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MODULAR NEUTRON SHIELD

Alexander Babin

February 1968

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MODULAR NEUTRON SHIELD

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Abstract

A flexible, low-cost shielding system, consisting of water-filled steel cans and lead bricks, is described.

The shield is designed to protect against radiation, primarily from a spontaneous fission source of 50 to 100 μg ^{252}Cf and from a 1-curie gamma source.

Because of the modular construction used, shielding wall thickness and overall geometry can be readily modified, in order to attenuate different levels of radioactivity or to accommodate different enclosure sizes. Portable components include plain tank sections, zinc bromide windows, turntable unit, master-slave manipulators, interlocking 2-in. lead bricks, and structural support for assembled shield.

Introduction

In 1966, James T. Haley[1] pointed to the desirability of additional personnel protection in a number of research operations using ^{252}Cf sources.

The following examples--taken from his report--give an indication of some of the problems existing in certain experimental areas at the time of the survey.

1. Source in hood. Use of paraffin as neutron shield constituting a fire hazard.
2. Source in hood. No shielding. 5-mrem/hr neutron field at surface of hood being ignored because of unavailability of proper neutron shielding.
3. Neutron survey readings as high as 25-mrem/hr found in working areas, outside enclosures, containing ^{252}Cf samples. Radiation levels in center of room ranged from 5 to 8 mrem/hr.

In conclusion Haley proposed initiation of a study and design program, to eliminate potential health hazards associated with work on ^{252}Cf.

My assignment was to review the economics of various shielding materials and to design and develop a system of neutron and gamma-shielding hardware to achieve the required level of protection.[2]

The following goals were established from the outset:

i. Shielding against radiation from a spontaneous fission source of 50 μg ^{252}Cf to achieve approximately 2.5 mrem/hr at the outside surface of the shield. Obviously a quantity up to four times as high could be easily handled.

ii. Selection of materials and fabrication methods that would contribute to lower shielding costs.

iii. Modular construction of portable components, to facilitate quick erection and disassembly for use in different experimental areas.

iv. Low weight and bulk of modular "building blocks" to enable one or two men to assemble shield without the use of powered material-handling equipment (such as hoists and forklifts), particularly important in small or crowded laboratories.

v. The following shielding materials, singly or in combination, were to be considered:

a. Water
b. Lead
c. Concrete
d. Polyethylene
e. Zinc bromide solution (for windows). (Lead glass was eliminated because of its high cost and low neutron attenuation.)

vii. A design and development program was to lead to the construction of an actual cave, for use by Nuclear Chemistry's Heavy-Element Group.

The following report describes steps taken in the development of the shielding system and test results with the first cave.

Shielding Material Costs

In her memo "Investigation of Shielding Properties of Certain Materials for Use with Spontaneous Fission Sources and Gamma Emitters," Rosemary J. Barrett[3] obtained results that are summarized in Table I. The calculated dose rates are assumed to exist at the outer surface of the shield, with a 50-μg ^{252}Cf source emitting 1.1×10^8 n/sec through a distance of 16 in. in air before reaching the inner shield surface.

With the exception of concrete, all the materials listed in Table I require containers and framing for retention and structural support.

Although the complexity and cost of such supporting members may vary, a rough comparison of material costs alone, in terms of shielding effectiveness, is of interest.

Sidebotham and Standen[4] define "shielding value" as "the reciprocal of the cost per unit area of a slab shield, which reduces radiation by a factor of e," while "relative shielding value" is defined as "the shielding value of a material divided by that of Whinstone concrete as used at Windscale (England)."

In view of the available data in Table I, my approach is based on the simple premise that we want to achieve the lowest possible dose rate at the lowest possible material cost.

Assuming an arbitrary shielding slab with a 1-ft^2 face, the volume in cubic feet is the same as the slab thickness used (in ft).

The cost of this volume of material in dollars (A) multiplied by the corresponding dose rate (from Table I) in mrem/hr (B) produces a factor (AB), which helps in determining the relative shielding economy of one material over another.

A low AB factor signifies good shielding economy. A high AB factor signifies a high-cost material, low attenuation, or both.

Basic material costs, used in the following computations, are listed in Table II.

Table III summarizes computations of AB factors for the materials and material combinations of Table I.

Although Case 1 (water alone) appears to have the lowest AB factor, it was not selected, since the 16-in. slab did not provide adequate attenuation and a thicker shield was not desired.

However, Case 2 (lead-water combination) has an outstandingly low AB factor, and was selected.

Table I. Attenuations obtained with various combinations of shielding materials. S refers to position of source; fn, γ_p and γ_c refer to fast neutrons, primary gamma, and capture gamma, respectively.

Case	Shield	Dose rate D(r) in mrem/hr from 50 μg ^{252}Cf	Unshielded dose rate at 1 in. from a 2.5-MeV gamma source that would be attenuated to 2.5 mr/hr through this shield (r/hr)	Remarks
1.	Air and water S←16 in. air→*←16 in. water→|	$D(r)_{fn}$ = 0.92 $D(r)_{\gamma_p}$ = 4.74 $D(r)_{\gamma_c}$ = 1.32 6.98	6	50-μg source: main dose from primary gamma.
2.	Air, 2 in. Pb, water S←16 in. air→|2 in. Pb|←16 in. water→|	$D(r)_{fn}$ = 0.49 $D(r)_{\gamma_p}$ = 0.56 $D(r)_{\gamma_c}$ = 1.03 2.08	46	50-μg source: the primary gammas reflect the attenuation by the lead. The fast neutrons are halved, but they were the least important contributor.
3.	Air and concrete S←16 in. air→*←16 in. concrete→|	$D(r)_{fn}$ = 15.90 $D(r)_{\gamma_p}$ = 0.60 $D(r)_{\gamma_c}$ = 1.12 17.62	30	50-μg source: fewer H atoms/cm^3 in concrete than in water allows more fast neutrons through; primary gammas are shielded better.
4.	Air, 2 in. Pb, concrete S←16 in. air→|2 in. Pb|←16 in. concrete→|	$D(r)_{fn}$ = 8.05 $D(r)_{\gamma_p}$ = 0.04 $D(r)_{\gamma_c}$ = 0.68 8.77	224	50-μg source: fast neutrons are halved, as they were in the Pb-H_2O case. Primary gammas are reduced, but they are least important.
5.	Air, concrete S←16 in. air→*←18 in. concrete→|	$D(r)_{fn}$ = 9.70 $D(r)_{\gamma_p}$ = 0.34 $D(r)_{\gamma_c}$ = 0.80 10.84	53	50-μg source: the 2-in. Pb was slightly better than this additional 2-in. concrete.
6.	Air, $ZnBr_2$ Soln (ρ=2.5) S←16 in.→*←16 in. $ZnBr_2$→|	$D(r)_{fn}$ = > 2.47; upper limit = 9.25[a] $D(r)_{\gamma_p}$ = 0.33 — 0.33 $D(r)_{\gamma_c}$ = 0.01 — 0.01 2.81 — 9.59	39	2.5-MeV gamma source: comparable to the air-concrete shield except slightly better, as would be expected from comparing their densities: ρ(concrete)=2.35; ρ($ZnBr_2$) = 2.5
7.	Air, RE Inc.[b] polyethylene S←16 in.→*←16 in.→| air polyethylene	$D(r)_{fn}$ = 0.32 $D(r)_{\gamma_p}$ = 3.58 $D(r)_{\gamma_c}$ = 1.00 4.90	1.4×10^4 for 50% Pb-polyethylene (RE Inc. Cat. No. 205) 135 for 25% Pb-polyethylene (RE Inc. Cat. No. 204)	

a. Water content of window (≈ 21 cm) may be inadequate to invoke full use of computed $ZnBr_2$ removal cross section; the upper limit is the value without use of the removal cross section.

b. Reactor Experiments Inc.

