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LEAD INDUSTRIES ASSOCIATION

420 LEXINGTON AVENUE
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LEAD SHIELDING BULLETIN NO. 1

To Members of the Lead Industries Association:

Attached is a reprint of the chapter on radiation protection from the Lead Industries Association's book "Lead in Modern Industry." Some revisions and corrections have been made on the original publication, and the reprint now represents current practice in radiation protection against both nuclear radiation and x-rays. Practical construction techniques are also included in the section under x-ray protection.

Additional quantities up to ten may be obtained free of charge from the Association as long as our supply lasts. Larger quantities may be had at 10 cents per copy.

Very truly yours,

Robert L. Ziegfeld

Secretary.

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RADIATION PROTECTION

Reprinted from
LEAD IN MODERN INDUSTRY

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CHAPTER THIRTEEN

Radiation Protection

The harnessing of atomic energy has brought with it the problem of controlling the powerful rays emitted during atomic disintegration. Basically the problem of protection from these rays is the same as from X-rays and radium. Technicians have for many years known the hazards involved and they have worked out several methods of protection. But while today's radiation problems are similar, they are far more significant both because of the wider use of radioactive materials and the potentially greater intensities to be worked with.

The various types of rays—alpha, beta, gamma, neutron—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 in. of wood will completely absorb beta rays. Gamma radiation on the other hand has great powers of penetration. High energy gamma will not be wholly absorbed by even a foot of lead while lower energy gamma may be safely absorbed by $\frac{1}{16}$ in. or less of lead. Gamma rays produce large scale ionization by a secondary process, that is, the gamma ray first produces a high-speed electron and this, in turn, produces the ionization. Neutrons emitted by the cyclotron and 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.

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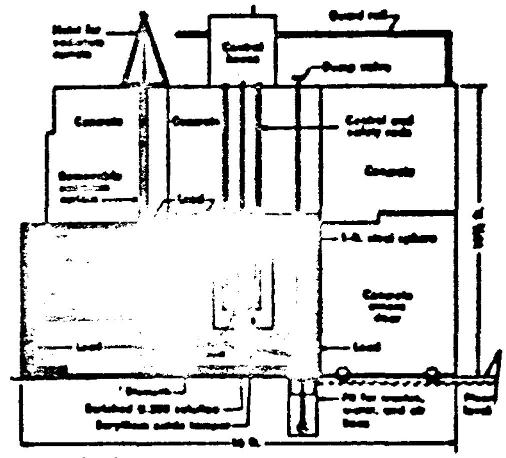
The dangers of exposure to radiation are classified into two separate categories: internal and external. The former is primarily a hygiene and medical problem and because it does not involve shielding as such it will not be discussed here. External radiation comes from a source outside the human body such as an X-ray tube, cyclotron, radium or radioactive samples. Protection against external radiation is a question of shielding the body from the rays, keeping a safe distance away from the rays, and limiting the time of exposure to the rays.

In shielding against neutrons metallic cadmium or a hydrogenous material such as water or paraffin is generally used. However, because gamma rays are emitted when the neutrons are absorbed, it is still necessary to provide a protective shield of lead. The use of protective shielding is identical in all cases, regardless of the type of ray, the thickness of the shielding depending upon the penetrating power of the rays.

The first consideration in preventing penetration of rays is density. Lead enjoys the advantage of being the densest of any commonly available material. Where space is at a premium and utmost radiation protection is paramount lead is always prescribed. Another advantage, particularly in shielding neutrons and gamma rays, is that lead does not become contaminated. It may be used continuously without fear of itself becoming radioactive and emitting its own harmful rays. For this reason it is important that lead specified for shielding purposes be free of alloying elements, particularly those which may become radioactive upon exposure to high energy radiation.

Being a metal, lead has an advantage over various aggregate materials such as concrete in that a uniform density is guaranteed throughout. In addition, because its surface is smooth it cannot become contaminated with dirt or other material which, in turn, may become radioactive. Oftentimes where exceptionally high energy levels are being shielded and where the concentrated load of the quantity of lead required would be prohibitive, a combination of concrete and lead has been employed. The lead may be sandwiched as a sheet between layers of concrete or may be used on either side of the concrete. Lead cast or extruded into bricks has proven especially useful in atomic shielding because the bricks can be easily moved to areas where special temporary shielding is needed and can be built up to any thickness or placed in any position desired.



