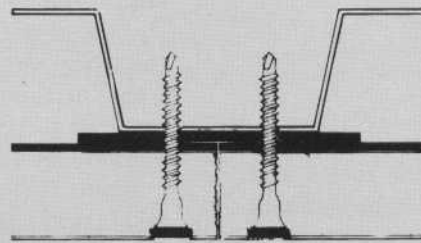
The lead lath should be installed with staggered vertical joints on either studs or furring strips with a minimum of 12 fasteners per sheet. A finish coat of plaster may then be applied to the lath by normal construction methods.



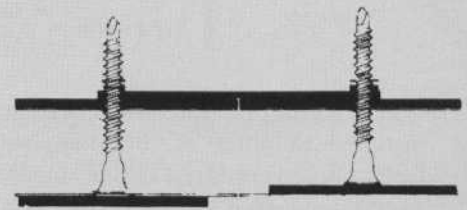
Fastening methods



LEAD NAIL
Wood installation only

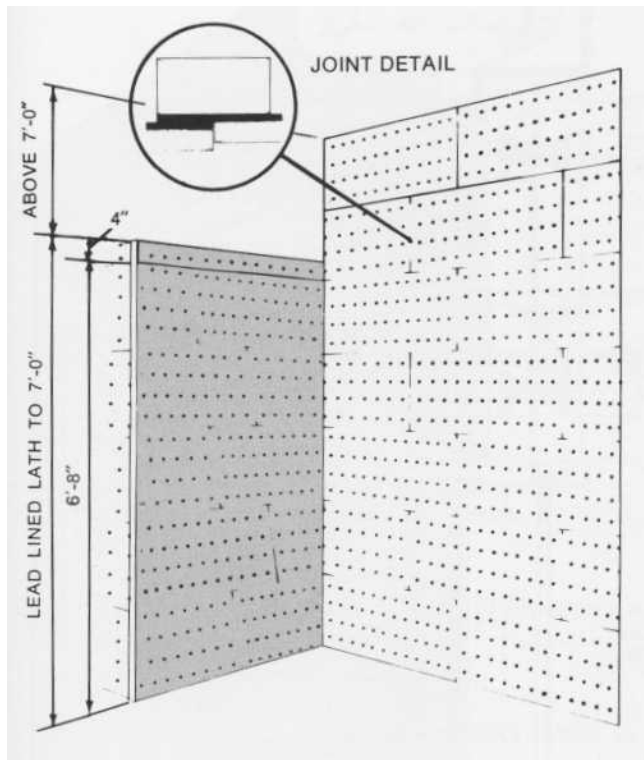


5/16" LEAD DISC
Used for installing 1/16" thick lead or less



1" DIAMETER LEAD DISC
Cemented on surface for multiple layer installation
—recessed for single layer

Figure 9
Typical Methods of Installing and Fastening Lead Laminated Gypsum Wallboard.



Lath

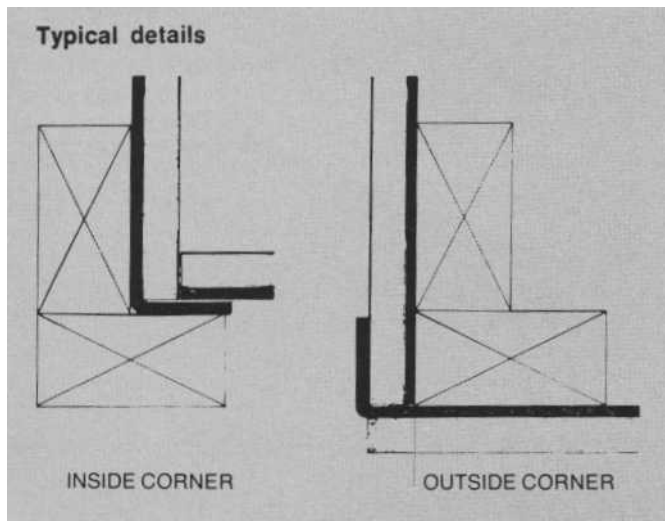


Figure 10
Typical Method of Installing Lead Lined Lath.

Radiation Protection at Barrier Openings

When the protective barrier is penetrated by any opening, special problems are encountered since they cannot be simply covered with sheet lead, and could result in discontinuity of the shielding systems.

The complicated problem of reflection of the ray should be solved in the early design stages and the resulting designs incorporated into the construction. For

ducts it could involve a lead shielded baffle, a leaded cowl or shielding within the mouth of the ductwork. A particular problem area is where the duct has a bend immediately behind the wall: Door openings may require a lead threshold, and, as a minimum, door buck shielding is required.

The remaining portion of this section deals with the unique problems of each specific type of barrier opening.

Door and Door Frame Shielding

The amount of shielding to be added to a door is equal to the shielding required by the wall in which it is installed. Due to the increased weight of a heavily shielded door, special consideration must be given to the hinging and supporting arrangements. Figure 11 illustrates the construction of a lead lined door.

Special consideration should also be given to maintaining shielding continuity at the door frame. How this is achieved will depend on whether the wall shielding lead is applied to the wall surface or used internally during construction. In all cases it will be necessary to ensure some form of overlap of the lead when the door is closed. A method of shielding a door buck is illustrated in Figure 12.

Where existing structures are being shielded, the lead shielding will normally be on or near the surface of the walls, and this will simplify door shielding. This will often be the case in new structures as well, but is less important since the positioning of the lead sheet around the door frame can be carried out before the frame is installed.

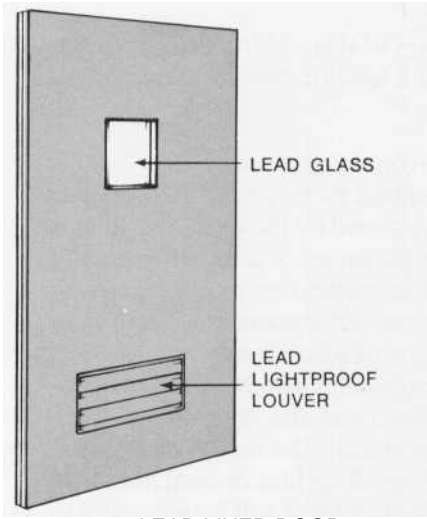
It is important to remember that both the face of the door frame and the door stop must be covered with lead to achieve efficient shielding.

Where sliding doors are employed, they should be made as close fitting as possible, with the lead or lead laminate applied to the side of the door closest to the wall shielding. In addition, an adequate overlap must be allowed, and the door should run in a lead-backed channel to prevent leakage underneath.