Table II. Cost factors for various kinds of shielding.

Material	Density (lb/ft^3)	Cost ($/lb)	Cost ($/$ft^3$)
Water	62	negligible	negligible
Lead	710	0.20	142
Concrete	150	0.12	18
Zinc bromide solution	156	0.61	95
Polyethylene			
+ 25% Pb	216	0.61	133
+ 50% Pb	378	0.46	173

Table III. Cost-and-effectiveness factors for various kinds of shielding.

Case number	Material or combination	Shielding slab, 1-ft^2 face: Thickness (in.)	Shielding slab, 1-ft^2 face: Volume (ft^3)	A: Cost of shielding slab volume ($)	B: Dose rate (from Table I) (mrem/hr)	AB: Factor
1	Water	16	1.33	negligible	6.98	7
2	Lead	2	0.167	24		
	Water	16	1.33	negligible	2.08	50
3	Concrete	16	1.33	24	17.62	423
4	Lead	2	0.167	24		
	Concrete	16	1.33	24		
				Total 48	8.77	421
5	Concrete	18	1.5	27	10.84	293
6	$ZnBr_2$ Solution	16	1.33	126	2.81	354
7	Polyethylene + 25% Pb	16	1.33	177	4.90	867
	Polyethylene + 50% Pb			230	4.90	1,127

General Cave Design

After water and lead had been selected as the basic shielding materials, the containment and support of a 16-in.-thick water shield, and the structural support for the adjoining 7.5-ft-high 2-in.-thick lead wall, had to be designed.

In accordance with the initial requirements of portability and low weight for individual "modular building blocks," it was decided to construct the water shield of special steel cans. Overall can dimensions of 8×16 in. ×12 in. height were to be compatible with the American Building Industry's 4-in. "standard module" and "standard grid."[5] Outside walls were to be flat and unobstructed, so that cans could be manually stacked and banded together with steel straps into larger, palletized subassemblies or "can stacks." Figures 1 and 2 represent the general design adopted.

For the 2-in.-thick lead shield, a commercially available system of precision-formed interlocking lead bricks was selected (Graviner system).

To support the water and lead walls, a bolted steel frame construction was chosen ("Unistrut").

Windows were to contain zinc bromide solution.

Master-slave manipulators were to be of the CRL model "H" type. They were selected after extensive testing for coverage and ease of operation in various enclosures. Particularly attractive features of these manipulators are their compact size, low weight, and portability, all basic requirements for components of this shield.

The neutron shield, consisting of stacked, water-filled flat cans, naturally contains many cracks between them. To determine the amount of radiation "shine" through such cracks, James T. Haley and Robert J. Walker conducted a simple experiment. Using eight water-filled 5-gallon steel cans (9-3/8 in. square), a PuBe source (6.8×10^6 n/sec), and a moderated BF_3 probe and scaler, they obtained results as shown in Fig. 3. Judging from these results it appears that cracks or joints between cans have a relatively minor effect on the overall water shield attenuation.

To minimize even this slight effect it was decided to construct the actual shield of two layers of water-filled cans, with all cracks overlapping by 1-5/8 inches, both vertically and horizontally (see Fig. 4).

The Modular Water Can and Filling Procedure

A first attempt at possibly using low-cost standard commercial 5-gallon paint cans was soon abandoned. The steel sheet used (about 0.012 in. thick) was found to be too thin to support the weight of a column of water-filled cans. The tin plating on the steel failed very quickly when exposed to water. In our test samples, corrosion and penetration of steel occurred within a few weeks. However, the most obvious drawback was posed by the projecting screw caps and handles, which made close stacking of cans impossible.

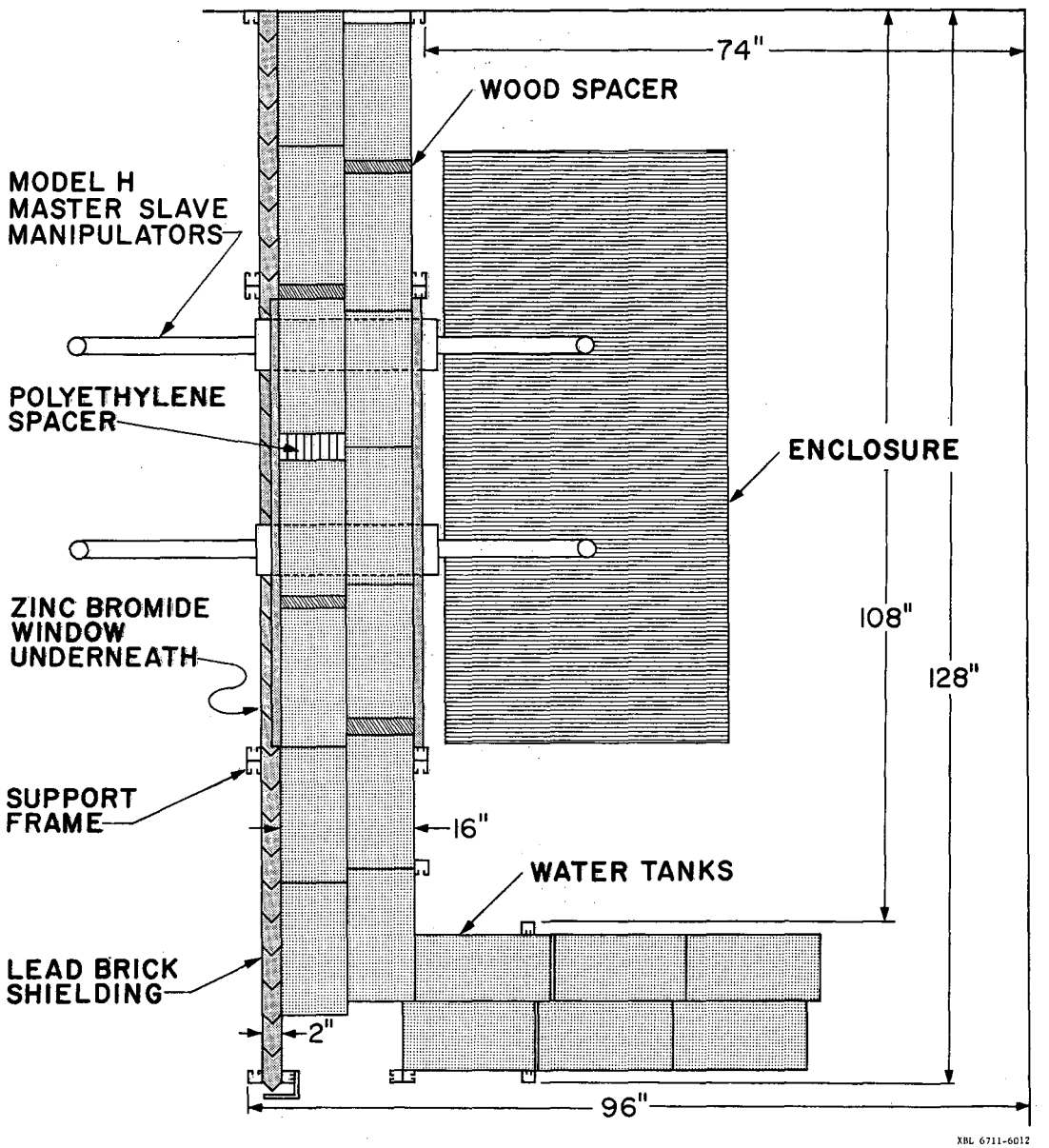

Fig. 1. Floor plan of cave assembly.

