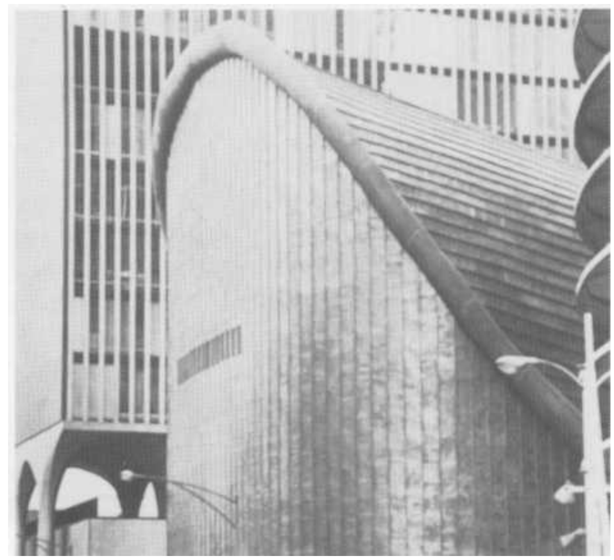
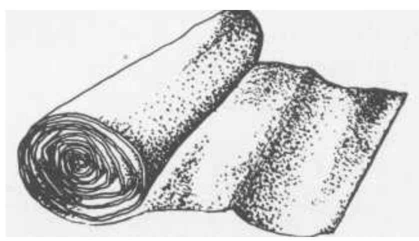
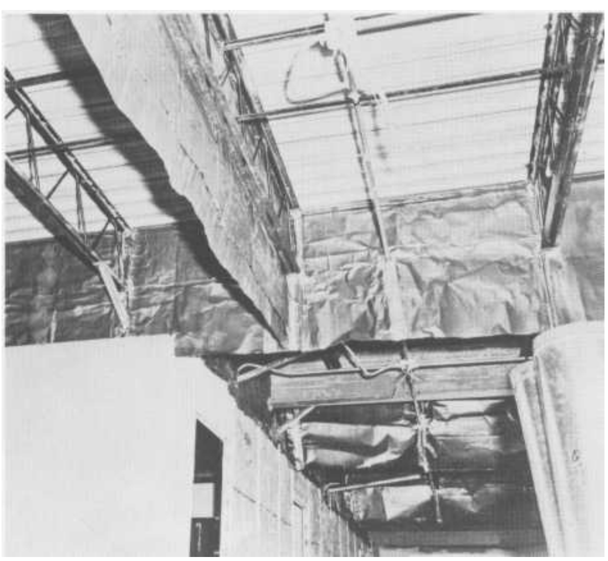
SHEET LEAD
The Protective Metal


WATERPROOFING


ROOFING AND FLASHING




SOUNDPROOFING


RADIATION SHIELDING

Cover Photographs

Waterproofing. Sheet lead membranes are easily installed on-site, then burned (welded) with same-composition lead burning bar to effect. a long-lasting, impermeable barrier.

Roofing and Flashing. Chicago's Marina City Theater Building is a completely sheet lead-clad structure with no flat surfaces or square corners anywhere. It is a fine example of lead for roofing/flashing.

Soundproofing. In commercial and industrial applications, sheet lead plenum barriers are hung from the ceiling to achieve the desired sound transmission class within the area.

Radiation Shielding. Lead-glass aprons/shields incorporating sheet lead have long been used to protect medical personnel from scattered X-ray exposure during diagnostic procedures.

LEAD INDUSTRIES ASSOCIATION, INC.

Lead Industries Association is the market development and information organization of the North American lead industry with sister organizations in major countries throughout the world. A non-profit trade association representing all segments of the lead industry, LIA neither produces nor sells lead, but promotes increased use of the metal and its end-products in a cost-effective and environmentally sound manner through publicity, educational activities and technical service.

An extensive library of lead information is housed at the Association's New York headquarters and data pertaining to lead and lead products is available through letter or telephone inquiry. Most of the services, publications and other offerings of the Association are available without charge to anyone interested in the use of lead and lead products.

SHEET LEAD: The Protective Metal

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Foreword

In seeking a solution to any material selection problem, an attempt is made, in general, to obtain the optimum material properties in a readily available commercial form at the least cost. Lead is readily available and is inexpensively fabricated into a wide variety of useful forms. These forms, combined with lead's unique properties-high density, malleability, flexibility, electrical and thermal conductivity, good corrosion resistance, and ability to form many useful alloys-provide a valuable material for the solution of a wide range of problems.

This booklet is a guide to sheet lead: the material, its specifications and its uses. Applications for sheet lead are so broad throughout commerce and industry that no review can include all uses. It is hoped this discussion will inform the reader about how sheet lead is being utilized and how important this material is to our modern way of life.

The previous paragraph states that the applications for sheet lead are so broad throughout commerce and industry that no review can include all uses. However, this review covers all of the "major" uses for sheet lead.

In addition to its proven performance, lead's ready availability and its recyclability are two very important factors to consider when specifying a sheet metal material for a given application. In the all-important cost comparison realm, sheet lead is usually very competitive with other materials that might be considered in its stead.

PROPERTIES OF LEAD

Density. The high density of lead makes it very effective in shielding against x-rays and gamma radiation. In very large installations it is often used for lining concrete structures to greatly reduce the mass of concrete that otherwise would be required.

The combination of high density, high "limpness" (low stiffness) and high internal damping capacity also makes lead an excellent barrier material to block the transmission of sound, and for isolating equipment from mechanical vibration.

