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Abstract

This paper describes general types of shielding doors and the drive systems for opening and closing them. It compares estimated costs of the different types of doors based on factors they have in common. It describes a number of shielding doors designed and built at Lawrence Radiation Laboratory. These include a vertically rising door actuated by a hydraulic cylinder in a pit beneath it, a rotating slotted-barrel door, a swinging door, and a number of more or less typical sliding doors. Some of the problems involved in the design and use of these doors are discussed. Actual costs for a number of doors are given.

Shielding Doors

The intention of this paper is to provide a very basic guide to aid in selecting a shielding-door configuration. The information contained herein comes from many different sources and no claim is made to originality.

Some elementary comparisons are made of such items as weight, space, power, and actuation systems. A few doors designed and built at Lawrence Radiation Laboratory are described, along with some of the experiences, good and bad, involved in their construction and use. Some actual costs we have encountered are presented, with the familiar comment that actual costs more often than not exceeded estimated costs. The personal conclusion is reached that sliding or rolling doors offer the most for the money. Swinging doors under the proper conditions can also be good. The other types should be considered when their advantages offset their disadvantages.

Figures 1 through 8 represent rather typical shielding-door types. In these figures the cave wall thickness is twice the door width. An average width for doors around Lawrence Radiation Laboratory is about 36 inches. It is well to remember that a door type selected on the basis of a 2-to-1 ratio is not necessarily the best selection for other ratios. The assumption is also made that the door provides shielding equivalent to the wall of which it is a part. All figures are drawn to the same scale to facilitate comparisons. A great deal can be learned about comparative features of different types of doors by simply looking at these figures. Block size and floor area comparisons can be made quite easily. The block size, when considered with respect to the drive method, gives a comparison of the power requirements.

Maze Doors

Figure 1 shows a maze door. The proportions and shape shown are certainly not sacred, but are drawn to give line-of-sight opaqueness equivalent to the thickness of the cave wall. This type of door has the decided advantage of being simple. There are no actuating systems to worry about. A simple wooden gate across the opening provides a safety interlock with the beam. These mazes can be rearranged or moved with a minimum of effort. They can even be combined with solid doors; they provide adequate shielding for lower-intensity particle beams with the solid door left open. This is done in the Medical cave at the 184-inch cyclotron when the beam consists of α particles. The most obvious disadvantages are the large floor areas and the excessive quantities of shielding required. The amount of shielding involved could make these doors cost more than a solid door. Another important disadvantage is that although the maze can serve effectively as shielding, it cannot, unless made extremely tortuous, compare with a solid door.

Sliding or Rolling Doors

Figures 2 through 5 show various kinds of sliding or rolling doors. They offer much in the way of versatility and simplicity. They should be given careful consideration in the preliminaries of selecting a solid shielding door.

These doors are often mounted on commercially available flanged-wheeled trucks, and are rolled in and out of position on railroad tracks. The doors can also be suspended from an overhead beam on rollers, leaving the floor area clear for access. A flat bearing plate on the floor with thin guide strips welded onto it could serve as a track, and with cam rollers as wheels, would provide a minimum-clearance undercarriage system.

A more novel system is to use an air cushion. Oil or water cushions can also be considered, but they are somewhat messy to work with. This approach, although simple in principle, is not as practical as one might wish. A good surface is required and the cushions are sometimes hard to stabilize. In some cases, however, they may be satisfactory if it is desired to move a door in an odd pattern. When these cushions work properly, friction is almost completely absent; for this reason it is necessary to provide a guide to control the motion. The lack of friction can make it difficult to stop the door.

The motive power for the types in Figs. 2 through 5 can be almost anything. The forces required to move them can be quite low. A manual drive is possible, but the required frequency and speed of opening are the primary factors that determine the practicality of a drive system. Electric motors, air motors, and pneumatic and hydraulic cylinders are the more common types of motive power. The cylinders are usually directly connected, and in many cases it is possible to use plant water or air as the powering fluids rather than a special pump system. The motors are used in conjunction with gear reducers, chain or belt drives, rack and pinion gearing, and whatever else designers can dream up.