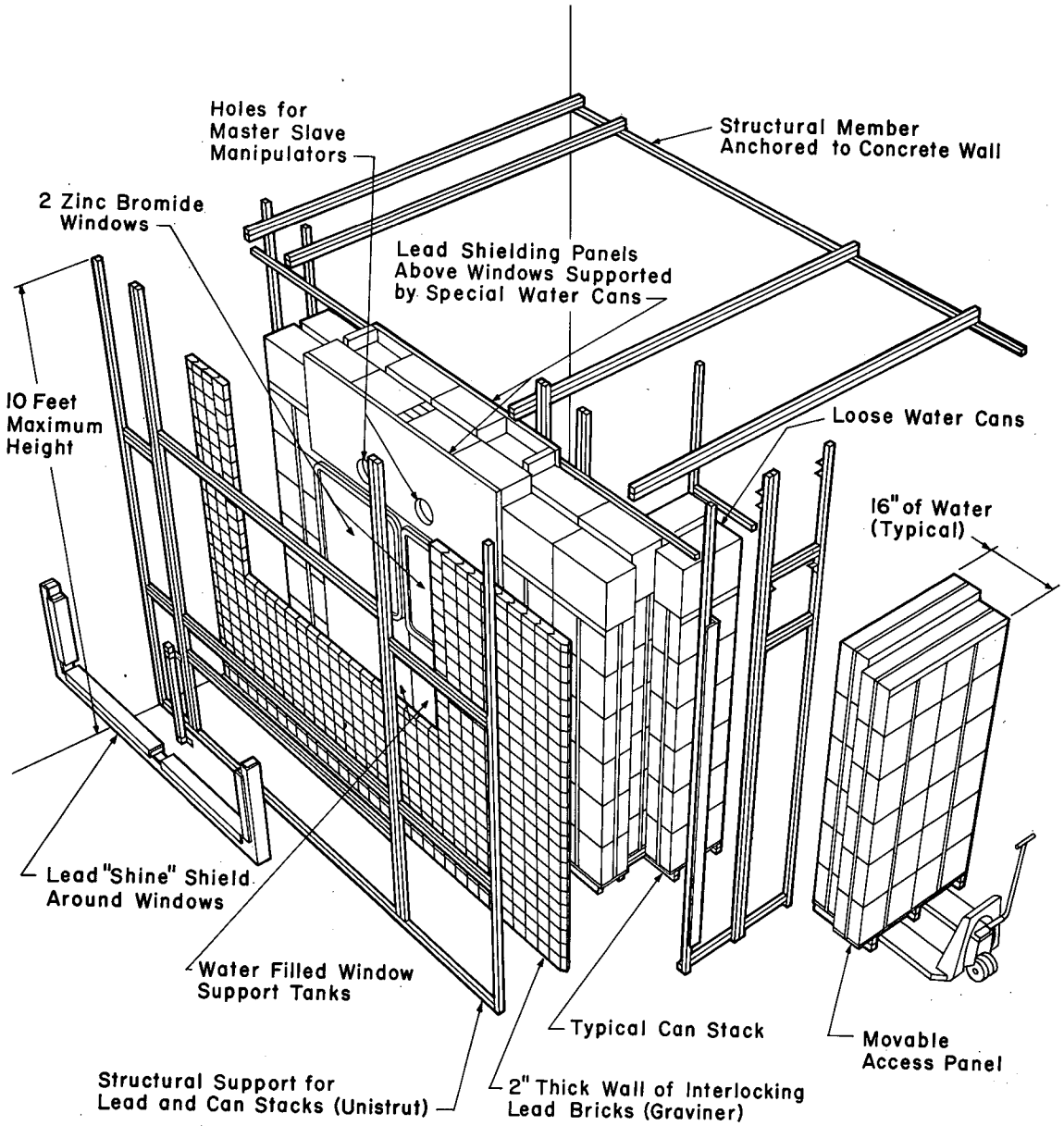

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Fig. 2. Cave assembly.

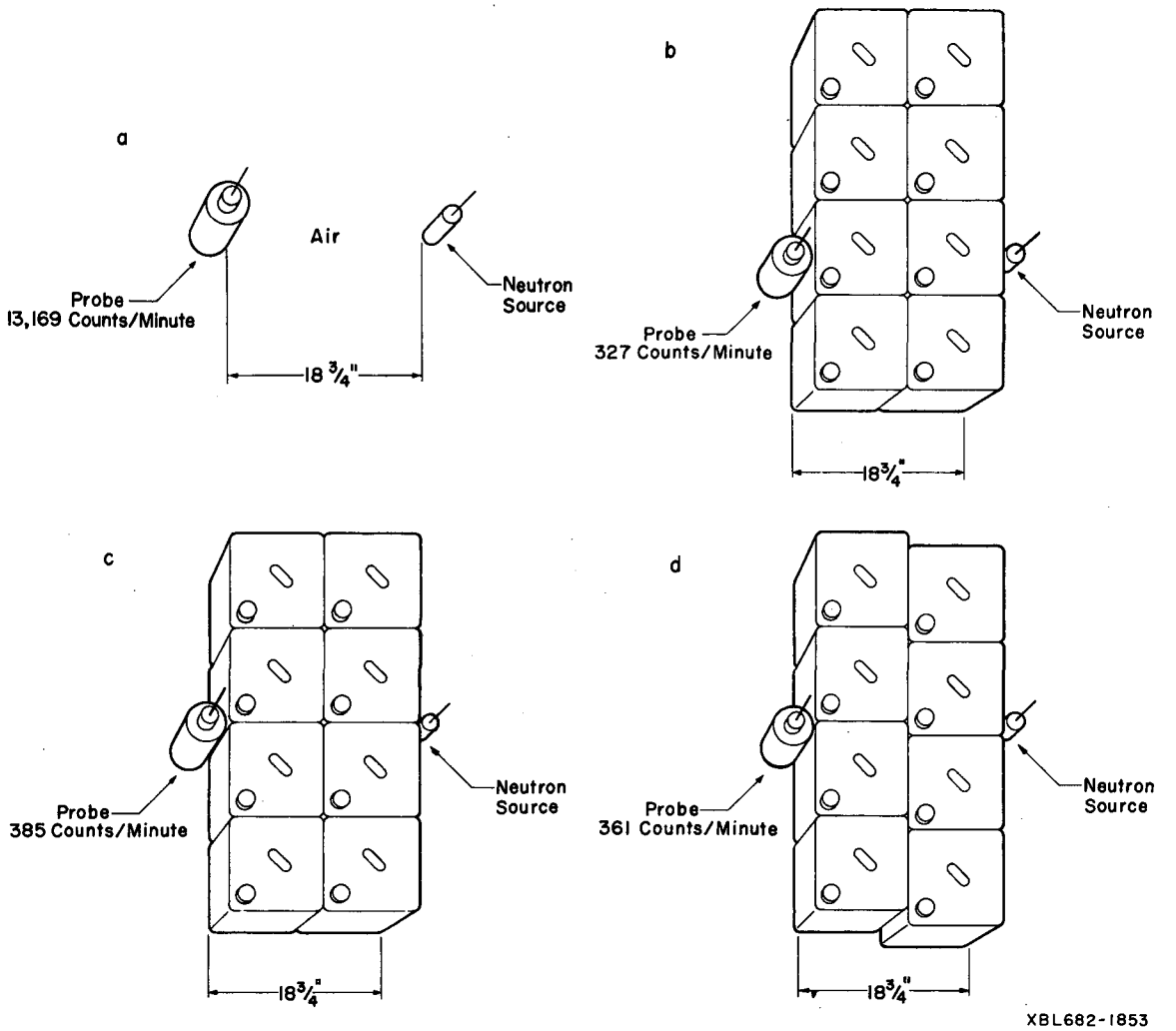

Fig. 3. Neutron counts received at probe through 18.75 in. of (a) air, (b) water-can shielding, (c) straight joint in shielding, (d) offset joint in shielding.