Lead and concrete shielded atomic reactor.

In atomic reactors or "piles" operated by the Atomic Energy Commission, cadmium, lead, concrete and distance are used to protect operating personnel from exposure to all types of dangerous radiation, chief among these being 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 are in turn stopped by a lead shield. Thus personnel during the loading and unloading of atomic fuel are protected from neutrons by the cadmium and from gamma rays by the lead.

In one type of reactor a 4 in. shield of lead-cadmium alloy surrounds the reaction area and fits snugly inside a concrete shield 8 ft. thick which encases the entire reactor. The lead-cadmium alloy protects the concrete from direct exposure to neutrons and gamma rays. An extra 1-ft. shield of lead bricks is located on top of the reactor to compensate for the absence of concrete. The thick lead shield at the side and bottom is constructed with internal copper tubing for circulating cooling water to remove heat generated in the shield itself and the exterior of the reactor chamber.

A column made of graphite bricks extends into the heart of the reactor to provide a path for thermal and slow neutrons. The end of the column protruding through the outer concrete shield is covered with a cadmium curtain and a 2-ft. lead and iron shield in which an 8-in. square opening is provided for access.

The first uranium-graphite reactor, breeder of the original Atom Bomb, looked like a windowless two-story square concrete building, 30 ft. wide, 32 ft. long and 21 ft. high. On the sides of this early reactor concrete alone was depended upon for protection. The top of the pile was paved with 6 in. of lead, totalling about 155 tons. On top of the lead was an additional layer of 4 ft. of solid wood. Resting on this shield was a small experimental laboratory in which operating personnel worked, secure in the trust that they were being protected from the tremendous energy being generated beneath them by the 4-ft. layer of wood and 6-in. layer of lead.

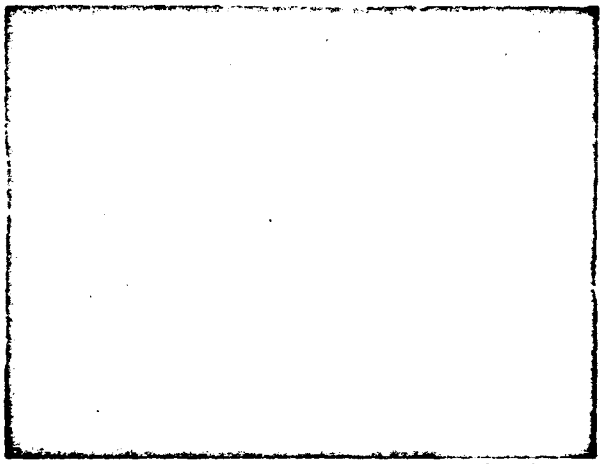
The table given below prepared by the National Bureau of Standards may be used to determine the required thicknesses for shielding from gamma ray sources in the laboratory. To use the table select the column for the energy required (use next higher if exact value is not given). The entry gives thickness in centimeters of lead for different source strengths at 1 meter for 8 hr./day to give 50 milliroentgens. Then add algebraically the correction terms for other working ranges or times to obtain the shield thickness required.

Example: Shield is required for the manipulation of 500 millicuries of radioactive material emitting 1.3 million electron volts (Mev) gamma rays at a minimum working distance of 50 cm., and for 4 hr./day.

$$\text{Shield thickness} = \underset{(a)}{8.60} + \underset{(b)}{2.77} - \underset{(c)}{1.39} = 9.98 \text{ cm. of lead}$$

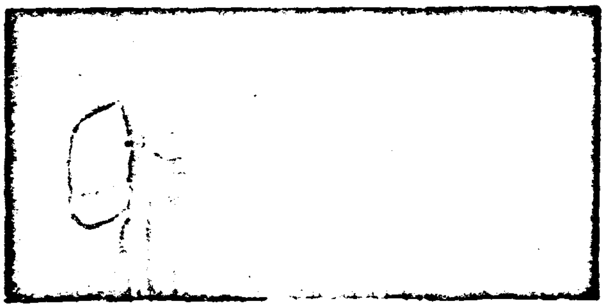
in which

a = basic entry.
b = correction for danger range = 50 cm.
c = correction for 4 hr./day.