The power required to drive these doors is a direct function of the weight and the coefficient of friction of the carriage system and the speed desired. The force required to move a door for any reasonable rolling element should not be greater than 0.01 the weight, and it is usually less than this.

Figure 2 Door. The door in Fig. 2 is simply a large block that is moved across an opening. (It is possible, by moving the block along an axis perpendicular to the opening, to form a simple maze in the open position.) An example of this door is installed at the 184-inch cyclotron. It has been in operation for many years and has given good service. The door weighs 60 tons, the opening is 72 inches, the opening time is 35 seconds. It is bottom-mounted on flanged wheels and railroad tracks. The tracks are inclined so that gravity helps to open the door. A pin at the bottom of the block carriage engages a special link in a chain which moves the block.

This door has an emergency opening feature worthy of some comment. The drive is by electric motor and a power failure puts it out of commission. During a power failure it is necessary to enter the cave quickly. To do this an emergency lever is pulled that disengages the drive pin from the chain, and this 60-ton behemoth goes roaring down the incline. It comes to a screaming halt amid a shower of sparks as it attempts to slide up a reverse incline on its underside. At least once someone not familiar with the cyclotron pulled the emergency lever, thinking it was the normal opening method. It is not difficult to picture the sequence of events that this action caused. A 30-ton crane is required to set everything back in order. This emergency opening feature is no longer used except in cases of dire emergency. In ordinary types of emergencies a brake on the drive motor is released and the door is allowed to drift open. This is not as quick or dramatic as the other system, but it saves time in getting the cyclotron back in operation.

Plug, Corner, and Common Doors. The 88-inch cyclotron has several very good examples of the door types shown in Figs. 3, 4, and 5. Table I gives some of the data on them.

Figure 3 (Plug) Door. This door is mounted on a commercial truck with flanged wheels and rides on tracks set into the floor. Two wheels are driven with an electric motor gear-reducer system that is mounted on the truck in a place accessible for servicing. The door block consists of a steel armor-plate slab tied into a 150-lb/ft^3 concrete block. This door is very simple, works well, and gives few problems.

Figure 4 (Corner) Door. The two Fig. 4 doors are mounted on trucks and tracks in a fashion similar to the Fig. 3 door. They are driven with hydraulic cylinders. One end of the cylinder is attached to the bottom of the door and the other end is fastened to the floor of a shallow pit in the floor area between the rails. The opened door almost completely covers the pit. A 150-psi hydraulic oil pumping system provides the driving fluid. The door blocks are again a composite of steel armor plate and 150-lb/ft^3 concrete.

Figure 5 (Common) Door. This door is suspended from overhead, and rolls on a large beam supported between two parts of the wall. It moves quite easily and is driven by a 3/4-hp electric motor in conjunction with a rack and pinion. In an emergency the drive can be disconnected and the door opened manually. The dual-purpose feature does increase the complexity of the interlock system. The door block consists of armor plate and 150-lb/ft^3 concrete.

The actuating mechanisms for all these doors are simple and are easily accessible for maintenance and servicing.

Pivoted Doors

These doors belong in a class that requires relatively small-diameter bearings upon which the door blocks can be pivoted. It is possible to carry very high loads in this way and still keep the opening torque low.

Swinging Doors

Figure 6 shows a type of swinging door that is being used at the Bevatron. Two are in use at this time. The doors weigh about 5.5 tons each. They are 2 ft thick × 5 ft wide × 7 ft high, and are swung on antifriction bearing hinges. The actuator is one man. A problem is to stop them once they get moving, and a shock absorber is required at the ends of the travel. The anchor points for the hinges have to be good and solid. If good hinge anchors were available, doors on the order of 30 tons could be built this way and still could quite likely be opened by one man. The opening speed, however, would be slow and if the required opening frequency is high a booster system would undoubtedly be necessary. By looking at the figure it can be seen that an important relationship must be maintained between the cave wall thickness and the door opening size. It is obvious that a 1:1 ratio doesn't work. By stepping the edge of the closing gap the width required can be minimized.