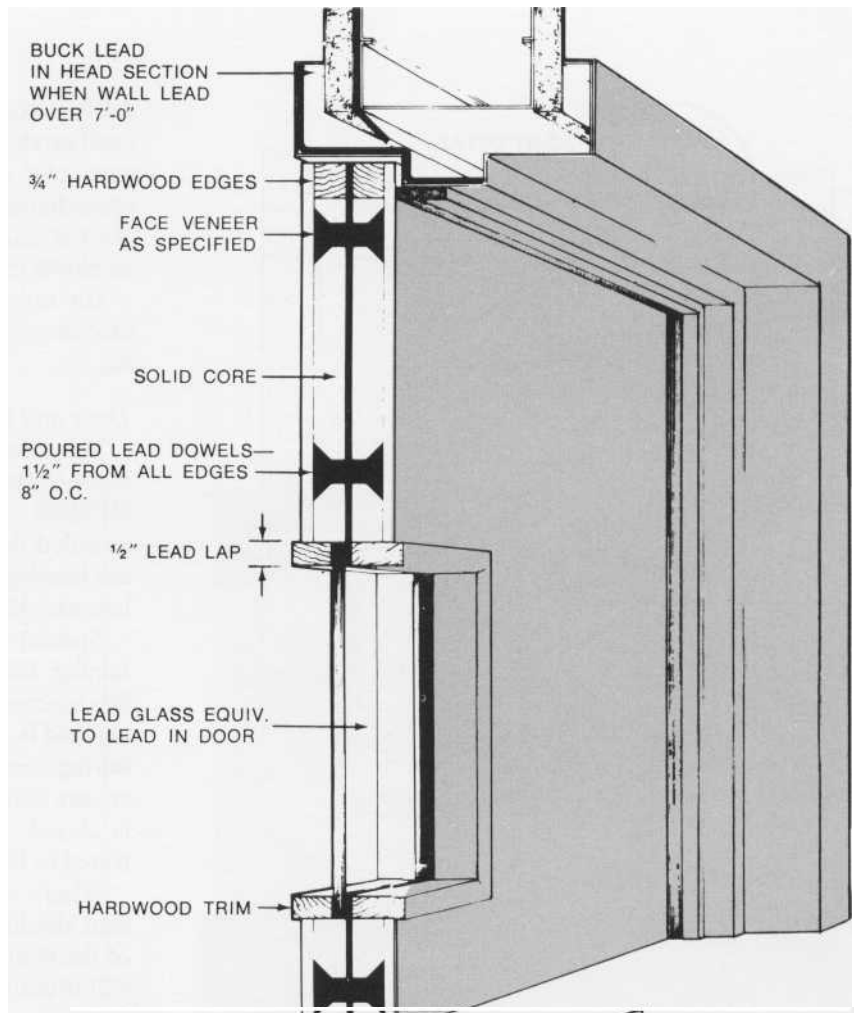
Viewing Windows

Lead glass viewing windows for patient observation from a control room or control booth are available in sizes ranging from 12 in. by 12 in., to 36 in. by 48 in. The frame is constructed of solid lead welded in one piece, splayed on four sides for one side angle viewing. An alternate type of frame is constructed from steel and lined with sheet lead. A horizontal trapped opening is provided in the bottom of the frame for voice transmission.

The frames are constructed to provide a minimum of 3/8 in. overlap at all points of the perimeter of the lead glass. Removable lead stops are provided for glazing in the field. Multiple lead glass layers (approximately 1/4 in. thick equals 1.5 mm sheet lead) are used to achieve



LEAD LINED DOOR



Standard door thicknesses

lead thickness	door thickness
1.0mm to 2.0mm	1 3/4" ± 1/16"
2.5mm to 3.5mm	1 13/16" ± 1/16"
4.0mm to 5.0mm	1 11/16" ± 1/16"
5.5mm to 6.5mm	1 7/16" ± 1/16"

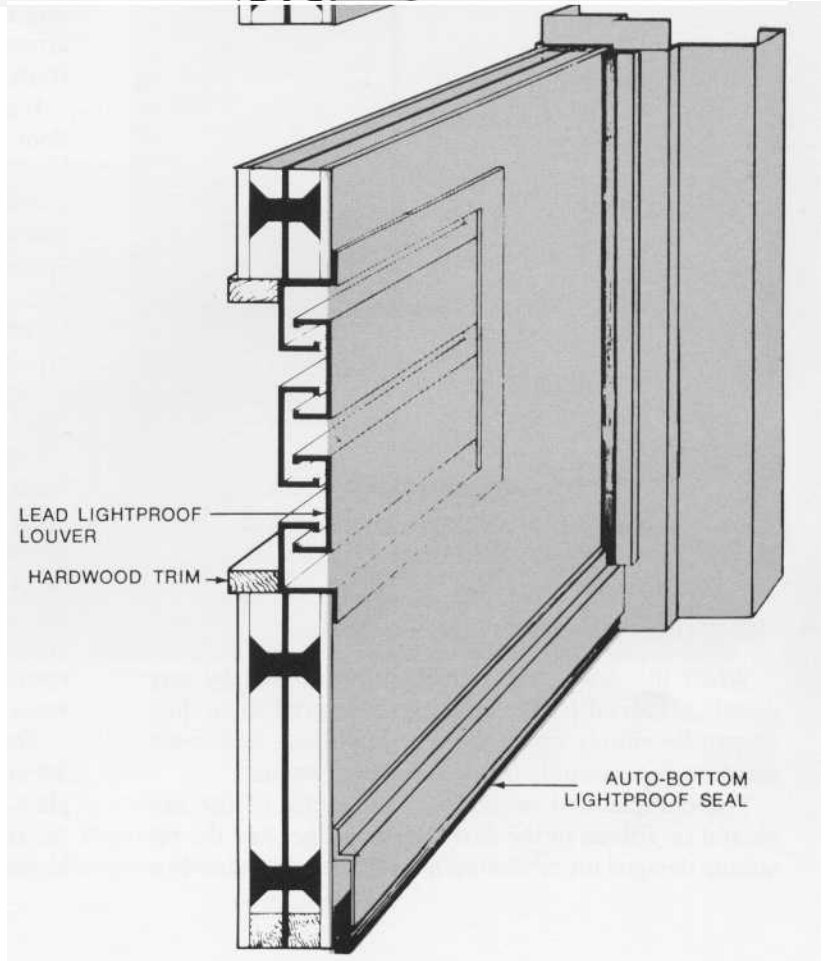


Figure 11
Typical Construction of A Lead Lined Door.