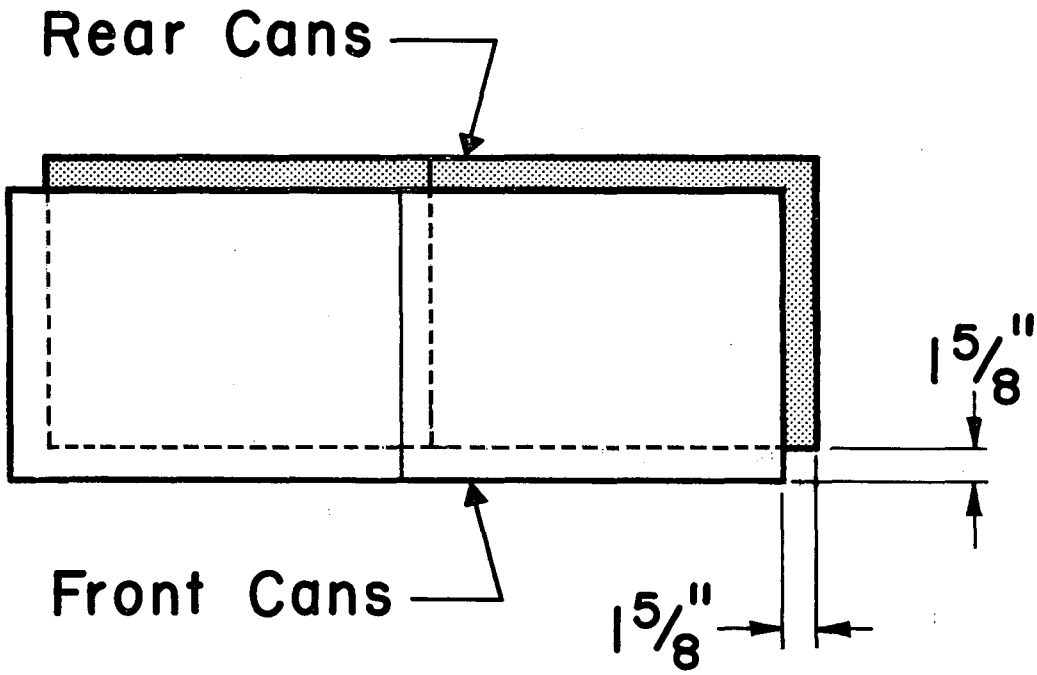

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Fig. 4. Method of stacking water cans to achieve overlapping joints.

Evidently, fabricated cans of special design were required, including the following features:

(i) Adequate structural strength: The steel gage selected (22 gage, 0.031 in. thick) was substantially heavier than ordinarily used for cans of this size.
(ii) Corrosion resistance: A lead-coated steel (long terne sheet) was selected for all parts of the can.
(iii) Unobstructed walls: To assure close stacking of cans, the normally exposed screw neck and cap were recessed below the can surface. This required a special filling procedure, described later. No handles were included in the design.

Cans were fabricated to our specifications by

Ellisco Inc.
American and Luzerne Streets
Philadelphia, Pennsylvania 19140

In the first group of fabricated cans, all joints were soft-soldered only. Although the conventional soft-soldered seam held up fairly well in an unloaded can, failure and subsequent leakage occurred rather frequently when water-filled cans were stacked six or seven high, strapped together with steel bands, and transported on forklifts and trucks.

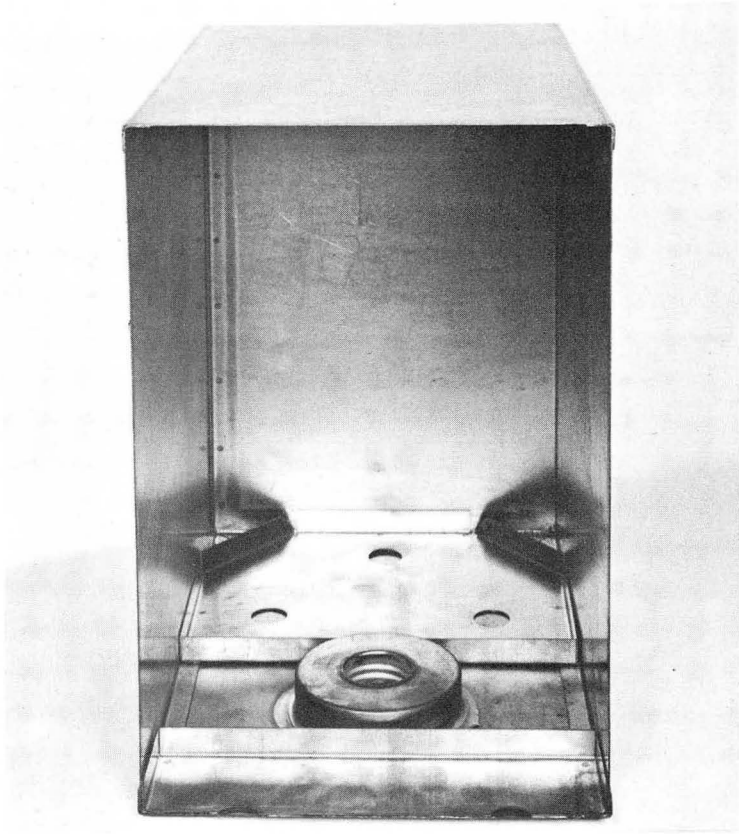
To overcome this structural weakness, silver soldering was briefly considered. It soon became apparent, however, that the higher temperatures needed to melt the hard solder would also melt the lead coating off the steel and expose it to corrosion.

A successful solution was to spot-weld the can seams before soldering. In our experience with hundreds of such cans, not one spot-welded seam ever opened due to mechanical stresses imposed on it. However, since there was no method available to spot weld the last four top seams, special internal reinforcing members were incorporated inside the cans to provide additional mechanical support to the can tops. See Fig. 5.

Despite these precautions a small number of top seams still failed from time to time, when subjected to severe banding stresses and vibrations. Since these occasional can seam failures occurred on top only, no loss of water resulted and the shield was not compromised. It is not a desirable condition, however, and the following possible remedies are suggested:

(i) The solder presently used is 50% lead and 50% tin, which is a relatively brittle combination. To obtain a more flexible joint, an 80% lead and 20% tin solder could be used.
(ii) Non-spot-welded seams could be riveted from the outside of the can (closed-end type "Pop" rivets). This would create a steel-to-steel contact, similar to the spot-welded seams.
(iii) A larger opening in the can top could conceivably be used to insert a special, swiveling spot-welding tool, making welding of <u>all</u> seams feasible.

Thermal expansion of water offered no problem, since all caps were left loose on their screw necks, to allow for possible overflow.