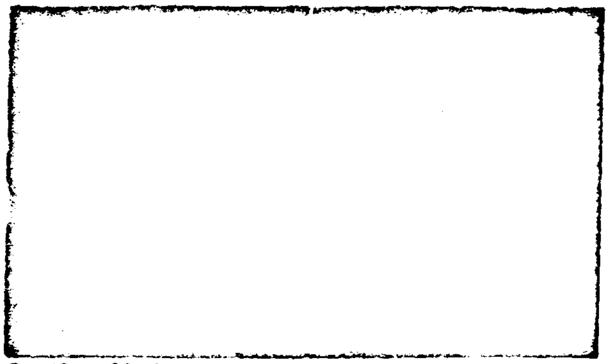


Atomic Energy Commission

At the shield face of a nuclear reactor, a cast lead entry port and lead bricks protect operating personnel from radiation injury.

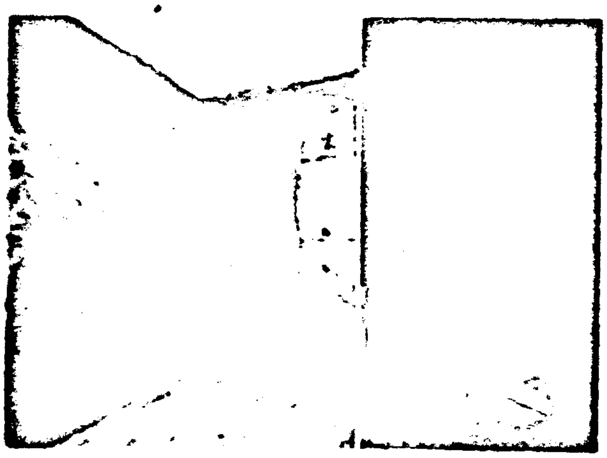


Left. In a radioisotope laboratory, special purpose lead castings and lead bricks protect the technicians. Radioisotopes are stored in the lead brick "hot" cave on the left. *Right.* Highly radioactive cobalt 60 is shipped in this lead lined steel container.



General Electric X Ray Corp. — Allis-Chalmers Mfg. Co.

Left. Two million volt X-ray unit with lead collimating cone for directing the rays. *Right.* Twenty-two million volt betatron with lead collimator and movable lead shield.



Left. A sheet lead lined hospital X-ray room and door. *Right.* A sheet lead covered X-ray room floor with cement block-lead sandwich wall construction.