Malleability and Flexibility. Lead is the softest of the common metals and, in refined form, is very malleable. It is capable of being shaped with ease at ambient temperatures without the need for periodic softening or annealing. It does not appreciably work harden. Lead sheet can, therefore, be readily manipulated with hand tools. In the thicknesses most commonly used-4 lb. to 12 lb. per sq. ft.-the risk of fracture is quite low and it is in the optimization of this property that skilled working and fixing of sheet lead, known as lead-working, has largely evolved. By the technique of "bossing," lead sheet can be worked into the most complicated of shapes. Lead flashings can be readily dressed in situ, thus a close fit to the structure is possible even when the surface is deeply contoured, such as in the case of some forms of single-lap roof tiling.

Thermal Expansion. The relatively high coefficient of thermal expansion of lead is another important design parameter. In lead roofing and flashing, for example, thermal expansion is a key consideration. Proper allowance for expansion and contraction is usually provided through (1) selection of lead sheet in accordance with the general rule: the thinner the sheet, the smaller each piece, and (2) through use of batten or loose lock seams, minimizing individual and cumulative expansion.

Corrosion Resistance. Lead is highly resistant to corrosion by the atmosphere, by sea water and by a wide range of industrial chemicals. Perhaps lead's best known property is its resistance to corrosion in various aggressive environments (especially sulfuric acid). Lead's ability to give good service in such situations often gives the erroneous impression that it is a passive metal. Lead is, in fact, a very reactive metal and it is this reactivity which enables lead to be used in corrosive environments. In a non-industrial atmosphere, for example, a close fitting and adherent film of lead oxide or carbonate is usually formed by rapid reaction with the newly exposed lead-first, to form lead oxide, followed by a second reaction between the lead oxide film and the carbon dioxide (which is always present in air) to form a protective film of lead carbonate. Further contact with the metallic lead underneath is then prevented and corrosion ceases.

Similarly, with sulfuric acid, a protective film of lead sulfate is formed. This, being closely adherent and insoluble in all but the most concentrated form of the acid itself, protects the lead from further attack. Similar protection is afforded to lead exposed to phosphoric acid and, to a lesser extent, to chromic acid. Where resistance to corrosion must be combined with long service life, the limitations imposed by the mechanical properties of lead must be carefully considered in the final design.

There are environments in which the film formed on the lead surface is soluble. Corrosion of the lead will, therefore, continue.

Dilute solutions of organic acid leached from timber can, over a period of years, cause lead to slowly corrode. Such attack may occur when lead is in close contact with damp timber for a long time-particularly western red cedar and hardwoods like oak and elm. There is a risk of such attack where roof construction permits warm moist air (which has picked up organic acids from hardwood roof timbers) to condense on the underside of the lead covering. Two methods for preventing this from occurring are: (a) insure that the timber has been treated to prevent moisture pick-up and (b) insert a barrier between the lead and the environment.

Portland cement contains free alkali which can stimulate a slow corrosive attack on lead in the presence of moisture. Therefore, direct contact with fresh Portland cement, in positions where the cement is slow to carbonate and dry out, should be avoided by the use of a suitable underlay or asphaltum coating for the lead surface.*

In general, when two dissimilar metals are in close contact it is possible to create a galvanic cell, thus stimulating electrolytic corrosion. It is important to electrically separate the lead from the other metals by insertion of such barriers, or other suitable membranes, as discussed above.

***a) Cold-applied brush coat bituminous compound (12-14 mils thick), equal to Fed. Spec. TTC 949, Type II, or Mil. Spec. MIL-C-18480.**

b) For wood surfaces, use min. 15#/sq. ft. asphalt impregnated building paper; for concrete surfaces, use min. 30#, per ASTM-D226.

TABLE 1
Physical properties of lead

Atomic weight	207.2
Atomic number	82
Weight	0.4092 lb/in3
	11.34 g/cm2
	1 sq ft of lead sheet 1 in thick weighs 59.2 lb
	1 m2 lead sheet 1 mm thick weighs 11.34 kg
Volume	1 lb = 2.44 in3
	1 kg = 88.28 cm3
Coefficient of linear expansion	0.0000163 per degree F
	0.0000297 per degree C
Thermal conductivity	241 Btu in/ft2 h degree F
	34.76 W/m degree C
Melting point	621 °F
	327.4°C

MECHANICAL PROPERTIES

The structural or so-called mechanical properties of lead and its alloys are relatively low when compared to other metals. Lead's superior corrosion resistance and malleability, however, call for its consideration in conjunction with other, structurally superior, materials in applications where both may produce a synergistic effect. One such example is when lead sheet is bonded to, or supported by, a steel structure for chemical piping or tank linings.

The limiting factors in the use of lead or its alloys as structural members are creep strength and fatigue resistance. Creep strength is generally accepted as the ability of a metal to withstand a sustained load without undue stretching or failure. For most design purposes, a limit of no more than '/z of 1% elongation per year is accepted. For common desilverized or chemical lead, a stress limit 200 psi per year at 68° F has been accepted, although this represents only about 10% of the ultimate tensile strength. These creep strength figures are obviously very low, and for this reason unalloyed lead is rarely used alone for structural purposes. Recent metallurgical developments have produced alloys with small additions of calcium and tin that permit an increase in the creep stress limit of at least an order of magnitude to 2,000 psi or more at room temperature. In addition, a variety of composite materials with soft lead can be produced, so that the phenomenon of creep need not be a problem.

Fatigue strength is the maximum cyclic stressing before failure in a test specimen when stressed indefinitely. Vibration or thermal cycling are chief causes of fatigue failure in actual service of lead or lead alloys, e.g., when a cable and its sheath continually expand and contract. See Table 1 for the main physical properties of lead.