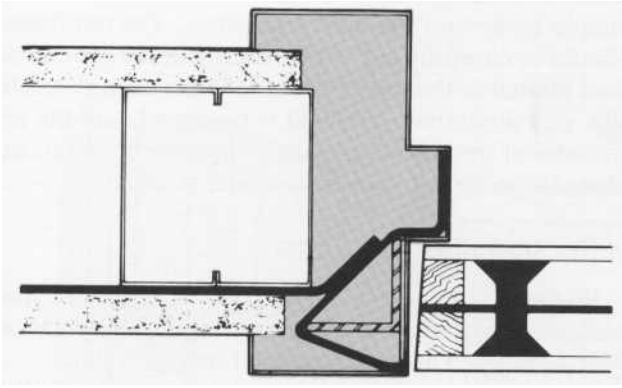


Figure 12 Reinforced Lead Lined Back.

the total shielding requirement. Figure 13 illustrates a typical lead glass viewing window.

Ventilation Louvers

Where ventilation is required in either walls or doors, lightproof louvers of solid lead are available. The louvers are constructed of inter-locking lead channels the same thickness as the lead used in the surface where it is to be mounted. A continuous flange is provided for surface mounting. The design of louver allows approximately a 30 per cent air flow. Refer to Figure 11 which illustrates a typical lead ventilation louver installed in a lead lined door.

Shielding of Ducts and Vents

Air conditioning vents and duct work in existing structures present a particular problem, since it is not possible to simply cover them with sheet lead. The main difficulty obviously occurs at their point of entry into a room.

In new construction, duct work should only be incorporated when absolutely necessary, and should enter the room well away from the direct rays of the useful beam. For example, the duct should enter as near to the ceiling and corners as possible to minimize the shielding requirements. Where practical, a lead shielded baffle may be constructed in front of and as close as possible to the mouth of the duct, or by providing a leaded cowl within the duct.

Since complicated reflection problems will often be encountered, the final design of the shielding system requires the services of a radiologist. However, in the initial design stage some idea of the possible extent of shielding can be estimated by considering the effect of the direct beam.

For additional information on providing radiation protection at wall openings for duct and pipe, the

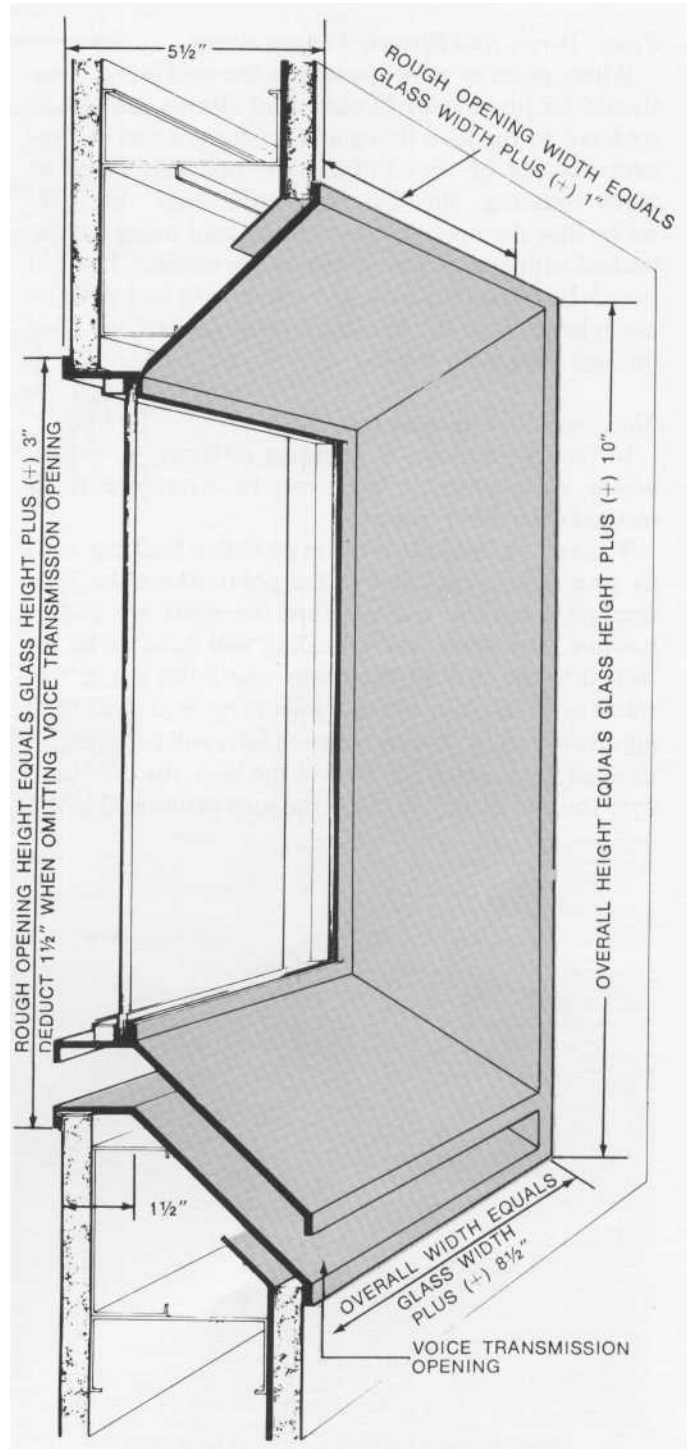


Figure 13
Typical Fixed, Solid Lead Viewing Window Frame with Lead Glass Panel.

readers attention is directed to Appendix A, a reprint of an article written by Messrs. Goodman and Hollands, outlining construction techniques to ensure continuity of the protective shield at barrier openings.

Pipes, Wires, and Electric Service Boxes

Where pipes or wires penetrate the lead lining, they should be fitted with flanged lead elbows welded or soldered to the lead lining and so designed as to prevent passage of rays through the opening. Pipes or wires passing through the wall may be offset so that the opening through the lead lining can be backed with a large lead patch on the outside. Electric switch boxes should also be backed with lead patches much larger than the opening so that rays cannot pass through even at an angle.

Shielding Continuity at Joist Ends

In new structures, a shielding difficulty at points where joists enter a wall, can be overcome by a method shown in Figure 14.

The end of the joist is covered with a lead cap with its four sides separated at the point where the joist emerges from the wall. Before the joists are laid in position, the main lead shielding will have to be attached to the wall of the room, and holes cut in this shield at each point where a joist is to be placed. During construction, the end of each joist will be threaded through the appropriate hole in the lead, the cap fitted over the end of the joist and the joist positioned in the

wall. The flanges at two sides and the bottom will simply lie behind the main lead sheet. The top flange should be carefully cut so that the top of the cap can be lead burned to the top of the hole in the main sheet. In this way a continuous shield is produced, and the remainder of the shielding to the ceiling can be continued along the joists before the floor boards are laid.