Barrel Door

Figure 7 shows what we term a Barrel door, (some people call it a "man valve"). One of these doors is in use at the 184-inch cyclotron. It consists of a large rotating cylinder with a man-sized slot in it. The slot is 32 in. wide × 80 in. high × 88 in. long. It can be opened (or closed) in about 20 seconds. The drive consists of an air motor coupled to a gear reducer and a long roller chain wrapped around the cylinder. It is capable of moving the door much faster, but the inertia of stopping dictates the speed of opening. The air motor provides a simple way of varying the speed. The cylinder is pivoted on its axis on relatively small commercial self-aligning spherical roller bearings. It moves very easily, and in an emergency can be opened with either the stored air in the plant air lines or with a stand-by nitrogen bottle.

This particular door is unusual in several respects. It was designed to be, and is, portable --with the aid of a 30-ton crane. It consists of four basic parts weighing 30 tons each. The complete assembly is 138 in. (11 ft 6 in.) wide × 136 in. (11 ft 4 in.) high × 88 in. thick at its thickest part. It is made to go into a 60-in.-thick wall and to provide a shielding thickness equal to almost 12 feet of ordinary concrete. It is made up of steel and 300-lb/ft^3 concrete. The "wings" shown in the figure are required to maintain the proper shielding thickness when the door is closed.

The total cost, including engineering, overhead and fabrication, was $65 000. Part of this was due to the required high-density shielding, which is expensive, and part to abnormal problems. It is difficult to see how another door like this could be built for less than $45 000. The obvious conclusion is that there must be a better way. It seems as though a sliding type of door could meet the basic requirements of portability and high density more economically.

Center-Pivoted Slab Door

Figure 9 shows a configuration that, to my knowledge, no one has an example of. It could be called an "inverted barrel" door. It obviously requires a large chunk of wall space, but it could be made of higher-density material than the main walls and be thinner, so that less space would be required. The load is well-balanced, as in the barrel door, so that the pivot points do not require the solid anchoring of the swinging-door hinges. It is even possible that it could be built at a reasonable cost.

Vertically Rising or Pit Doors

Figure 8 shows a door type that is in use at the 184-inch cyclotron at the Medical cave. The door is opened by lowering it into a pit in the floor. When it is completely open the top of the door block serves as a walkway into the cave. This door is neat in its basic function, but there are problems involved in its construction and use. The pit is expensive and it fixes the position of the door in a permanent location. This particular door has an opening 48 in. wide × 82 in. high × 108 in. thick. The door block weighs 34 tons. It is actuated by an oil hydraulic system. The hydraulic cylinder is 8 in. i. d., with an 82-in. stroke, and requires a pressure of 1500 psi. A gear pump driven by a 30-hp electric motor supplies the power. The opening time is about 20 seconds and the closing time is 25 seconds. Opening is accomplished, simply, by a solenoid valve that opens on command and lets the weight of the block force the fluid out of the cylinder through a flow control valve into the pump reservoir. The hydraulic cushion at the bottom of the cylinder that is supposed to stop the piston gently at the end of its stroke unfortunately doesn't work properly, and it is necessary to compromise the opening rate. The time of opening could probably be cut by a factor of two if the cushion worked properly.

An extra set of microswitches is necessary to keep the door from opening because of leakage in the hydraulic system. The switches sense that the door has opened a predetermined amount and tell the motor to start and push it back up again. The odds of having a perfectly tight system are almost nil, so these switches are a necessity.

Space has to be found for a rather large pump and reservoir. Access to the pit has to be provided for servicing the cylinder and equipment below the door. Incidentally, props have to be available to hold up the door during servicing.

Emergency opening is easily done with a bypass hand valve.

Instead of a hydraulic system it has been suggested that an overhead cable hoisting system be used. This idea offers advantages over the hydraulic system. The pit could be much simpler, and the hoist might be of the same type as is used on cranes, and could be located on top of the door wall where it is out of the way and still accessible.