Compositional Effects. Although many properties of lead make it ideal for certain applications, some means of strengthening or improving its corrosion resistance may be required for other applications. Unlike steel, transformations induced by heat treatment do not occur in lead alloys, and strengthening by ordering phenomena, as in the formation of lattice super-structures, has no significance.

Small traces up to moderate percentages of various alloying elements are added to pure lead to alter its physical and mechanical properties. The importance of these elements generally is to strengthen the lead matrix via solid-solution or precipitation hardening. Dispersion hardening with a finely dispersed insoluble second phase, e.g., lead oxide, has also been shown to be technically viable. More recently, composite materials such as a lead matrix strengthened by graphite fibers have been produced.

Pure lead is commercially available up to 99.999 + %, from several producers. According to ASTM B29 (Table 2), there are four different grades of lead. Common desilverized lead contains a minimum of 99.85% lead with a maximum of 0.002% silver; acid-copper lead and chemical lead contain a minimum of 99.90% lead, and both grades are made by adding a maximum of 0.080% copper. The major difference between these two grades is that acid-copper lead contains a maximum of 0.002% silver. Corroding lead contains a minimum of 99.94% lead. Different alloys of lead are commonly produced. Antimony-lead contains nominally 0.05 to 8% antimony.

These alloys have greater strength at ambient temperatures but this improvement decreases above 248° F (120° C) because of the lower melting points of these compositions. The alloy Pb-3.5Sb can be heat treated and quenched followed by aging. From a maximum tensile strength of 11,500 psi (79 MPa), 5% elongation, 100 days of aging reduces this to 8,000 psi (79 MPa) and increases elongation to 9%. Lead alloyed with 6% antimony has double the tensile strength and hardness of chemical lead. Generally, not more than 8% an-

TABLE 2
Chemical Requirements[A]
(ASTM B29-79 Specification*)

Type	Corroding Lead[B]	Common Lead[B]	Chemical Lead[B]	Copper-Bearing Lead[B]
	Composition, weight %			
Element:				
Silver, max	0.0015	0.005	0.020	0.020
Silver, min	. . .	. . .	0.002	. . .
Copper, max	0.0015	0.0015	0.080	0.080
Copper, min	. . .	. . .	0.040	0.040
Silver and copper together, max	0.0025	. . .	. . .	. . .
Arsenic, antimony, and tin together, max	0.002	0.002	0.002	0.002
Zinc, max	0.001	0.001	0.001	0.001
Iron, max	0.002	0.002	0.002	0.002
Bismuth, max	0.050	0.050[C]	0.005	0.025
Lead (by difference), min	99.94	99.94	99.90	99.90

The following applies to all specified limits in this table: For the purpose of determining conformance with this specification, an observed value obtained from analysis shall be rounded off "to the nearest unit" in the last right hand place of figures used in expressing the limiting value, in accordance with the rounding method of Practice E 29.

[B] By agreement between the purchaser and the supplier, analyses may be required and limits established for elements or compounds not specified in Table 1.

[C] By agreement between the purchaser and the supplier, bismuth levels of up to 0.150 weight% may be allowed.

*1984 Annual Book of ASTM Standards, Section 2

timony is used because these alloys are brittle and have decreased corrosion resistance and workability.

Calcium-lead alloys maintain the corrosion resistant properties of pure lead. Additions of small amounts of calcium to lead increase mechanical strength without notably affecting workability. Tensile strength, fatigue strength, and creep strength can all be increased considerably, depending on the amount of calcium added. Generally no more than 0.l% calcium is required to produce at least a doubling of the tensile strength of pure lead. Where even more strength is needed, small amounts of tin up to a maximum of about 1% can be added along with calcium, producing strength levels at least four times that of pure lead. With proper selection of alloy content, intermediate levels of mechanical properties can also be achieved. Copper is a potent strengthener of lead but is not usually added in amounts greater than 0.06% because higher amounts segregate in the melt. Copper, even at the .04-.06% level, improves tensile, fatigue and creep strength. Tellurium in amounts as low as 0.05% refines grain size, increases tensile and fatigue strength and, to some extent, improves corrosion resistance.

SPECIFYING SHEET LEAD

As with many other commodities, sheet lead is sold by the pound. A rather fortunate circumstance results from the fact that one square foot of lead will weigh approximately one pound when rolled or cast to a thickness of/64th of an inch. For each additional'/64-inch increase in thickness, the original square foot of sheet lead will increase in weight by one pound. Thus, 4 lb. sheet lead, as it is termed commercially, is 1/16th-inch thick; 8 lb. sheet lead is '/8th-inch thick. Above 16 lb. sheet, this relationship does not hold exactly: and 'h-inch sheet lead weighs 30 lbs. per square foot, while one inch weighs 60 lbs. per square foot. The thickness of foil-weights less than about 3/4 lb. per square foot-is usually designated in thousandths or ten-thousandths of an inch.

Table 3 gives the thicknesses and weights of commercially available lead sheet. By industry definition* lead conforming to various thicknesses and widths is classified as follows:

STRIP: .187 inches (4.75 mm) and under in thickness, less than 24 inches (610 mm) wide.

SHEET: .187 inches (4.75 mm) and under in thickness and 24 inches (610 mm) or more in width.

PLATE: over. 187 inches (4.75 mm) in thickness and over 10 inches (254 mm) in width.