X-Ray Machine Control Booth

Where it is inconvenient to erect a permanent stud wall to shield the machine operator, consideration should be given to a prefabricated control booth.

The control booth is fabricated from panels, similar to lead lined door construction, available in sizes up to a maximum of 48 in. wide. The sheet lead in the center of each of the individual panels extends beyond the panel so as to provide an overlap with the adjoining panels.

The panels are installed using 16 gauge steel wall channels, floor channels, and joint strips, which can be provided to accommodate any desired configuration. Leaded glass vision panels can be provided in one or more individual panels at any desired location.

Inasmuch as the panels are completely self supporting, they are well suited for alteration purposes. In addition, the panels can be dismantled easily and erected in a new location. Figure 15 illustrates a typical control booth installation and construction details.

Thru-wall X-ray Film Transfer Cabinet

To prevent the transmission of light or radiation from the x-ray room to the film developing room, an x-ray film transfer cabinet is usually installed in the partition separating the two rooms: Figure 16.

A typical film transfer cabinet is of a double wall construction of heavy gauge steel, with a lead lining equivalent to that provided in the partition. In addition to being designed to prevent the transmission of light and radiation, the cabinet is of a fireproof construction. The integral face flange usually contains a baffled voice transmission passage. The doors are usually full height with concealed hinges, and are clearly marked exposed and unexposed. An interlocking mechanism is furnished to prevent the doors on opposite sides of each compartment from opening at the same time.

The film transfer cabinet may also be provided with a weight sensitive signal light system to indicate the presence of a x-ray film in either compartment.

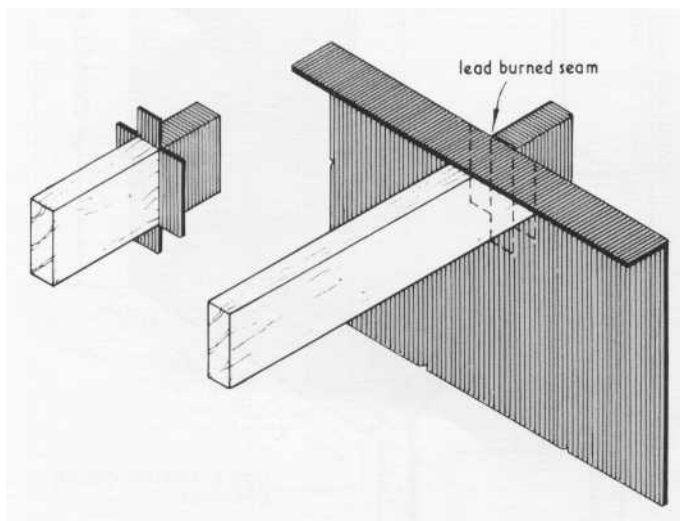


Figure 14 - Shielding continuity at joist ends.

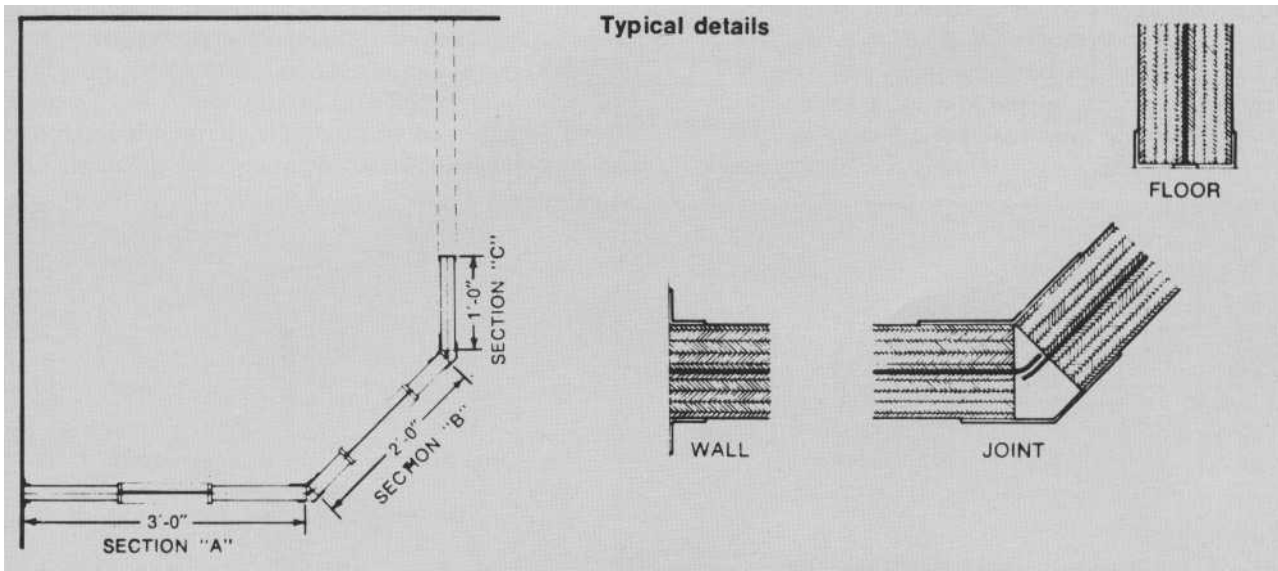
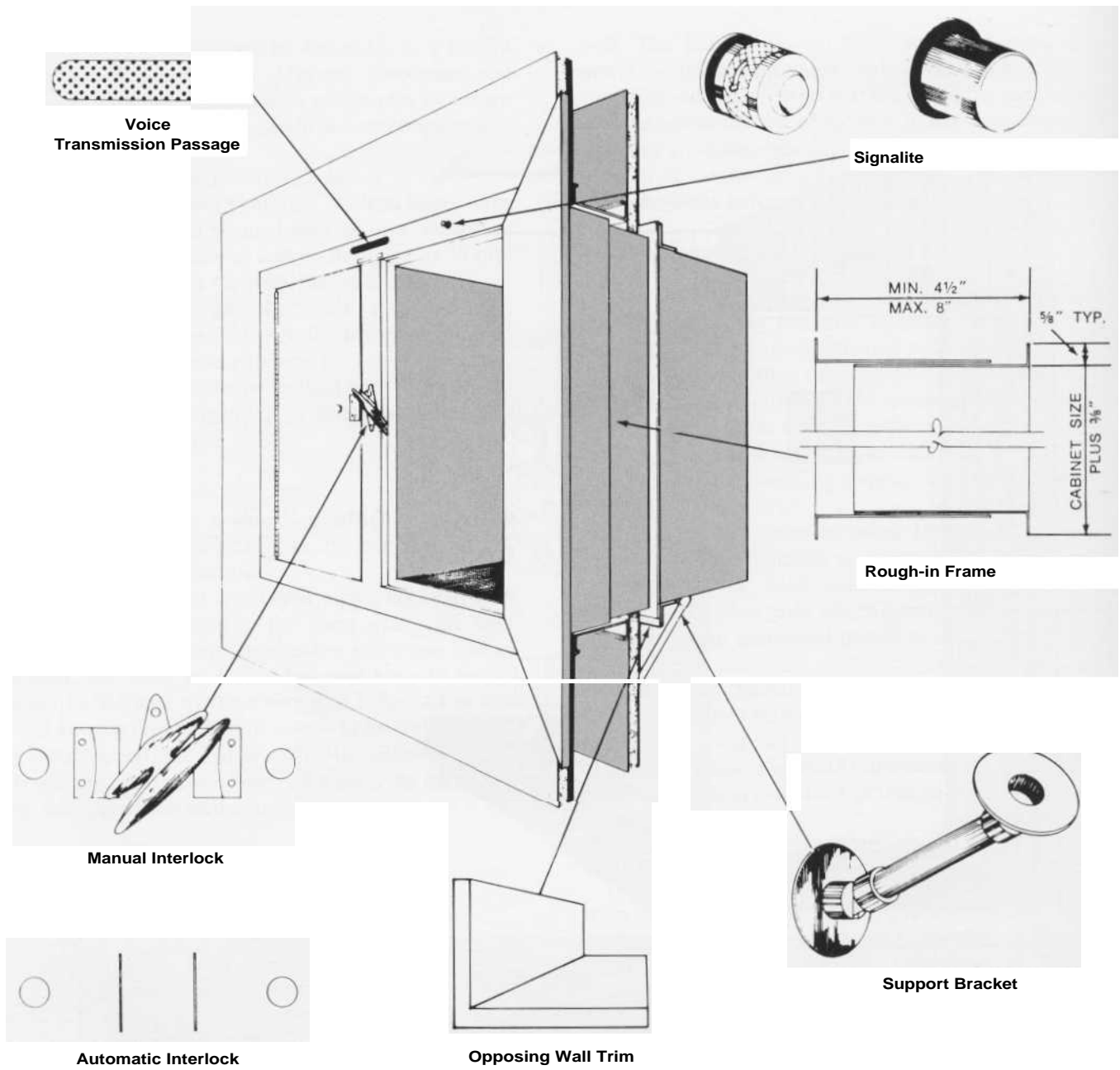