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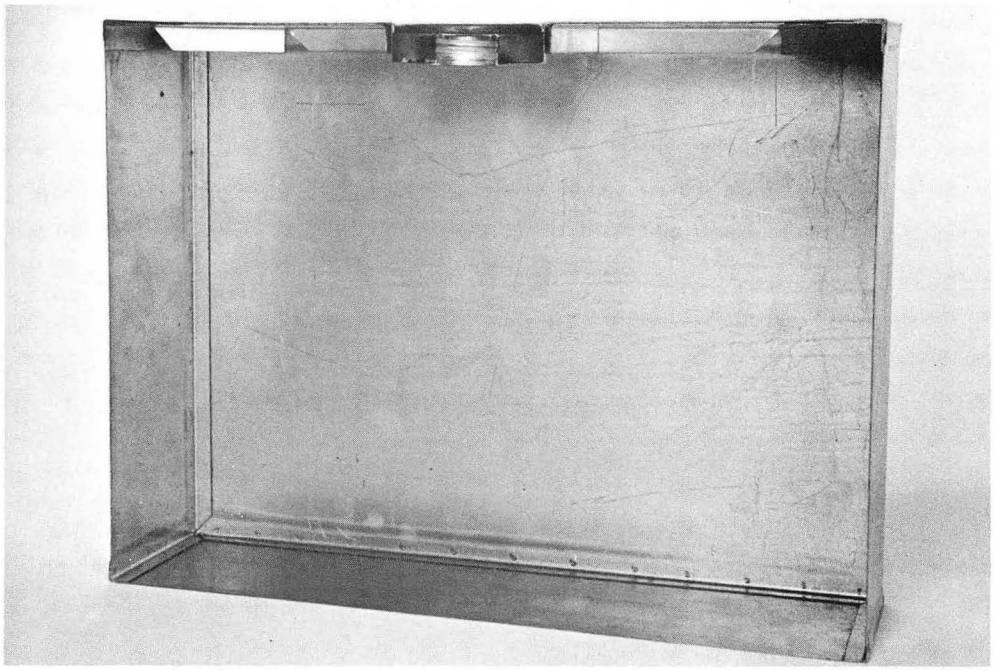

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Fig. 5. Sections through can, showing internal reinforcing members.

Since the can's screw neck opening is recessed below the top surface, and the can must be completely filled with water without entrapping air, special filling equipment was devised. Figure 6 shows the can filler, essentially a water supply line with a concentric adjustable vent tube, evacuating the air over a rising water surface. Since the can is filled with the screw neck facing downward, a stand was constructed, to revolve the can 180 deg, and simplify and speed up the filling procedure.

A corrosion inhibitor was added to each can before the filling operation (Fig. 7). The material used was sodium dichromate, and the concentration desired was 25 to 100 ppm.

Since a certain amount of water spillage during the filling process was unavoidable, material actually added was somewhat in excess of need.

Can Stack

Although the first attempt at building a water shield of modular cans consisted in loosely stacking them within a retaining framework of light steel members ("Unistrut"), this method did not provide the flexibility desired of the overall shielding system.

An alternative solution, which was adopted, involves the assembly of water-filled cans into a stack of 24, strapped to a special pallet and sheet-steel top plate with 0.020-in. -thick 0.75-in. steel strapping.

To produce the overlapping of cracks, mentioned earlier, a wood filler was placed under one row of can columns, raising them 1-5/8 in. above the level of the adjacent cans. The shape of the special mounting base, or pallet, as well as the top plate, were designed to position one row of can columns 1-5/8 in. to the left or to the right of the adjacent row, thus creating the desired horizontal displacement between cracks.

Figure 8 shows the elements of the can stack and the steel strapping tieing them together.

Window Unit

The basic window unit consists of the

(i) bottom tank,
(ii) zinc bromide window tank,
(iii) top tanks, including through-tubes for manipulator.

Bottom Tank

This bottom tank[6] serves a dual function, as a water shield and also as structural support for the window tank, top tanks, master slave manipulators, and lead shielding laminations mounted on top.

Neutron shielding requirements call for the use of a maximum amount of water and a minimum amount of steel.

Structural requirements call for stiffeners and beams within the tank, to make it strong enough to withstand both the internal (hydrostatic) and external

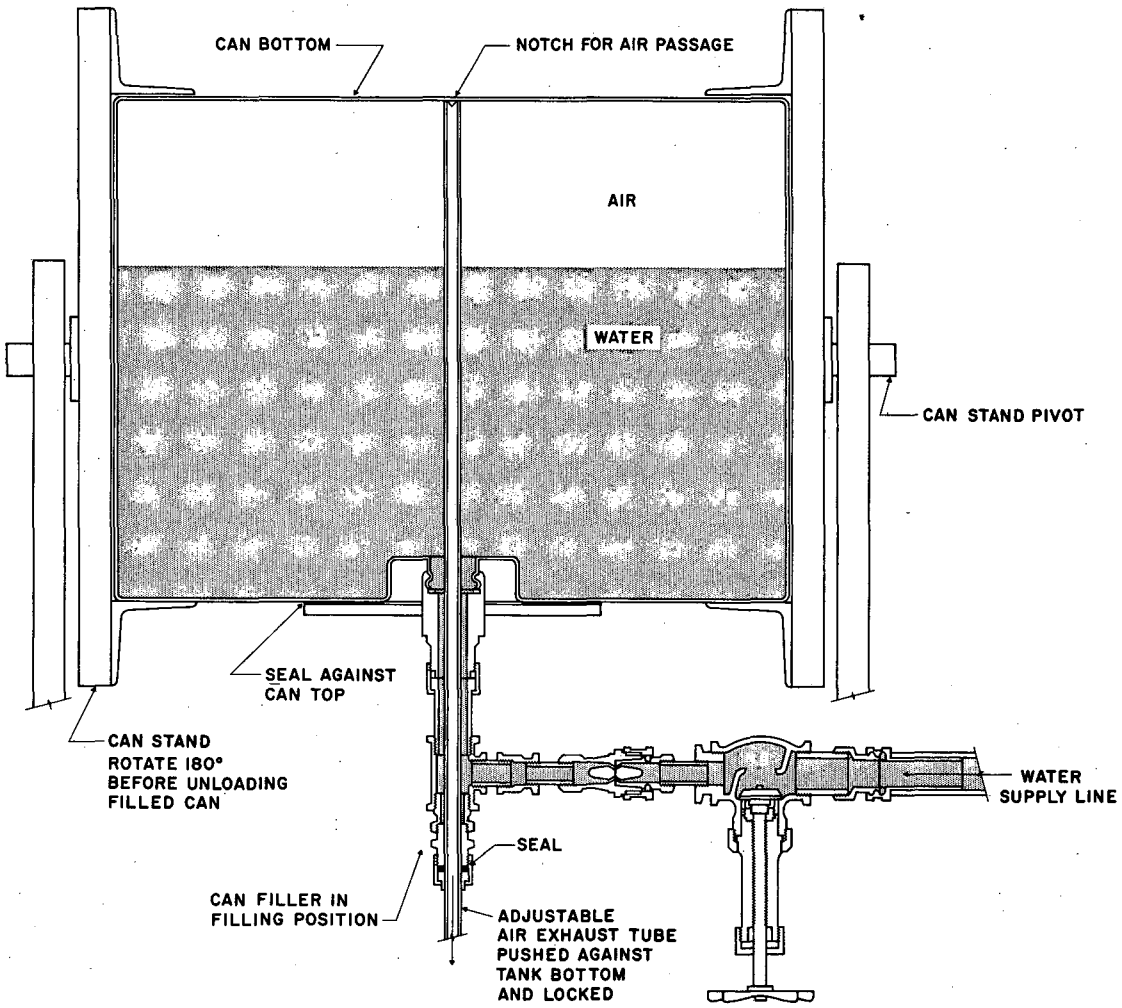

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Fig. 6. Can filler.