TABLE 3
Sheet Lead Thicknesses and Weights(a)

Actual Thickness (lb/sq ft)	Weight lb/sq ft	Approximate thickness inches (decimal)	inches (fraction)	mm
1	3/4	0.0117	1/60	0.297
	1	0.0156	1/64	0.396
	1½	0.0234	3/125	0.594
2½	2	0.0312	1/32	0.792
	2½	0.0391	5/128	0.993
	3	0.0468	3/64	1.19
4	3½	0.0547	7/128	1.39
	4	0.0625	1/16	1.55
	5	0.0781	5/64	1.99
8	6	0.0937	3/32	2.35
	8	0.1250	1/8	3.18
	10	0.1563	5/32	3.97
16	12	0.1875	3/16	4.75
	14	0.2188	7/32	5.56
	16	0.2500	1/4	6.35
30	20	0.3333	1/3	8.47
	24	0.4000	2/5	10.16
	30	0.5000	1/2	12.70
	40	0.6667	2/3	16.93
	60	1.000	1 inch	25.4

(a) The weights given apply to soft, chemical and tellurium lead. Other types of lead, such as antimonial or hard lead, weigh slightly less for a given thickness.

ARCHITECTURAL/CONSTRUCTION APPLICATIONS

The major applications for sheet lead include architectural and building construction (e.g., waterproofing, flashing, roofing, noise abatement, and radiation shielding). Smaller, yet important, applications include corrosion resistant tank linings for chemical processing, storage and transport equipment, shower pans, bearing plates, weights, non-spark flooring, gaskets and leveling shims.

Lead's appeal to architects, engineers and builders for roofing, flashing and ornamental applications arises largely from its great durability, ease of installation and the fact that it does not cause unsightly stains or discoloration on adjacent materials. Its pleasing grey patina blends well with any decorative or functional color scheme and lead's long life and reclaim value lower its life cycle cost.

Because of its malleability, lead can be rolled to almost any desired sheet thickness for architectural and construction purposes. As a roofing or waterproofing membrane, it is one of the most durable of the common metals. In industrial and salt rich coastal atmospheres, it possesses even greater corrosion resistance.

Since sheet lead offers its full thickness-not merely a coating-to protect a more vulnerable substrate material, it is many times more durable than coated products. Corrosive media form insoluble lead compounds on lead's surface so adjacent materials remain unstained. Sheet lead is easily worked and installed, and it readily conforms to the surfaces on which it is applied. Joining methods for sheet lead are standard to the sheet metal trades.

Sheet lead is directly cost competitive with other quality building materials. Architects and builders have found that the freedom from costly call-backs and the ease of maintenance and repair offered by sheet lead often make it the least expensive construction option for the long term. Then, too, salvage value is a function of construction costs which, with lead, oftentimes equal the total installation cost. Another consideration: much leadwork can be prefabricated. This means site work can often be performed quickly with minimal delay to contractors.

ROOFING AND FLASHING

Lead for roofing has a successful background of hundreds of years under all sorts of climatic conditions. In addition to being a common roofing material on many European buildings erected centuries ago, lead is widely used on modern buildings in the U.S. and abroad.

The architect, utilizing alloys of lead (e.g., antimony or antimony-arsenic) can specify thinner gauges down to 31b. weight without reducing lead's traditional advantages. Today, in addition to snow and ice and intense heat and cold, there are the corrosive elements of modern industrial atmospheres to combat (e.g., acid rain). Thus, lead is a natural material for atmospheric exposure due to its insolubility in sulfuric acid. The practice of using thinner gauge lead sheet for many applications increases the relevance of three basic rules to be followed if lead sheet is to have the long service life that may be expected. These are:

* Individual pieces should be limited in size (the thinner the lead, the smaller each piece) so that the natural expansion and contraction is kept to a minimum, and the risk of severe distortion (with attendant danger of fatigue cracking) is thereby avoided.

  Fixings must not restrict thermal expansion and contraction, but must provide adequate long-term support to the lead.

  Joints must allow for thermal expansion and yet still be weather tight for the position in which they are used.

Table 4 gives the suggested sheet lead weight class to be used for various building purposes. When lead is in alloy form (e.g., antimonial lead), these weight classes might be reduced.

TABLE 4
Suggested Sheet Lead Weight Classes[(a)(b)]

Application	Weight Class (lb./sq.ft)				
	3	4	5	6	8
Flat roofing					
a) small and with no traffic		x	x		
b) large with traffic			x	x	x
Parapet gutters			x	x	
Pitched roof		x	x	x	
Chimney flashings					
a) back gutters		x	x		
b) apron and side flashing		x	x		
c) soakers	x	x			
Hip and ridge saddles		x	x		
Valley gutters		x	x		
Weatherings to cornices, etc.		x	x	x	
Damp proof courses	x	x	x		

(a) Based on soft, chemical and tellurium lead. (b) Local codes should be followed.

Rooftop skylight openings on many residential homes are edge-flashed with sheet lead for waterproof, weathertight seals. Lead's natural pliability allows it to conform exactly to surface configurations, and also makes it easy to cut, shape, and install the sheet.

WATERPROOFING

Today's building techniques, especially in urban areas, involve total use of land, underground as well as above. This means that underground garage and parking spaces, shops and storage areas must be situated without prejudice or restriction from above-ground installations. Lead waterproofing is a pressing need when such installations include plazas or other rentable areas beneath landscape plots, reflecting pools, fountains or planter boxes.

Waterproofing today usually means "membrane," which includes built up or laminated coverings made up of large unbroken surfaces demanding continuous integrity of the barrier for watertightness. Generally speaking, such installations in lead employ lead "burning" (welding) to join sheets as large as can be conveniently handled. Soldering is less frequently used for smaller installations, and has the disadvantage that the solder joint does not have the structural strength or corrosion resistance of lead burning with the same composition burning bar as the sheet lead membrane itself.