Figure 15
Typical Control Booth Installation.



Roughing-in details

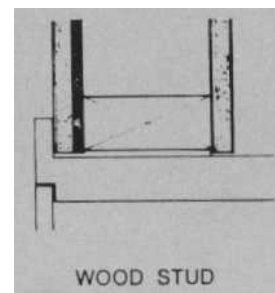
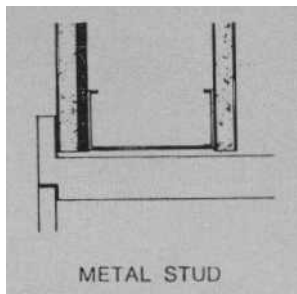
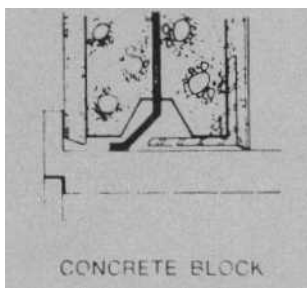


Figure 16
Thru-wall film-transfer cabinets.

RADIATION PROTECTION AT WALL OPENINGS FOR DUCT OR PIPE

Harrison D. Goodman* and George Hollands**

The purpose of these data sheets is to acquaint the air conditioning engineer with the means for shielding ductwork and other openings that penetrate protective barriers around radiation facilities, particularly X-ray rooms.

Protection against radiation from X-ray tube, cyclotron, radium or other radioactive material is primarily a question of shielding to reduce the level of radiation to a safe or specified amount, of maintaining safe distances from the rays, and/or of limiting the time of exposure.

The prime consideration in preventing penetration of rays is density of the shielding material. Lead is the densest of any commonly available. Where space is at a premium, particularly in modern buildings, and where utmost radiation protection is demanded, lead is invariably used. Lead is useful, especially where neutrons and gamma rays are concerned, in that it does not itself become contaminated and emit harmful rays.

Lead, usually in sheet form, is used to line the walls, floor and often the ceiling of rooms containing radiation facilities. Openings through the barrier for air ductwork, piping, service boxes, conduit, etc., require shielding, usually obtained by a lead barrier around or behind these building utilities of sufficient coverage and thickness to prevent penetration of these rays.

Determining Shielding Dimensions

Shielding of duct and other openings in the protective barrier of radiation facilities depends on energy of radiation, orientation of the beam, dimensions and location of opening in the protective barrier, geometrical relationship between the radiation source and opening, and geometrical relationship between opening and persons, materials or instruments to be protected. The complexity of these factors requires the services of a radiological physicist, who de-

termines extent of shielding, materials for shielding (usually lead or concrete) and the thickness of the shielding material. After the radiological physicist has done the basic design for this shielding, the protective barrier contractor provides the required shielding for the openings.

Role of Engineer

Design of ductwork, piping, etc., should *anticipate* some of the problems encountered both in the design and installation of shielding. Also, coordination between air conditioning contractor and shielding fabricator can best be achieved by understanding and forethought on the part of the air conditioning designer.

Figures 1-4 give some idea of the *area of shielding* required around ductwork. They show various duct installations which penetrate the protective barrier for walls or partitions of X-ray rooms. Lead shielding is used to cover these openings, the *approximate* extent of which is indicated in terms of simple equations involving the opening dimensions and wall thickness. These are *Conservative estimates*, which will aid the air conditioning designer to understand what to expect as to the area of shielded ductwork. The radiological physicist actually determines for *each* case the *lead thickness* and the *exact amount of shielding* required.

Note in Fig. 4 that the protective shielding deals with *primary* radiation, while Figures 1-3 show protection against *scattered* or *secondary* radiation. Primary radiation comes directly from the source; scattered radiation has been deviated in direction; and secondary radiation is emitted by an irradiated material. Primary radiation requires more protection because its energy level is higher.