REQUIRED LEAD SHIELDING THICKNESS FOR GAMMA RAYS

	Energy (Mev)								
Activity	0.2	0.5	0.8	1.0	1.5	2.0	2.5	3.0	4.0
10 mc.	−0.14	−0.36	−0.27	− 0.11	+ 0.27	+ 0.78	+ 1.15	+ 1.40	+ 1.70
20 mc.	−0.00	0.00	+0.41	+ 0.76	+ 1.57	+ 2.16	+ 2.63	+ 2.91	+ 3.21
50 mc.	−0.01	+0.47	+1.21	+ 1.90	+ 3.15	+ 4.00	+ 4.57	+ 4.90	+ 5.20
100 mc.	+0.06	+0.82	+1.90	+ 2.77	+ 4.34	+ 5.38	+ 6.06	+ 6.41	+ 6.71
200 mc.	+0.10	+1.17	+2.67	+ 3.63	+ 5.54	+ 6.77	+ 7.52	+ 7.92	+ 8.21
500 mc.	+0.17	+1.64	+3.57	+ 4.78	+ 7.12	+ 8.60	+ 9.47	+ 9.91	+10.21
1 c.	+0.22	+1.99	+4.25	+ 5.65	+ 8.31	+ 9.99	+10.96	+11.41	+11.71
2 c.	+0.28	+2.35	+4.93	+ 6.52	+ 9.51	+11.37	+12.42	+12.92	+13.22
5 c.	+0.34	+2.81	+5.82	+ 7.66	+11.09	+13.21	+14.37	+14.91	+15.21
10 c.	+0.41	+3.17	+6.50	+ 8.52	+12.28	+14.59	+15.85	+16.42	+16.72
20 c.	+0.47	+3.52	+7.18	+ 9.39	+13.48	+15.98	+17.32	+17.93	+18.23
50 c.	+0.54	+3.99	+8.08	+10.54	+15.06	+17.81	+19.27	+19.92	+20.22
100 c.	+0.60	+4.34	+8.76	+11.40	+16.25	+19.20	+20.76	+21.43	+21.73
Danger range	Plus	Plus	Plus	Plus	Plus	Plus	Plus	Plus	Plus
20 cm.	+0.28	+1.64	+3.16	+ 4.02	+ 5.55	+ 6.44	+ 6.85	+ 7.00	+ 7.00
50 cm.	+0.11	+0.71	+1.36	+ 1.73	+ 2.39	+ 2.77	+ 2.95	+ 3.01	+ 3.01
1 m.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 m.	−0.11	−0.71	−1.36	− 1.73	− 2.39	− 2.77	− 2.95	− 3.01	− 3.01
5 m.	−0.28	−1.64	−3.16	− 4.02	− 5.55	− 6.44	− 6.85	− 7.00	− 7.00
10 m.	−0.37	−2.36	−4.52	− 5.76	− 7.94	− 9.21	− 9.80	−10.01	−10.01
Working time, hr/day	Plus	Plus	Plus	Plus	Plus	Plus	Plus	Plus	Plus
1	−0.17	−1.06	−2.04	− 2.60	− 3.59	− 4.16	− 4.42	− 4.52	− 4.52
2	−0.11	−0.71	−1.36	− 1.73	− 2.39	− 2.77	− 2.95	− 3.01	− 3.01
4	−0.06	−0.35	−0.68	− 0.87	− 1.20	− 1.39	− 1.47	− 1.51	− 1.51
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	+0.09	+0.56	+1.08	+ 1.37	+ 1.90	− 2.20	+ 2.34	+ 2.39	+ 2.39

Notes

(1) Source activity is quoted in millicuries or curies, where 1 curie is that amount of radioactive material that disintegrates at the rate of 3.7 x 10^{10} disintegrations per second. However, the table is computed on the further assumption that each disintegration yields one gamma photon of the selected energy. This will lead to inaccuracies whenever the disintegration is complex. More accurate calculations can be made by obvious methods when the disintegration scheme is known.

(2) The tabulation ignores the increased effective transmission of shields under wide beam irradiation.

(3) This form of shielding table is intended to form a guide in rapid erection of temporary shielding structures in the laboratory. Where permanent installations of maximum economy are planned, more detailed calculations by conventional methods are required.

LEAD EQUIVALENTS OF VARIOUS MATERIALS

Material	Mass density, g per cu. cm.	Lead equivalent, mm.	Corresponding thickness of materials, mm. — X-rays excited at peak voltages of 150 kv.	200 kv.	300 kv.	400 kv.	Gamma rays
Iron	7.9	1	11	13	13	11	2.5
		2	25	27	20	18	5
		3	37	40	28	23	7
		4	50	55	35	28	9.5
		6			48	36	12
		8			60	45	16
		10			75	56	19
		15				75	27
		20					35
		50					80
		100					150
Concrete:	2.2	1	55	80	60	50	8
2 parts ballast		2	100	150	95	75	16
2 parts sand		3	230	210	125	100	22
1 part cement		4	296	275	150	120	30
		6			210	150	40
		8			260	185	55
		10			300	230	65
		15				300	90
		20					120
		50					220
		100					550

Some common applications of lead in the development of atomic energy and in the handling of radioactive materials include: lead bricks (interlocking or ordinary rectangular), lead plates and castings, "hot" laboratory table and sink tops, storage, carrying and shipping containers, lead rubber gloves and aprons, lead glass aprons, lead glass windows, Geiger counter tube shields, lead shot, lead sheet sheathing, lead headed nails, lead plywood, lead lined cinder blocks, lead safes, and so on.

X-RAY PROTECTION

X-rays are widely used both by the medical profession and by industry. Since these rays can cause physical damage to persons exposed to them it is necessary to enclose X-ray generating units in chambers made of or lined with a material which is resistant to X-ray penetration. Since the impermeability of the shielding material is a function of its density, lead, which is the densest commonly available material, will give the greatest protection per unit of thickness. Lead is the least bulky and usually the lightest and most economical material for such shielding.