Lead specified for waterproofing membrane should be 6 lb. or S lb. square foot weight equivalent to 3/32 or ⅛ inch thickness. However, for less demanding service, 41b. or 1/I6 inch lead can be used. The lightest weight of lead sheet is employed for small, less critical areas, such as shower stalls. The heavier weights are used for larger areas, such as reflecting pools where the safety factor required demands the highest level of long-term reliability.

One of the largest applications of lead for waterproofing purposes in recent times was at New York City's massive World Trade Center. Approximately 700,000 lbs. of lead sheet were installed in critical areas around the huge center for moisture protection. This enormous use of lead included what is believed to be two record setting applications:

The most lead used to flash the base of buildings-about 72,000 lbs.
The most lead used in a single installation to line landscaping planters-about 500,000 lbs.

Most of the lead was installed in the World Trade Center Plaza, a huge five acre elevated platform that surrounds the center's building complex and covers hundreds of underground shops and actively-used space. Lead's corrosion resistance, freedom from maintenance, and the fact that it provides for a trouble free waterproofing membrane are the primary reasons why it was specified. There has been no water leakage in the lead protected areas since the center was completed in 1974.

Lead was used on the plaza level of the World Trade Center to line 26 huge landscaping planters used as flashing around the base of buildings facing the plaza's center court. In addition, about 77,000

Reflecting pools and decorative fountains make extensive use of sheet lead waterproofing. The sheets on the sides are formed to follow the cant profile, then burned (welded) and flashed to other sheets to complete the waterproofing integrity.

lbs. of lead were used to waterproof the center court's huge water fountain.

Lead also was used to line 30 planters on the street level and to waterproof exterior stairways leading from the street level to the plaza and from the plaza to the center's concourse level. About 51,000 lbs. of lead were used for the latter application.

Both 6 psf (3/32 of an inch thick) and 8 psf (1/8 inch thick) lead were used. The lead contains not less than 3 3/4 percent antimony and an arsenic content of 0.10 percent to provide for increased fatigue resistance and decreased thermal expansion. Sheet sizes as large as practical were used in order to keep joints to a minimum and thereby help to insure the watertight integrity of the lead.

NOISE CONTROL

Noise-it can destroy hearing. It can create physical and psychological stress and contribute to accidents by making it impossible to hear warning signals. The technology to curb noise levels of many sources now exists. The many variations of materials to control noise are all derived from three basic noise reduction principles:

* Blocking of Sound Waves-Materials must act as barriers to noise transmission. The essential characteristics of a barrier are high mass and limpness.
* Damping of Sound Waves-Materials must reduce radiated noise. Materials used for this function would be resilient in nature.
* Absorption of Sound Waves-Materials must dissipate noise. The characteristics of this type of material are an open, fibrous or cellular structure and generally light weight.

Sheet Lead as a Barrier-The effectiveness of any barrier to noise transmission is established by three factors:

Mass	The greater the weight per square foot of barrier, the more sound it can block.
Limpness	A limp material blocks sound over a wider range than a rigid material, which can radiate the sound.
Integrity	There must not be a path through or around a barrier.

Sheet lead is heavy. Its high surface density (59 lb./sq. ft. per inch of thickness) will provide more of a sound barrier than a thicker layer of plaster, glass or concrete. There is a point where these other materials will gain stiffness that negates the effectiveness of their density. (Table 5).

Because of its inherent limpness, or softness, lead cannot be easily set in vibration. It does not resonate or "ring," hence it cannot radiate sound.

Being a metal, sheet lead has an advantage over various aggregate materials, since it is more uniform in density throughout. Also, its softness allows it to be easily cut, folded, formed or crimped. This allows sheet lead to have the flexibility required to insure the integrity of the barrier system.

Thus, sheet lead meets all the criteria for a good barrier. This, coupled with the fact that it can be readily adhered or fastened to other materials for structural or sound absorption purposes, facilitates the development of effective noise control systems.

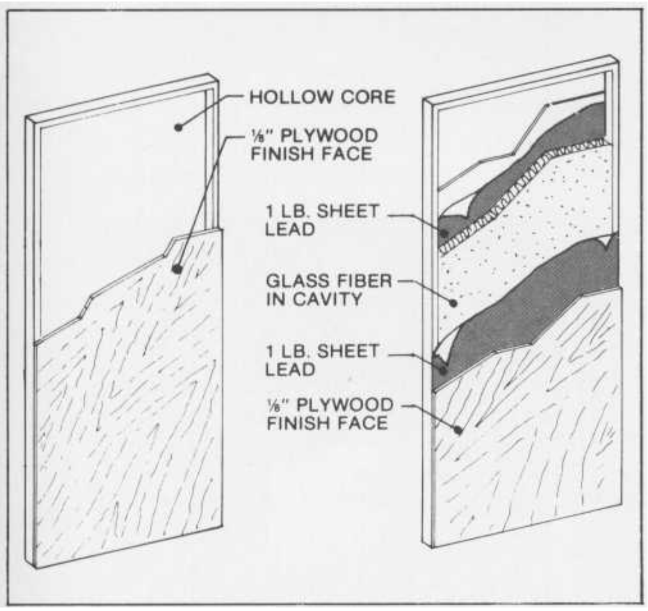
TABLE 5
Lead for Noise Control Compared to Other Materials

Approximate thickness of single, simple partitions to meet permissible transmission loss requirement.

Material	Thickness required in inches		
	Moderately noisy office	Quiet office	Very quiet office
Fir plywood	3.67	6.67	13.33
Sand plaster	0.20	4.45	8.9
Glass	0.13		9.3
Dense concrete	0.14	4.85	12.2
Aluminum	0.13	5.7	11.3
Steel	0.045	0.20	7.0
Lead	0.030	0.135	0.54

The stepped line indicates the break between those materials which are limp enough to use their weight efficiently (below the line) and those which are stiff enough to lose the effectiveness of their weight (above the line).