However the door is actuated, it is difficult to conceive of a method that would require more horsepower than that of lifting the full weight of the door through its full height in a reasonable time. Though the power required is not always of prime importance, the other advantages and disadvantages of this door type should be carefully weighed before it is chosen over another type.

General Considerations

Safety Interlocks

All doors at Lawrence Radiation Laboratory are interlocked with the accelerator in such a way as to prevent the beam from being turned on if the door is not properly closed; when the beam is on, opening the door will shut it off. In addition to the beam interlocks, there are certain basic safety measures to prevent anyone from becoming entangled between the moving and static elements of a door. A common system is to interpose a scissors-type gate across the opening so as to prevent the door from being operated when the gate is open. This system prevents anyone's being in the closing line when the door is moving.

The interlock system should be given careful consideration during the design stage. How much one uses interlocks is determined largely by the experience and philosophy of the accelerator operators who will be concerned with their use. It would be well to consider, however, that the experimenters who frequently use these doors are concerned with carrying on their own particular work, and it is worth some extra effort to try to make a door function so naturally that one hardly knows it is there.

Inertia

These doors, even though they move relatively slowly, generate large forces if they are stopped quickly. Enough difficulty is encountered in this area to make one think inertia is not always sufficiently considered. Pins in shear have been particularly bad actors, probably because they were not or could not be made large enough. Provision should be made for making all parts strong enough to take large stopping forces; otherwise, a means of bringing a door to a more or less gentle stop should be provided. One simple method is to cut the drive power before the door reaches the end of its travel and let it coast to a halt. Hydraulic or pneumatic cushions or mechanical springs are also good.

Earthquakes

At Lawrence Radiation Laboratory equipment is designed to resist an overturning moment of 0.2 g applied at the center of gravity. This can be a problem with narrow-based doors. Some areas, because of nearness to earthquake faults, require a design for earthquake loadings of 0.4 g.

Costs

Cost data can be deceptive and should be used with caution. The armor plate mentioned for use in the 88-inch cyclotron doors was available at almost no cost to the Laboratory at the time the doors were fabricated. If someone were to try to duplicate these doors without this advantage they would run into trouble. Perhaps the best way to keep costs down is to give careful consideration in the preliminary design stage to selection of the simpler types of doors. Special conditions, of course, may make a more complex door the more economical choice.

The costs in the table below are for concrete delivered to the site and ready for pouring. Anything else–such as forms, steel work, and the labor for pouring and finishing--is extra.

Concrete density (lb/ft^3)	Cost/yd^3 ($)	Cost/ton ($)	Cost/lb ($)
150	15	7.40	.0037
225[a]	130	42.80	.0214
300[b]	300	75.00	.0375

a. Aggregate consists of magnetite ore.
b. Aggregate consists of ferrophosphorous materials obtained through the AEC at $65 per ton.

The actual cost of a door block will depend upon any number of variables. A few are size, shape, steel fabrication work involved, forms and steel reinforcing requirements, tolerances, and the size of an order. In the space allotted for this paper, it is difficult to quote any actual door block costs that would make any sense. A true general statement can be made that smaller blocks cost more in dollars per pound of shielding than larger blocks-by as much as a factor of four. It is interesting to note that there is a point at which, if the fabrication work prior to pouring the concrete is expensive, the unit cost per pound of shielding can be decreased by filling the fabrication with the more expensive high-density materials. (The cost per block, however, still goes up).

Conclusion

Select the simplest door possible that will do the job.