Fabrication and Installation

Sheet lead is not structurally self-supporting, so must be mounted to prevent sagging by its own weight. For lead thicknesses up to 3.5 mm, sheet lead can be readily shaped around round and small rectangular ducts, say 24-inch maximum diameter or width, with all joints overlapped at least 1/2 inch. To hold these lead sheets in place, 1-inch wide iron bands should be placed around the periphery of the duct on approximately 12-inch centers, care being taken not to cut into the lead when the bands are bolted up.

When lead thickness is greater than 3.5 mm or duct width exceeds 24 inches, lead shielding should be laminated on a plywood or similar structural core, which is made in sections or panels to conform to the

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** Mr. Hollands is chief engineer, in charge of design of radiation shielding materials and equipment, for Bar-Ray Products, Inc., Brooklyn, N.Y. He is a member of ASTM, Society for Nondestructive Testing, Acoustical Society of America and American Institute of Physics.

sides of the duct. The laminated sections are mechanically fastened at the seams and corners. These joints are lapped with sheet lead angles or lead strips, the width of which is twice the thickness of the lead, but not less than $\frac{1}{2}$ inch in any case. Nails, bolts, screws or other fasteners used to secure the lead sheet or panel must be covered with lead of thickness equal to the lead sheet. Lead headed nails may be used as shown in Fig. 5.

For lead shielding of 1.0 mm or less, flexible leaded vinyl sheets can be used for easy forming to complex shapes and contours. The flexible leaded vinyl sheets can be applied in layers where heavier than 1.0 mm lead shielding is required. If the duct has a flexible connection or is made of a flexible material, the flexible vinyl sheets could be applied over it more readily than other forms of shielding.

Duct hangers are best installed on the outside of the lead shielding so that the hanger rods or straps do not have to pierce the shielding. The lead shielding adds considerably to the weight of the duct and the hangers should be substantial, with such adequate anchoring in the slab above as fish plates. For rectangular ducts, trapeze hangers would be the most practical. For design purposes, estimate each $\frac{1}{16}$ inch of lead at 4 lb. per sq. ft.

Tests for radiation leakage are usually made after the room is finished and the equipment is installed. It is very important to install all shielding properly during the course of construction because of the expense in making corrections to the finished protective barrier. Moreover, equipment such as dampers should never be put in the shielded section of the ductwork, as repairs to this equipment would be very costly if the shielding must be dismantled.

A simple way to avoid penetration of the protective barrier's lead lining by pipes or wires is to offset them as close behind the lead lining as possible so that they can be backed with a lead sheet of sufficient size to prevent passage of the rays at any angle. This lead patch method is also used for electric switch boxes located in the wall.

Medical Installations

The extent of the protective barrier for medical installations is summarized below so that the air conditioning designer can tell whether ducts or pipes running through such spaces are likely to be a problem. For medical radiographic and fluoroscopic rooms the lead shielding generally does not extend above a line 7 ft., 0 in. from the finished floor; and if the service lines and ducts can be located above this line, shielding around them is obviously unnecessary. For X-ray therapy rooms, lead shielding may extend to the ceiling or structural slab. The ceiling or slab above and the floor may also be lead lined, depending upon output of the machine and other conditions. For industrial X-ray work, wall shielding may extend to the ceiling. Both ceiling and floor in some cases will require lead lining.

For shielding in supervoltage rooms, special conditions may apply. In any event, the radiological physicist should be consulted to design the proper protection. Where concrete is considered for the shielding material, it is often more practical to use lead of equivalent value for the shielding of openings. Where recesses occur in concrete barriers for equipment, lead backing, equivalent to the thickness of the concrete removed, should be provided.

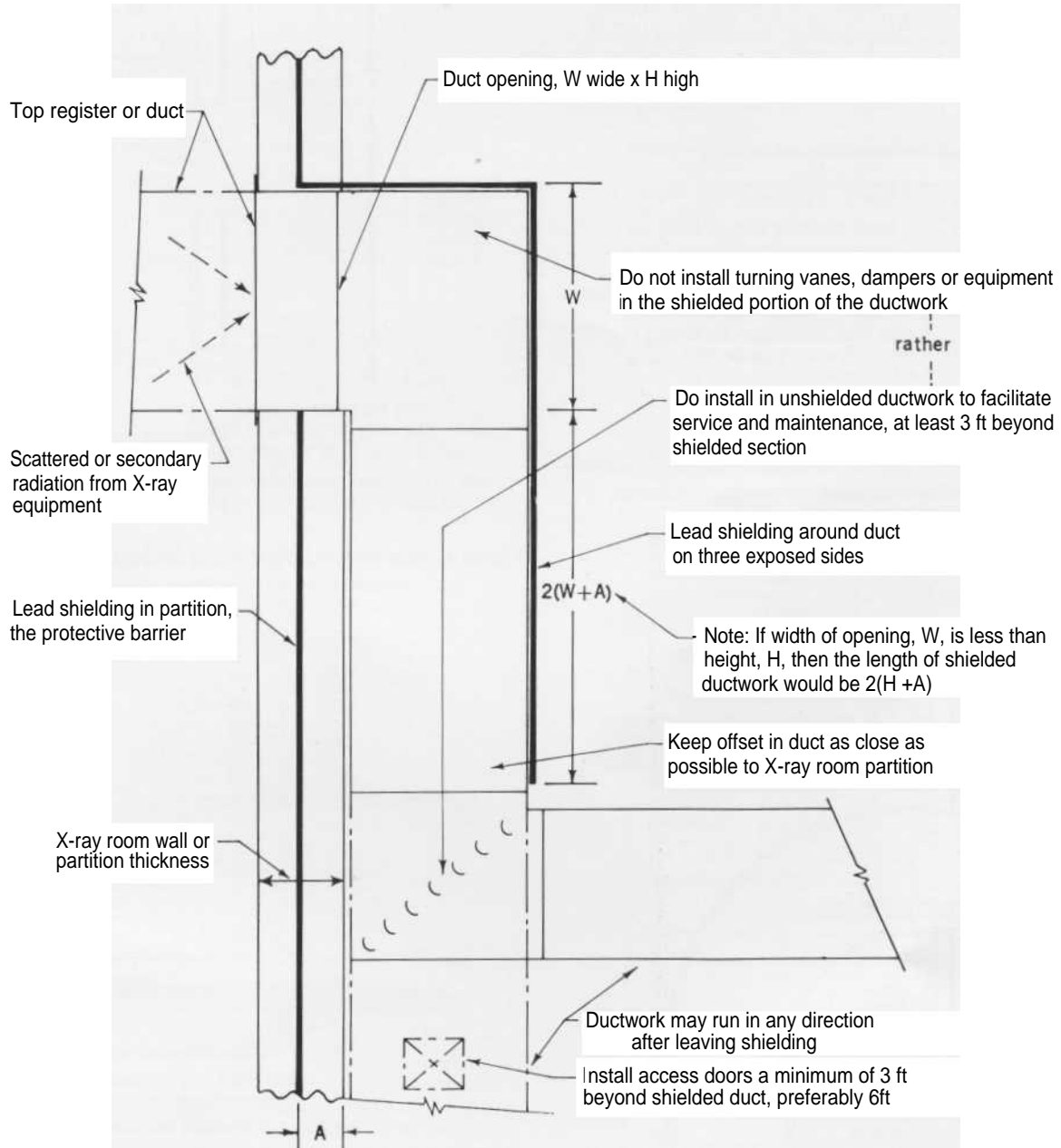
Bibliography

Of the many publications available on the subject of radiation protection, these two are the most useful:

1. Medical X-ray Protection Up to Three Million Volts, Handbook No. 76, National Bureau of Standards, 1961;
2. Radiation Protection, Lead Industries Association, 292 Madison Avenue, New York, N.Y.

In addition, the New York City Health Department publishes the New York City Health Code requirements dealing with radiological hazards (Article 175).

RADIATION PROTECTION AT WALL OPENINGS FOR DUCT OR PIPE



RADIATION PROTECTION AT WALL OPENINGS FOR DUCT OR PIPE

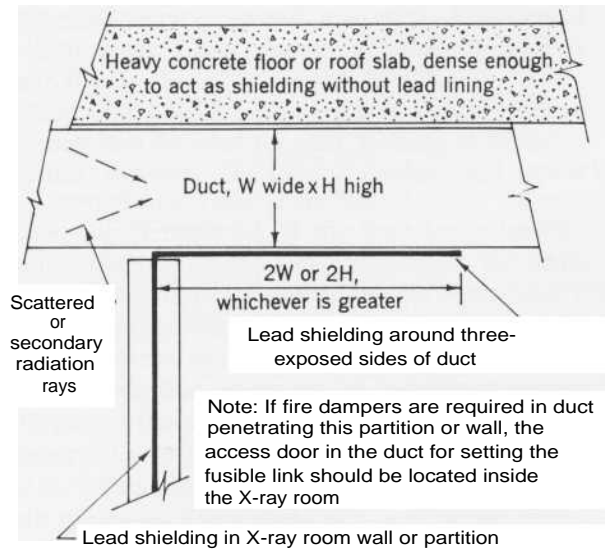


Figure 2. Evaluation of section through X-ray room partition where duct opening is exposed to secondary radiation.

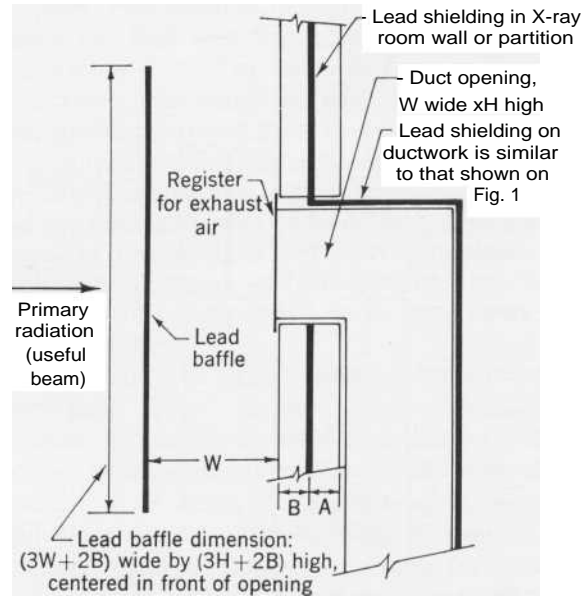


Figure 4. Plan view of duct running through partition of X-ray room, exposed to primary radiation.

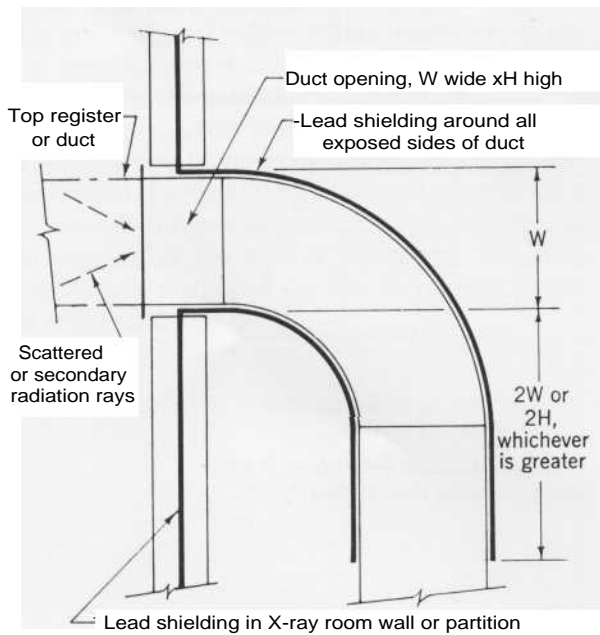
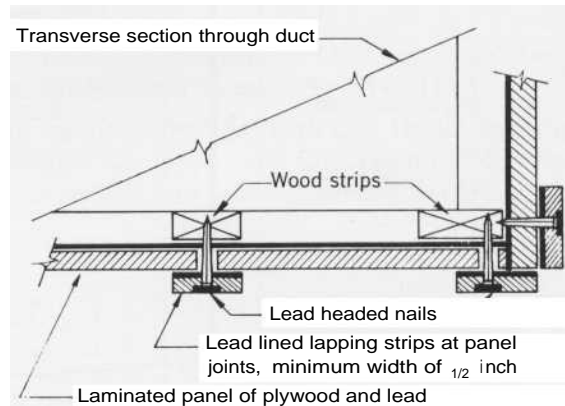


Figure 3. Plan view of radius elbow in ductwork running through partition of X-ray room, exposed to secondary or scattered radiation.



Note: Let duct rest on wood strips for support. Substantial trapeze hangers should be used for supporting shielding enclosure. Hanger rods must be rigid enough to prevent any sway of the enclosure

Figure 5. Construction of laminated panel enclosure around shielded ductwork.