Although certain types of X-ray machines intended for production line operation are self contained in lead lined cabinets with automatic controls to shut off the course of power before the doors can be opened, a general X-ray department usually requires the provision of a lead lined room. Such a room must be carefully planned and constructed with the lead lining of sufficient thickness to keep the exposure of persons in its vicinity below safe tolerance limits. The principal factor in determining the proper thickness of lead is, of course, the intensity of the X-rays to be generated but consideration must also be given to the cumulative time of operation during the working day, the distance of the operator and other 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.

The intensity of the rays is a function of the voltage impressed on the tube and therefore it is customary to use voltage as a primary guide in selecting the proper thickness of lead required for X-ray protection. An accompanying chart gives the thickness of sheet lead protection recommended for installations of various voltages and correlates these recommendations with commercial

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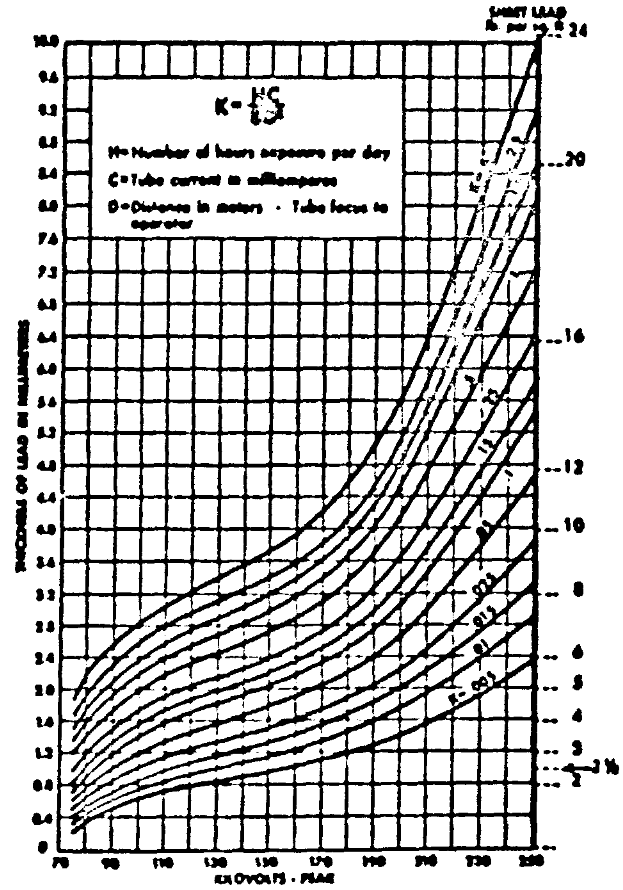


Thickness of lead barrier required to reduce X-ray dosage rate of the useful beam to 300 milliroentgens per week under indicated conditions.

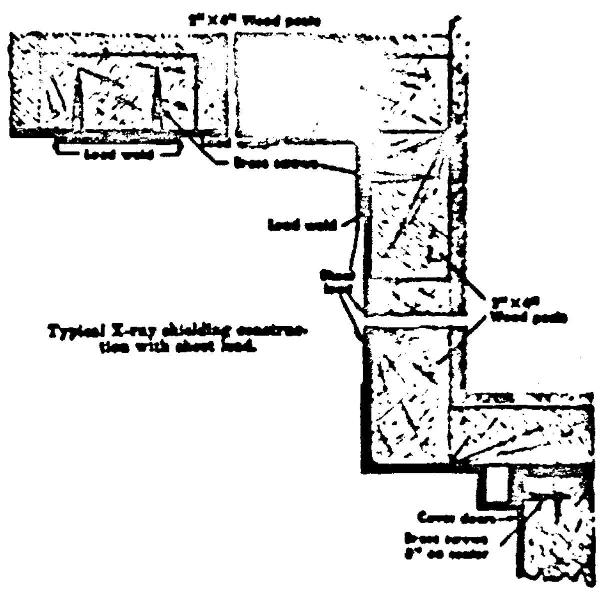
thickness of sheet lead. Having selected the proper thickness of sheet lead, the principal feature to watch in obtaining effective shielding is to see that no even minute space exposed to the rays is left unshielded. Thus no screw or nail holes, *with or without screws or nails in them*, or cracks around doors are left without being completely shut off or shielded by lead.