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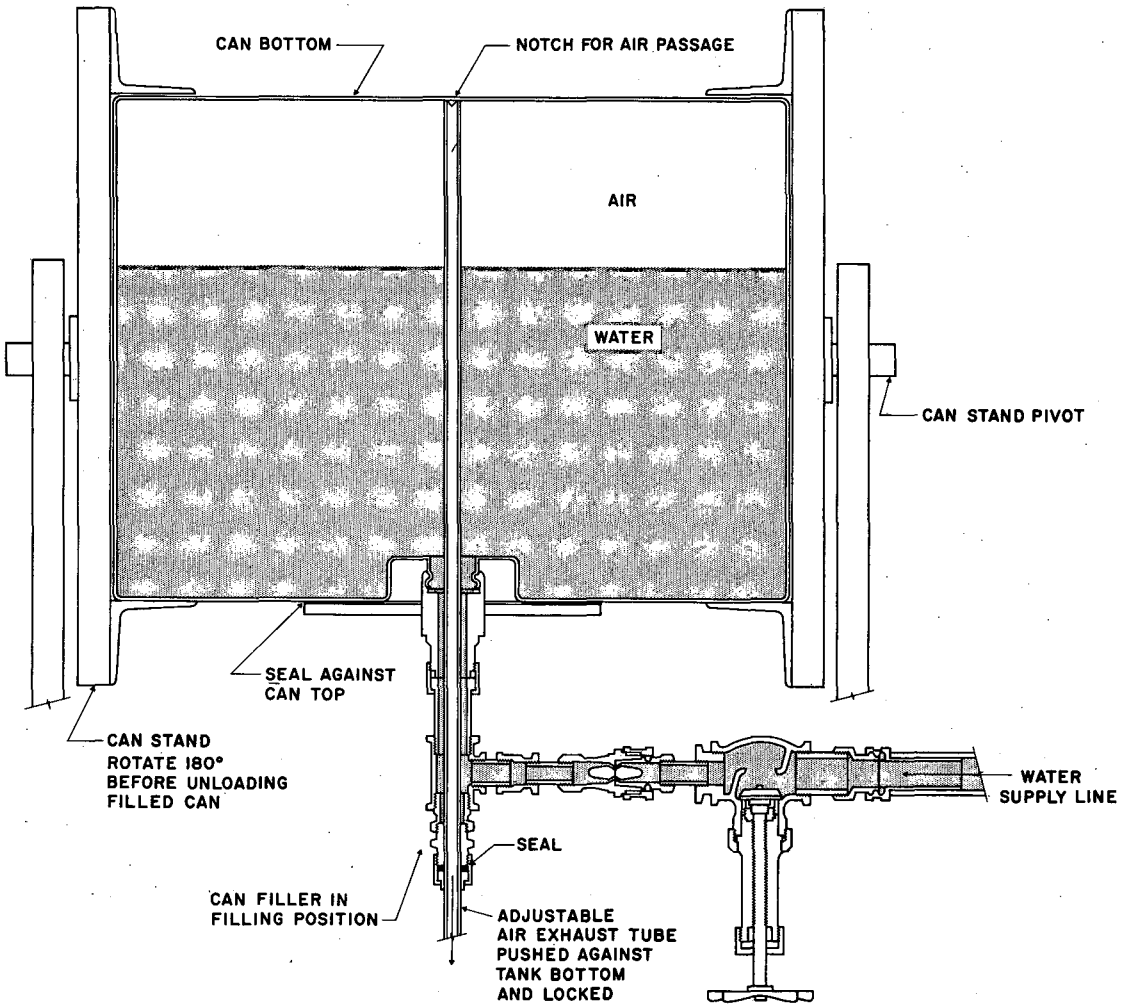

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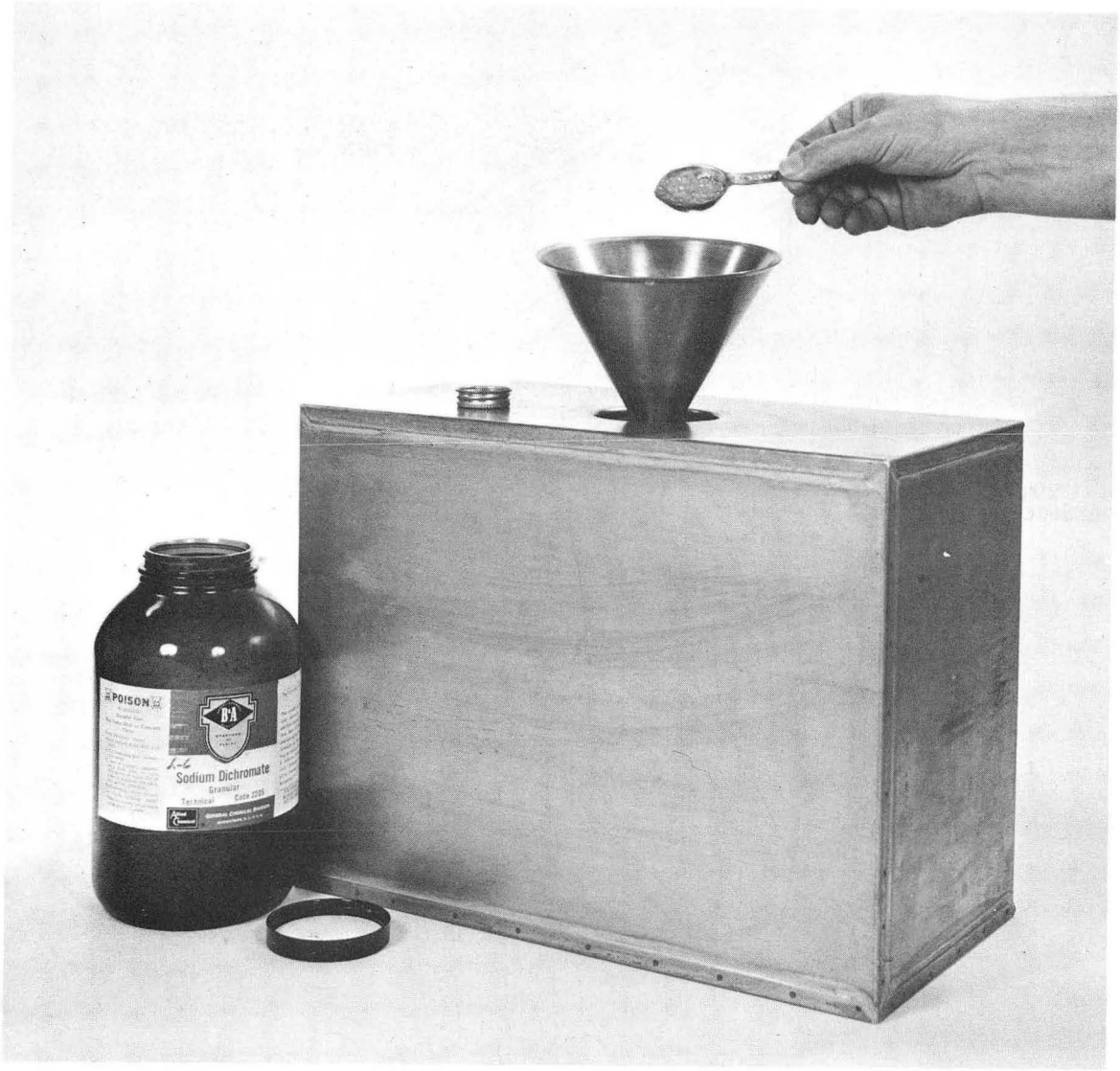

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Fig. 7. Corrosion inhibitor being added to can.