Besides its effectiveness alone in sheet form, lead can lend its properties to other materials. Leaded plastics in sheet, tile or bulk are effective in blocking airborne noise, as well as damping the ringing of metal structures-from small stamped metal panels to steel decking.



Laminated materials using lead make the confinement of noise within rooms relatively simple. Doors, however, are usually the weakest links in such walls. But doors can be made equal in effectiveness to flanking walls by means of lead laminated to the inner faces of finishing piles, as diagramed above.

Typical Uses

Today, lead and leaded materials are being used in office equipment, transportation, skyscrapers, and industry to control noise. In typewriters and sound movie cameras, leaded damping materials are modifying the character of the noise produced.

Plenum Barriers. Today's typical office has a hung ceiling of lightweight, sound absorbent material. Usually there are perforations through the ceiling for lighting fixtures, sprinkler heads, air diffusers and the like. At each such opening, in fact, the entire lightweight ceiling surface acts as a point of entry for sound to get into the plenum above. And sound can escape through the same paths. Thus, walls between offices are bypassed and privacy destroyed. By hanging a sheet lead plenum barrier from the slab above to the top of the partition, this sound path can be blocked. Or a sheet lead barrier can be laid right over the ceiling tile or pans. While this latter scheme is often distinguished as an "over-the-ceiling" barrier, in a general sense it is also a plenum barrier. Because dense, limp materials have a terrific edge over light, stiff materials in blocking sound transmission, sheet lead is an ideal barrier to airborne sound. In addition, the ease with which sheet lead can be cut, shaped and formed in the cramped plenum makes it far and away the easiest material to install. This is invariably reflected in an acoustically better job at lower cost.

High Transmission Loss Ceilings. High transmission loss ceilings provide a means of attenuating sound generated by noisy or vibrating mechanical equipment on upper floors. These floors are frequently adjacent to prime rental areas requiring low overall noise levels.

Two pound sheet lead is commonly used for this application. It may be attached to gypsum lath or board, using staples or adhesive before installation, or may be laid as a blanket over the ceiling construction during installation. Sheets should be lapped a minimum of two inches and should be carried up perimeter walls a minimum of four inches. All laps and joints should be dressed snugly together and may be taped if necessary. Caulk thoroughly at all perimeter points and at penetrations. Vibration isolation hangers are recommended at all points of suspension.

Finally, at least half, and preferably the entire area of ceiling construction or soffit of slab above, should be covered with any fibrous, absorptive material available in batt, sheet or blown form.

In cases where the source of noise comes from above, the sound barrier location should be moved from ceiling below to floor above. In the typical case of an apartment dwelling with joist construction and rough and finish floors of rigid construction, the noise level in the apartment below can be excessive. Acoustical improvement, in such cases, can most easily be achieved by installing sheet lead directly on the offending floor-being careful to turn the material up around the entire perimeter of the room behind baseboards or mop strips. Quickly and economically installed, two or three pound lead ($^3/_{32}$ or $^3/_{64}$ inch thick) will yield a five decibel increase in sound transmission loss, making loud noises above barely audible below (after the addition of carpet underlayment and carpet).

Ducts. Noisy ducts are quieted by covering them first with a layer of sound absorbing material, then a wrapping of sheet lead. If the duct is exposed to view, then a layer of aesthetic covering, such as aluminum or plastic, may be applied.

In the case of a rectangular duct, it is often more convenient to use an absorber of the board type rather than a blanket. Glass and mineral wool batts and boards are suitable absorbers. Duct seal tape or spot application of adhesive are simple ways of anchoring the absorber while applying the lead sheets.

When the width of the duct exceeds 30 inches, it is good practice to support the sheet lead to prevent sagging.

Acoustical Walls. The problem of internal noise in buildings is not new. Nevertheless, changing trends in building construction towards lighter and thinner walls, ceilings and partitions-coupled with increasing noise levels caused by growing numbers of telephones, typewriters and/or business or household machines-have accentuated the problem.

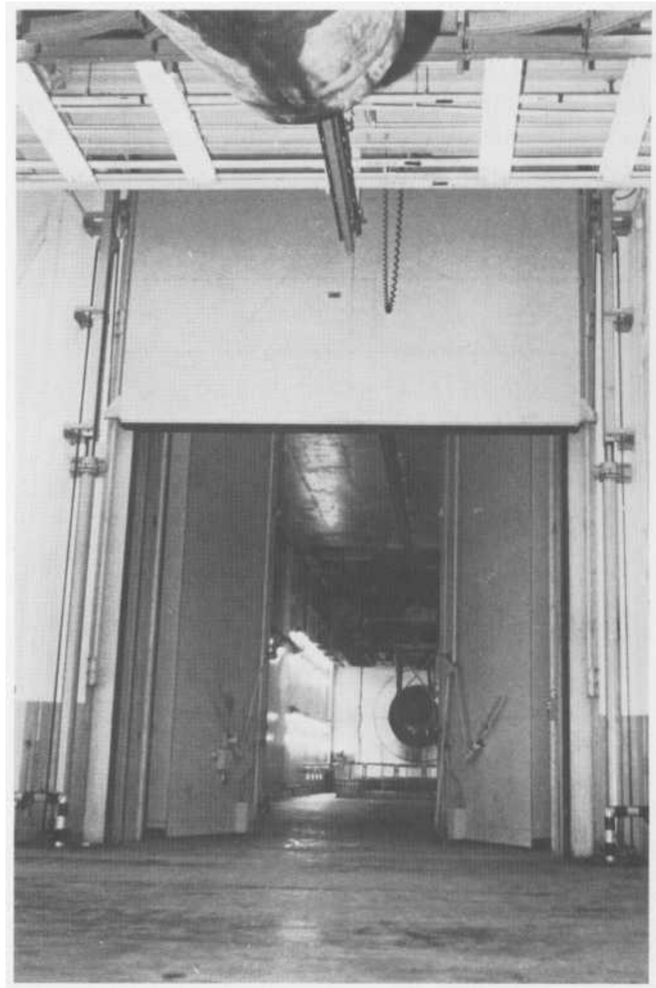
The excellent sound-stopping properties of sheet lead, either alone or in combination with other materials, have made it possible to cope with these problems. Lead's contribution as the most effective noise control measure in well built acoustical walls makes them available for:

* privacy between adjacent rooms or offices.
* containment of noise sources, such as office machines or household appliances.
* isolation of noisy or quiet areas, such as conference rooms or a furnace room near a family playroom.

Doors. Laminated materials using sheet lead simplify the confinement of noise within rooms. Doors are the weakest links in such walls. However, doors can be made equal in effectiveness to the flanking walls by means of one pound lead laminated to the inner faces of finishing piles. Approximately 1/64 inch thick lead sheets, with a decorative wood veneer laminated to one face of the sheet and a pressure sensitive adhesive laminated to the opposite face, can easily be added to one or both faces of doors where high acoustic isolation is required. Thorough and complete gasketing at jambs, head and sill is, of course, required for a successful installation.

Anti-Vibration. Massive without being stiff, sheet lead is a poor conductor of vibration. Its ability to effectively block vibration makes it a popular material for use under buildings and machinery. Sheet lead and asbestos or lead and synthetic rubber anti-vibration pads can be used to cut noise and vibration from intense sources. Accepting static loads up to and above 1,000 psi, anti-vibration pads block the structural path by which vibration can get to radiating surfaces where it emanates as noise. High tonnage presses, drop hammers, and other high impact machines create vibration in addition to airborne noise. These vibrations, unless short circuited, can be transmitted throughout the structure of an entire plant, even into office areas where they are translated into audible noise. To prevent this from occurring, and to isolate the vibration source from its foundation, is the function of these pads.

The sheet lead also protects the pad from environmental attack-by ground water in the case of foundations, by oils or corrosive fluids in machinery mounts.



Double-swinging lead-lined sound reduction doors, coupled with a secondary vertical sliding door, effectively isolate most unwanted noise from industrial operations, such as this jet engine test cell.

Engine Compartments (Marine or Industrial). Noise control features can be built into new tankers, pleasure boats, industrial plants or retrofitted where access is available.

The engine compartment can be treated as an acoustic enclosure. The compartment walls reflect engine noise, which creates a higher noise level due to reverberant build-up. Lining the compartment with a combination of one lb. per sq. ft. sheet lead (septum) and an absorbent material can eliminate the noise build-up and improve the noise barrier properties of the compartment walls.

Plant Noise Control. The scope of possible plant application is too broad to cover in detail here. In addition to the benefits given already in utilizing sheet lead, other factors for consideration in a plant are:

* The lead sheet noise control system can be designed so that it is easily integrated into a plant, both physically and operationally (e.g., does not cause costly disruptions).
* Lead sheet is unaffected by coolants, cutting oils, drawing compounds and other common industrial materials.

RADIATION SHIELDING

Criteria for the Selection of a Shield Material. Theoretically, almost any materials can 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.

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. 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 (e.g., tantalum, tungsten, and thorium are higher on the density scale), but lead is readily available, easily fabricated and the lowest cost of these materials.

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

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.

The main use of lead as a shield is against x-ray and gamma radiation, where the presence of other elements (as impurities or deliberate alloying additions) will have a minor effect, depending only on the degree of dilution of the lead. Where neutrons are also present, however, impurities or additions which would become radioactive must be avoided.

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.

Lead is heavier than roughly 80 percent of the elements in 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. In mobile shielding, 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 the levels 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.

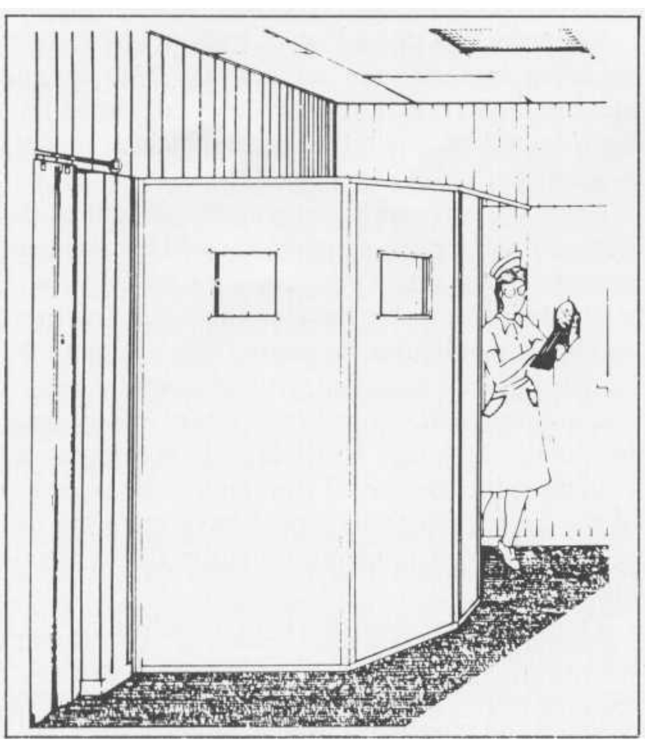
The traditional concept of lead being heavy must be re-evaluated in terms of providing a highly effective shield structure, with the lowest volume and weight of the commonly available material.