Acknowledgments

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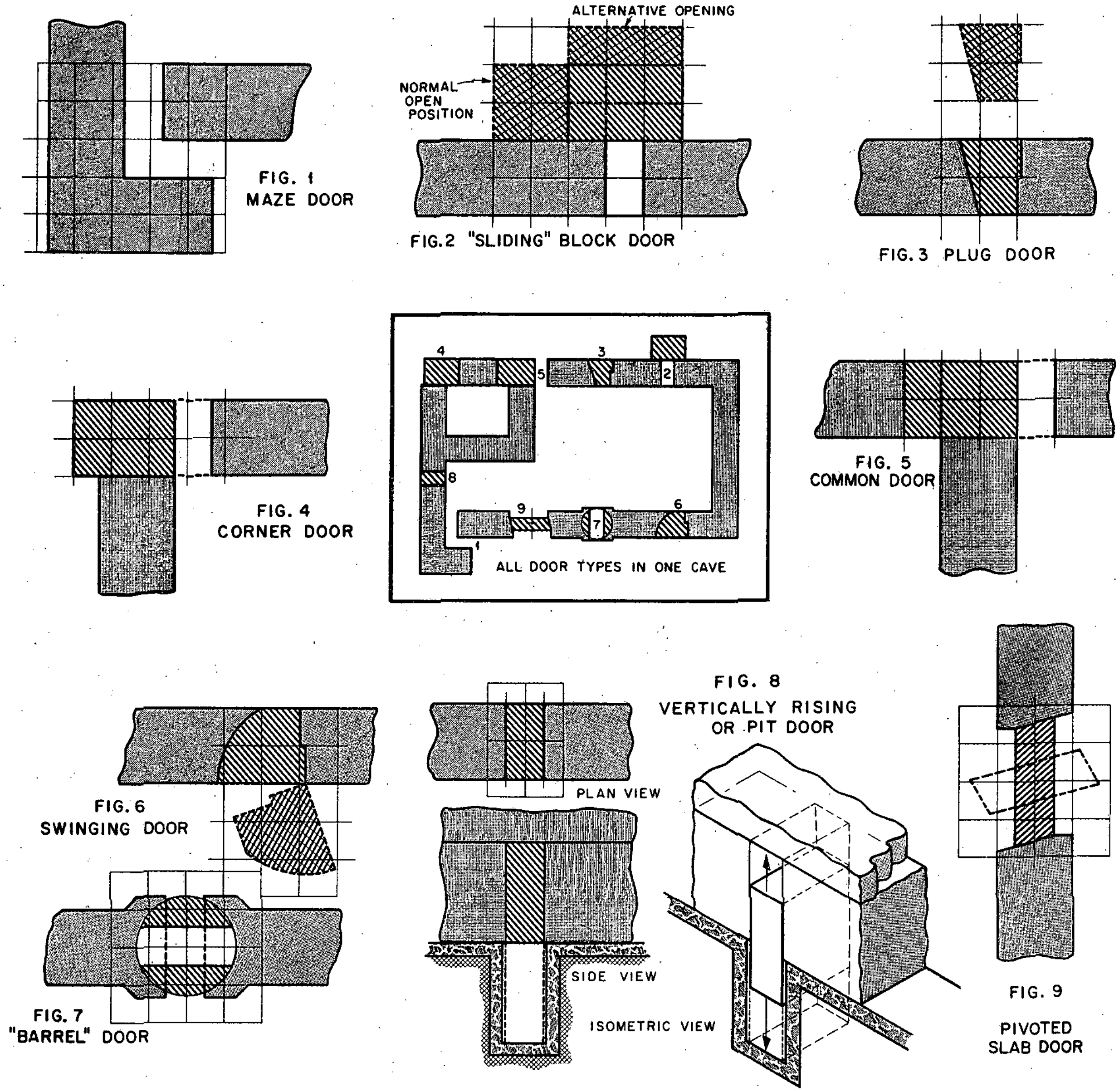
Table I. Data on shielding doors of types in Figs. 3, 4, and 5.

Type figure	Door wt (tons)	Opening (in.) W × H × Th	Travel (in.)	Opening time (secs)	Opening rate (fpm)	hp	Cost ($)
3	19.5	$39\frac{1}{4}$ × 96 × 48	$108\frac{1}{2}$	25	7.85	1.5	8 200
4	68.5	52 × 96 × 57	55	100	2.55	cyl.	*n. a.
4	41	$29\frac{1}{2}$ × 96 × 57	$29\frac{1}{2}$	35	4.22	cyl.	*n. a.
5	26	96 × 48	48	22	10.88	0.75	10 684

*Not available



Figs. 1 thru 9. General shielding-door types.