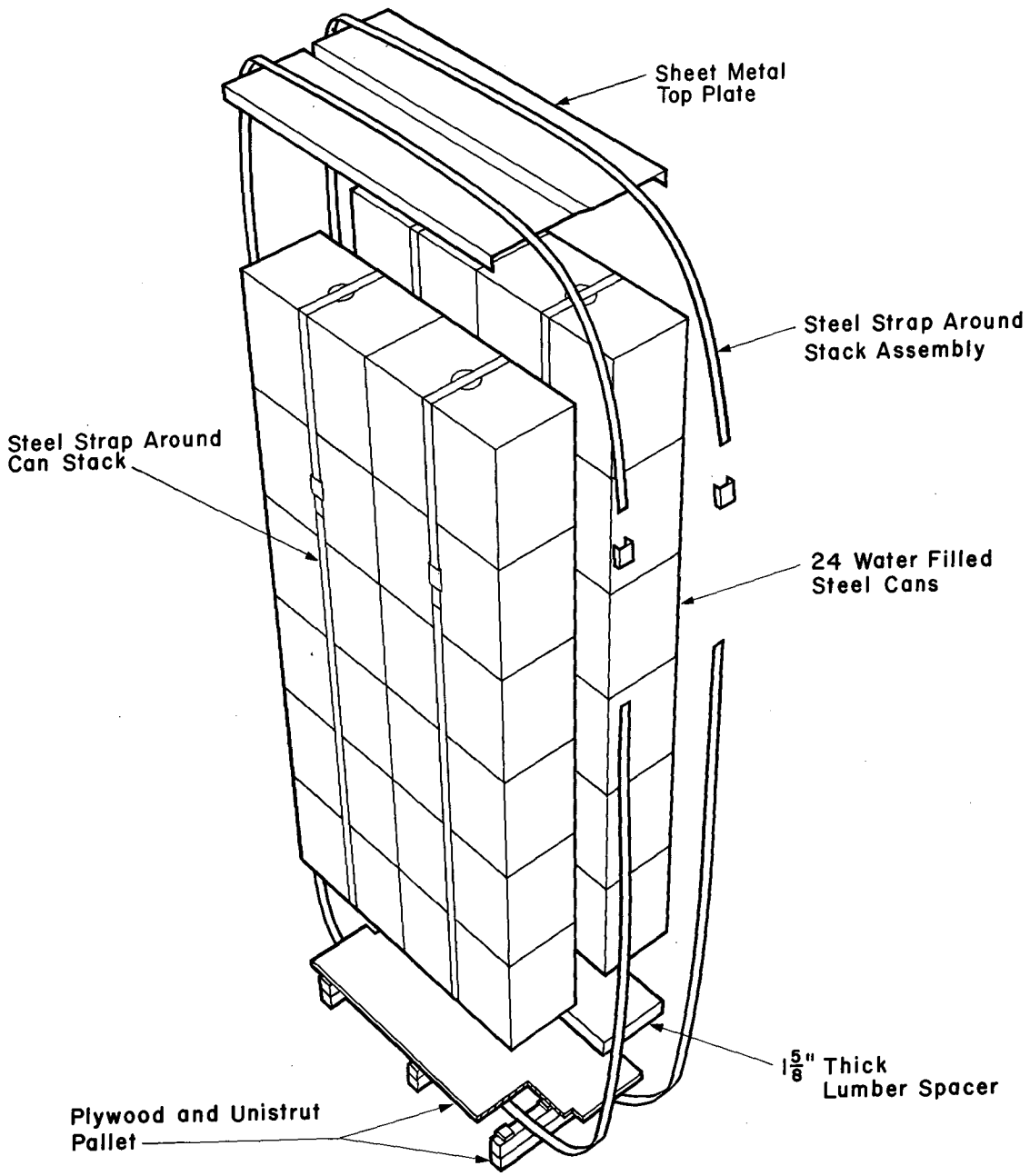

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Fig. 8. Can stack assembly.

loads. In addition, dynamic loading had to be considered, since the water-filled tank is moved on fork lifts and trucks.

As a result I designed a sheet steel tank with sheet steel stiffeners, having a minor effect on the overall neutron attenuation.

Zinc Bromide Window Tank

This tank was developed by George L. Wigle. All details of design, fabrication, material testing, and handling of the highly corrosive optical-grade zinc bromide solution are described in his report.[7]

Top Tanks

The master-slave manipulators used require openings in the front shielding wall. This required design of special water tanks that would permit both penetration of the shield and attachment of lead laminations to provide gamma shielding above the window.

Design features of these tanks, and the installation of the lead and the manipulators, are shown in Figs. 20 through 26.

Turntable Unit

The obvious purpose of a turntable, placed in the shield between the internal cavity and the outside, is to provide access without loss of shielding.

My original proposal[2] called for a modular turntable unit to be part of the overall cave, and I developed a turntable design accordingly. In the interest of saving cost and time, however, construction of such a unit was deferred. Instead, an access opening was provided at the rear of the cave, of adequate width for a person to pass through and introduce or remove materials from the enclosure within. With the relatively low radiation levels expected for this particular installation, and with the short exposure times used, such a method was not considered to pose undue hazards to the personnel involved. However, a wooden mock-up of a turntable unit was built to demonstrate its size and mode of operation, and to test mechanical drive schemes and other features. It is hoped that an operational turntable unit will be built in the future, for use with this or other modular caves of the same type.

Lead Shielding

In this particular cave only the front wall was shielded with 2 in. of lead. The lead shield below and along the sides of the zinc bromide windows was placed on the floor in front of the water shield. Cold-pressed interlocking precision lead bricks were used for this portion of the shield. The bricks, made of 4% antimonial lead, are protected by a film coating, which prevents oxidation and facilitates decontamination. They are pressed into various shapes and sizes (base bricks, top bricks, corner bricks, end bricks, etc.), thus allowing for great flexibility in shield design. The individual bricks vary in weight but generally do not exceed 15 lb, so they can be easily handled and stacked by one man. When in position, full-size bricks present a 4-in.-square face.

Thanks to the precision manufacturing methods used, there is very little tolerance buildup or misalignment, even in fairly long rows or columns of bricks. Because of the chevron-type interlock between adjoining bricks, there is no radiation "shine" through cracks, and assembled walls are structurally quite stable.

This "Graviner" system of lead bricks is distributed by

Nuclear Associates, Inc. Inc.
35 Urban Ave.
Westbury, N.Y. 11590

Since additional lead shielding was required above the windows--shielding which obviously could not rise up from the floor--eight layers of 1/4-in. -thick lead sheet were attached to the special tanks mounted on top of the windows. The sizes--and resultant weights--selected for these lead laminations still permitted manual handling and assembly.

Cave Support Structure

As shown in cave assembly drawings (Fig. 2), the major purpose of this structure is to keep the lead and water can "walls" from tipping over.

Since earth-filled and concrete walls of the room form two sides of this particular cave, only two shielding walls were built and retained.

For speed of erection, flexibility, and reusability, I selected a system of light-weight bolted steel members ("Unistrut") to provide the retaining framework in front and back of the shielding walls. The structural members were tied to the building wall in the rear of the cave. However, in a different location a free-standing structure could be built as well.

Pieces of the framework were precut and partially preassembled, and erected manually at the required time within a matter of hours. Disassembly and relocation of these structural members could be accomplished just as quickly. The only tool required is a wrench.

Another convenient feature of this system is the availability of a great number of special fittings that can be attached to the basic framework. This allows additional equipment or apparatus to be mounted on the frame, without any welding or drilling or permanent modification of any kind.

Transportation and Assembly of Cave

The first shield was erected in a corner of Room 141, Bldg. 70, Berkeley's Nuclear Chemistry "water cave" room.

Preassembled can stacks, window units, "Unistrut" framing members, and palletized lead bricks were delivered by truck to the building's receiving deck and wheeled into the cave room, and then placed in position with the help of one small hydraulic foot-lift pallet truck (Lewis-Shepard model HP-50, 5000 lb capacity).