LEAD SHIELDING CONSTRUCTION

There are a number of methods of applying lead for X-ray protection. Several special devices incorporating lead are available for wall construction. These include sheet lead bonded at the factory to plywood, wall or other board materials on one or both sides with special lead covered strips for covering the joints and special lead headed nails for securing the material in place. Another device is a concrete or gypsum block with an unperforated sheet of lead anchored at its center. The two halves of this block on each side of the lead are about 1 in. off center so that their edges are offset by that amount. The sheet lead, however, extends to the outer edge all around. Thus when a wall is built up of these blocks, the lead in one block overlaps that in all adjoining blocks by 1 in. and provides a continuous lead lining. Other special devices include lead-lined doors and lead-covered windows glazed with glass containing a high percentage of lead.

If such special methods are not used, there are a number of ways of applying sheet lead linings, all of which are satisfactory and the choice of which may depend upon the type of construction and other installation conditions. Some of these methods are described here.

In one method sheet lead is placed against the wall surface or studs with the long dimensions of the sheets running vertically. Sheets should not exceed 36 in. in width for ease of handling and should be of such width that joints will occur over vertical supports. Such joints should have 2-in. overlaps. At the top, sheets should turn out at least 2 in. onto a continuous horizontal support. Over the lead at joints and at about 16 in. intervals, 2 x 4 in. wood strips or steel angles or channels are placed running from the floor to ceiling. These are secured top and bottom and at intermediate points, the spacing of which depends on the weight of the lead but in no case should be more than 4 ft., by bolting through the lead to the wall. One or two horizontal braces between each pair of studs may be used to give additional support to thick linings. Lead patches are then welded or soldered to the lead on each side over all bolts. These patches should extend several inches in each direction beyond the bolt hole so that rays striking at an angle cannot penetrate the bolt holes. Metal lath can then be fastened to the supports and the wall finished in the usual way. Patches should be of the same thickness of lead as the lining to eliminate any possibility of leakage.



Typical X-ray shielding construction with sheet lead.

A method suitable for masonry walls is to build 2 x 4 in. wood studs into and flush with the wall at 16 in. intervals. Sheet lead with the long dimension running vertically may then be screwed

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to these studs. A perforated steel strip against the lead under the screw heads helps to distribute the load. Strips of lead may then be placed over the screw heads or steel strip and welded or soldered to the sheets on each side. Screws should be about 6 in. apart. A slight variation of this method is to screw the edge of only one sheet to each stud, allowing the edge of the adjoining sheet to overlap the screw heads and steel strip and be welded or soldered to the first sheet, thus covering the screw holes.

Still another method is to use horizontal wood sleepers built into and flush with the wall at 2 ft. intervals. The sheet lead is then applied as in the previous methods, but with the long dimensions running horizontally, the screw heads being covered as before by overlapping.

Another method successfully used is to employ boards screwed horizontally to regular studs. The lowest boards are applied first to a height of about 18 in. and are then covered with a sheet of lead which is turned back over the upper edge of the top board and then turned upward about 1 in. against the studs, where it is screwed. Another tier of boards 18 in. wide is then applied in the same way, fitted down over the set-back of the first sheet of lead, and covered with lead in the same manner. The joints between the lead sheets are then soldered or welded.

Sheets in all cases should be bent around corners and at intersections so that they can be welded or soldered to the sheets on the adjoining wall to make the lining continuous. Wall sheets should be turned out several inches on the floor to insure ample lap between wall shielding and floor shielding. The lead lining should also be carried around the rabbet of door jambs so that it will overlap the lining of the door itself when in the closed position.

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.

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Protection on ceilings may be accomplished most easily by laying lead, with overlapped joints, on the floor above or on a drop ceiling. In such cases, the lining should be extended well beyond the lead walls below it. This projection of the floor lining should be enough to prevent passage of the rays through the gap of the floor construction between the lead walls and the lead on the floor above, as the rays travel in a straight line at an angle to the wall and ceiling.

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 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 15-lb. felt. In either case it is advisable to protect the lead from the action of "green" concrete by coating it with a thin layer of asphaltum.