Also, 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 materials which, in turn, may become radioactive.

Composition of Lead Used

Grades of lead are specified by the American Society for Testing Materials (ASTM): B29, Federal Specifications QQ-L-171, Pig Lead, and QQ-L-201, Sheet Lead. For x-ray or gamma ray shielding, the grades of interest are a pure commerical lead (ASTM designation, Corroding Lead), and an undesilverized lead (ASTM designation, Chemical Lead). In the presence of neutrons it is important to consider a lead with a minimum purity of 99.99 percent.

Where lead is used as an unsupported shield in the absence of neutrons, greater hardness and rigidity may be required due to pure lead's relatively low structural strength. In these circumstances it has been usual to utilize a 4-6% antimony level, however similar improvements in strength can be obtained with calcium and tin alloy additions in lower total quantities, retaining the highest possible lead purity for shielding effectiveness.



Typical X-ray machine control booth design (prefabricated) utilizes sheet lead-filled panels. Leaded glass vision panels can be provided in one or more individual panels at any desired location.

Forms of Sheet Lead

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

It should be noted that there are a number of methods of applying lead for x-ray or gamma radiation protection, including sheet lead, lead laminated to common building materials, lead brick, lead lined block, leaded glass, and a variety of leaded vinyls.

The following forms of lead sheet are available from most manufacturers, their representatives, or specialized lead burning companies.

Sheet, plate and foil lead in thicknesses from 0.002 inch up to many inches. (See section "Specifying Sheet Lead" for details). Lead shielding, in the form of sheet/plate lead, is extensively used in hospitals, laboratories and industrial facilities for installations that often encompass a large area.

Homogeneous bonded sheet lead. It is manufactured by, as the name implies, homogeneously bonding lead sheet to a substrate material such as steel. This product finds applications in ductwork, pumps, etc., that carry radioactive particles or material.

Laminated panels of sheet lead, adhesive bonded to such materials as steel, wood, gypsum board, plastic and aluminum or other supporting material. This product is frequently used for space shielding because of its self-supporting nature and ease in erecting and handling.

Fabrication Methods

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.

Flat Sheet/Plate Construction. When lead shielding is required between the walls of a rectangular box container, use of flat sheet/plate is a simple technique for accomplishing this objective. The base, sides and lid are fitted with lead of convenient thickness, cut such that the joints between sides, sides and base, etc., are all of a stepped construction.

Cylindrical Sheet/Plate Construction. The sheet/plate should be of convenient size and weight to handle in relation to the container. The lead can be formed into a cylinder and adjacent edges lead welded (burned) together. If the shield is to be relatively thick, then a series of concentric tubes can be used or a stepped semi-cylindrical form made to fit the space between the container walls.

Wrapped Sheet Construction. Another relatively simple technique for forming a cylindrical shield is to rotate the inner shell on a lathe or similar equipment. While the shell is rotating, lead sheet is wrapped continuously around the shell up to the desired thickness

Homogeneously Bonded Lead. See above.
Laminated Panels. See above.

Typical Uses

Space Shielding. The basic protective barrier involves the use of sheet lead for the protection of the general area (e.g., 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 provide a more rigid building material. This type of shielding is found in hospital, medical and industrial x-ray installations.

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 and 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.

Lead Shielded Containers. With the development of nuclear power, and the 'increasing usage of radioactive materials in medicine and industry, there has been a growing need for shielded containers of all types and sizes. The materials to be transported include reactor fuels, irradiated fuel, radioactive waste, and radioisotopes. As a result, containers vary in size from isotope containers of a few pounds, to the large and complex fuel shipping casks of several hundreds or thousands of pounds.

Transportation Containers for Low-Level Waste. The primary goal in transporting any form of radioactive materials is public safety. In the event of a transport accident, the container design must provide the ultimate in structural integrity. It has to be constructed to prevent the release of large quantities of radionuclides, and the resulting significant increase in the radiation level, under any condition where the container is damaged. Transport containers can be made with sheet/plate lead for the smaller sizes. The larger containers are generally made by casting the lead between the steel plates.

Transportation Containers for High Level Waste. High-level nuclear waste is defined as the highly radioactive fission products which are stripped out of the spent fuel elements in the chemical extraction cycles used in the nuclear fuel processing plants. These wastes are initially in a liquid form. After a period of storage, the liquid is converted into a dry, stable solid which is highly radioactive.

The technology for building safe transport containers already exists, as the containment and shielding requirements for high level waste are almost identical to many types of spent nuclear fuel casks already in widespread use. It is expected that when these containers are designed, lead will again be the most logical choice for the shield material.

Storage Containers. There are two general classifications of storage containers: shipping containers for storage, and specially built facilities for storage. A common form of a storage container is a recess in a solid wall or floor, which requires the addition of lead shielding as a lining, as well as for any doors or covers. The area may be lined with sheet lead or a variety of lead laminates. However, any door or cover may require the lead shield to be encased in steel.

Nuclear Reactor Shielding. In atomic reactors or "piles," cadmium, lead, concrete and distance generally are used to protect operating personnel from exposure to all types of dangerous radiation. Chief among these are neutrons and gamma rays. Neutrons escaping from the uranium section of reactors are absorbed by a thin cadmium shield. This absorption causes the cadmium to emit gamma rays which in turn are stopped by a lead shield. Thus during the loading and unloading of atomic fuel, personnel are protected from neutrons by the cadmium and from gamma rays by the lead. Lead sheet/plate is also used in retrofitting sections of the reactors in which "leaks" have been detected.

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