APPENDIX B

GENERAL PROPERTIES OF LEAD

general properties

Color Bluish gray
Patina On atmospheric exposure lead takes on a silvery gray patina except in industrial atmosphere where it changes to dark gray to black
Atomic number 82
Atomic arrangement Cubic face-centered
Length of lattice edge 4.9398 Å
Atomic weight 207.21

weight and density

weight
 Cast lead, 20°C., calculated . 0.4092lb. per cu.in.
 equivalent to (density 11.34 grams per c.c.)707 lb. per cu. ft.
 Rolled, 20°C. (density 11.37) calculated0.4103 lb. per cu. in.
 equivalent to 709 lb. per cu. ft.
Liquid, 327.4°C., calculated 0.3854 lb. per cu. in.
 equivalent to 666 lb. per cu. ft.
Sheet lead, 1 ft. square by 1/64 in. thick approximately 1 lb.
Volume of 1 lb. cast lead, 20°C., calculated2.44 cu.in.
density
 Cast lead, 20°C 11.34 g. per c.c.
 Rolled, 20°C 11.35 to 11.37 g. per c.c.
 Just solid, 327.4°C 11.005 g. per c.c.
 Just liquid, 327.4°C 10.686 g. per c.c.
 Density, vapor (Hydrogen), calculated103.6

thermal properties

Melting point, common lead327.4°C. (621°F.)
Melting point, chemical lead 325.6°C. (618°F.)
Elevation of melting point for ^{686c}
 150 atm. increase in pressure1.2°C. (2.16°F.)
Casting temperature790 to 830°F.

boiling point at different pressures

Pressure, in atmospheres 0.14 0.35 1.0 6.3 11.7
Boiling point, °C. 1325 1410 1525 1873 2100
Boiling point, °F. 2417 2570 2777 3403 3812

vapor pressure

Temperature, °C. 11000 1200 1136511525 1 1870 1, 2100
Pressure, mm. Hg. 0.08 1.77 23.29 166. 760. 6.3atm. 11.7atm.

specific heat (cal. per g.)

specific heat		thermal conductivity (cal./cm/cm ² /°C./sec.)	
Temp °C	specific heat	Temp °C	specific heat
-150	0.02805	-247.1	0.117
-100	0.02880	-160	0.092
-50	0.0298	0	0.083
0	0.0303	100	0.081
50	0.0309	200	0.077
100	0.0315	300	0.074
200	0.0325	400	0.038
300	0.0338	500	0.037
327.4 (solid)	0.0340	600	0.036
327.4 (liquid)	0.0333		
378	0.0338		
418	0.0335		
459	0.0335		

Latent heat of fusion6.26 cal. per g. or 9.9 B.T.U. per lb.
 To melt 1 lb. of lead heating from 20°C requires 7100 g.cal. or 27.9 B.T.U.
Latent heat of vaporization202 cal. per g.
Relative thermal conductivity (silver 100)8.2

coefficient of expansion

Linear (-190 to 19°C. mean)0.0000265 per °C.
Linear (17 to 100°C. mean)0.0000293 per °C.
 or 0.0000163 per °F.
Cubical (liquid at melting point to 357°C.) 0.000129 per °C.
Increase in volume from 20°C. to liquid at melting point6.1
Decrease in volume from liquid at melting point to 20°C. calculated
 Increase in volume on melting 5.8
 4.01
Decrease in volume on solidification 3.85%
Shrinkage on casting taken in practice as 7/64 to 5/16 in. per ft.

low temperature properties

temperature °F.	tensile strength	elongation percent	Brinell	impact
cast lead				
room	3000	33	4.3	2.3
-300	6200	40	9.0	3.8
rolled lead				
59	3600	52		
-4	7200			
-40	13300	31		
-103	15200	24		

electrical properties

Specific electrical conductance
 at 0°C.5.05 x 10⁷ cm. ' ohms
 18°C. ... 4.83
 melting point .. 1.06
Atomic electrical conductance, calculated .. 1.139 x 10⁶
Relative electrical conductance (copper 100) 7.82
Relative electrical resistance (copper 100)1280
Magnetic susceptibility per g.
 18-330°C. -0.1Y x 10⁶
 300-600°C. -0.08 x 10⁶
Electrolytic solution pressure
 ions of Pb++ 6.3 x 10⁶ ' atm.
 ions of Pb++++ 3.0 x 10⁶ ' atm.

mechanical properties

Hardness, Moh's scale1.5
Brinell no., 1 cm. ball, 30 sec., 100 kg. load
 Common lead 3.2 to 4.5
 Chemical lead 4.9 to 6.0
Influence of temperature on Brinell hardness (chemical lead)
Temperature °C. 2.5 100 150
Hardness 5.3 3.6 2.6
Ultimate tensile strength
 Common lead 1400 to 1700 lb. per sq. in.
 Chemical lead 2300 to 2800 lb. per sq. in.

Effect of temperature on tensile properties (lead annealed at 100 °C.)

Temperature		Tensile strength psi	Elongation percent	Reduction in area percent
°C	°F			
20	68	1920	31	100
82	180	1140	24	100
150	302	710	33	100
195	383	570	20	1p0
265	509	280	20	100

tensile strength and elongation

(laboratory rolled specimens, room temperature, pulling speed 1/a in. per min. per in. of test section)

grade of lead	tensile strength *psi	elongation percent
corroding (99.99 + 0.006 Bi)	1904	37.7
common (99.85 +0.13 Bi)	1931	34.4
common (0.002 Cut	2093	43.0
chemical (99.92 + 0.06 Cu)	2961	42.2
chemical (commercial sheet)	2454	47.0
chemical (extruded)	2200	48.0

resistance to bending

(extruded strips under 200 lbs. per sq.in stress subjected to alternate 90° reverse bends over 5-in. rolls, 11 cycles per min)

grade of lead	cycles to failure	elongation percent
corroding	54	35
common	72	49
chemical	103	52

creep (room temperature)

stress lb. per sq. in.	creep, percent per hour	
	common lead	chemical or copper lead
200	5 x 10 ⁻¹	0.4 x 10 ⁻¹
300	3.5 x 10 ⁻¹	1.5 x 10 ⁻¹
400	11 x 10 ⁻¹	3 x 10 ⁻¹

fatigue

Fatigue limit (50,000,000 cycles extruded)215 lb. per sq. in.)

metal	endurance limit at 5 x 10 ⁷ cycles, lb. per sq. in.	endurance limit at 10 ⁷ cycles lb. per sq. in.
lead	215-400	407
lead + 0.026% calcium		1038
lead + 0.038% calcium	685-840	
lead + 0.04% calcium	820-1500	
lead + 0.041% calcium		1180
lead + 0.06% calcium	1120	
lead + 1 % antimony	300-1000	
lead +2% tin	800	
lead + 0.06% copper	600	725
lead + 0.045% tellurium		1000

While every effort has been made to assure that the information given in this booklet is technically correct, Lead Industries Association, Inc. does not warrant its accuracy.



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