Figures 9 through 30 show, better than any verbal description, the progress of the cave assembly.

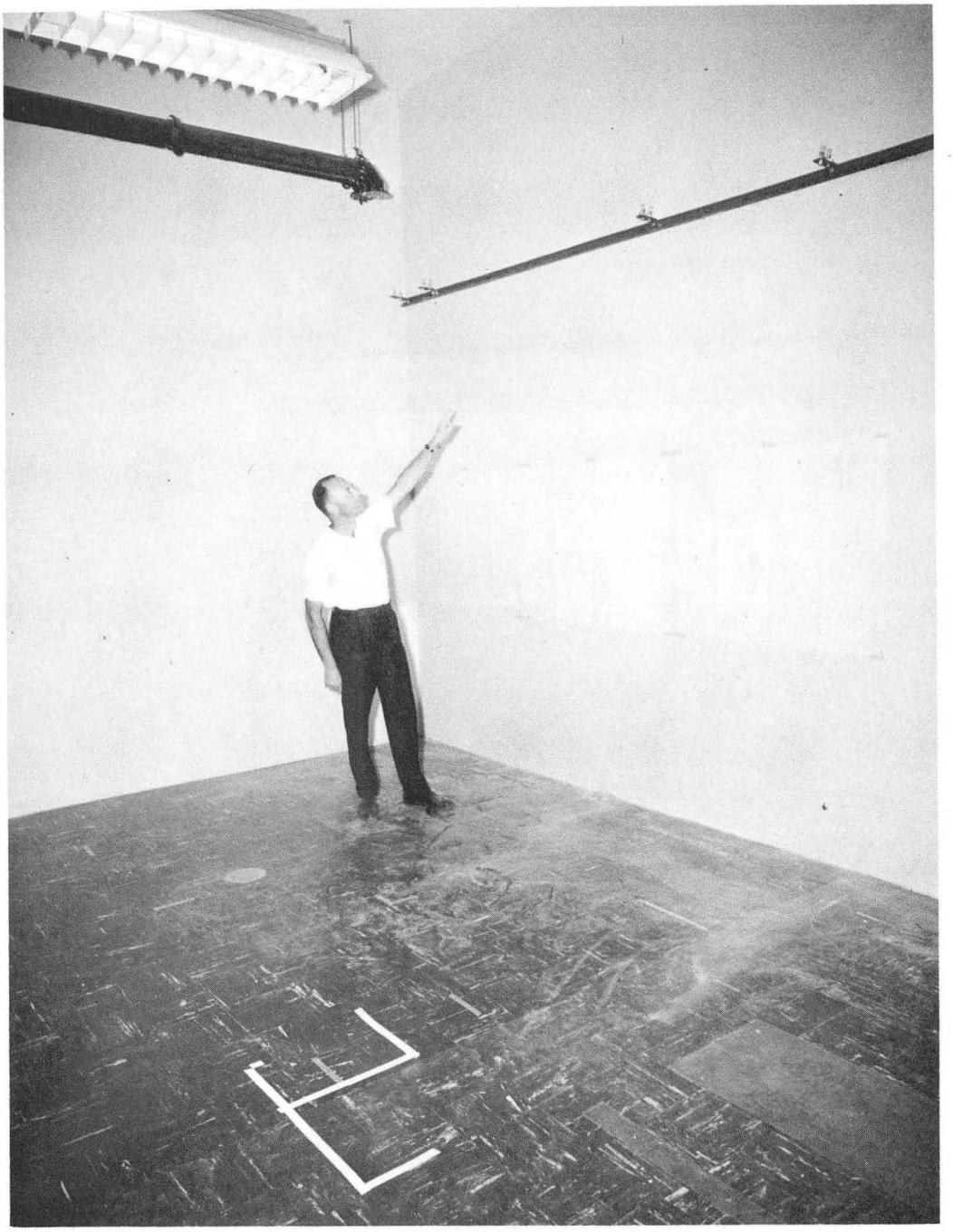

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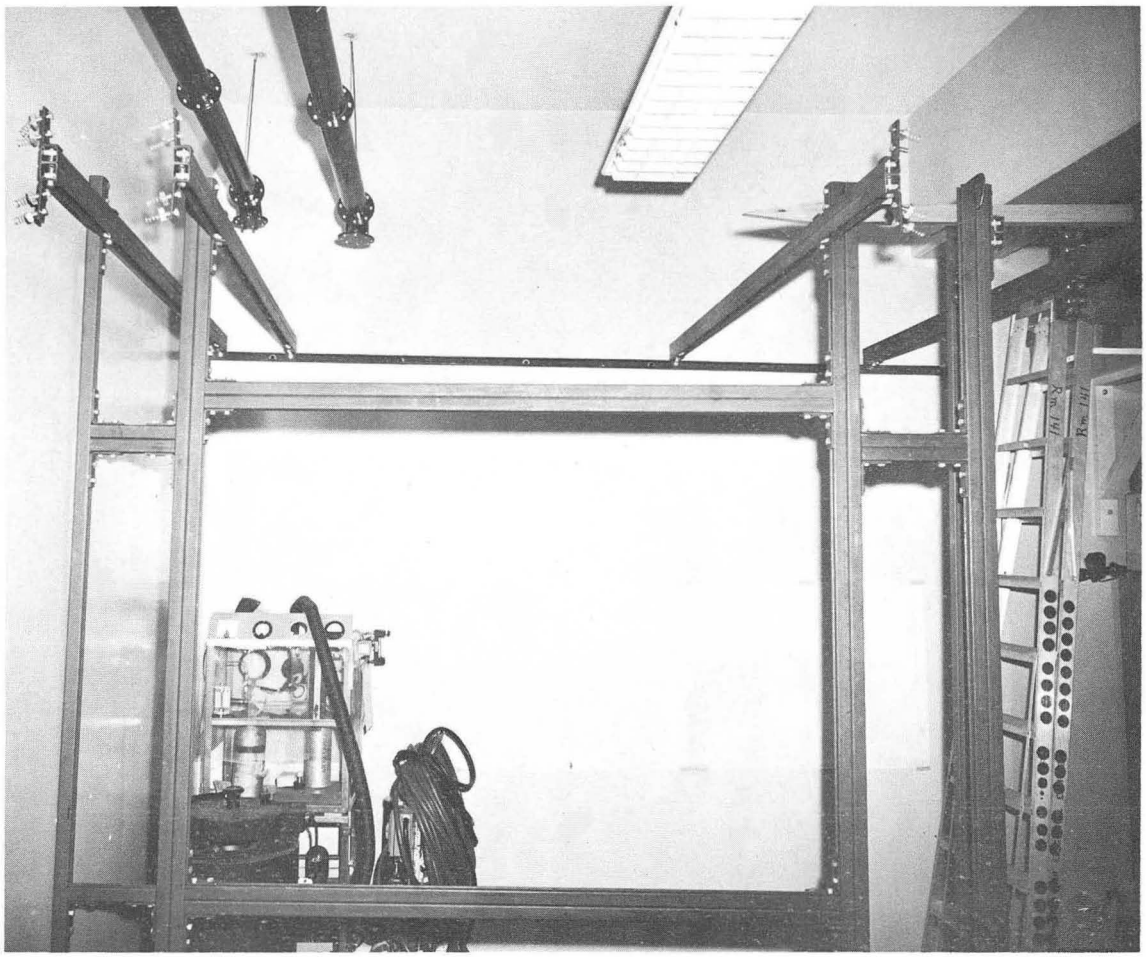
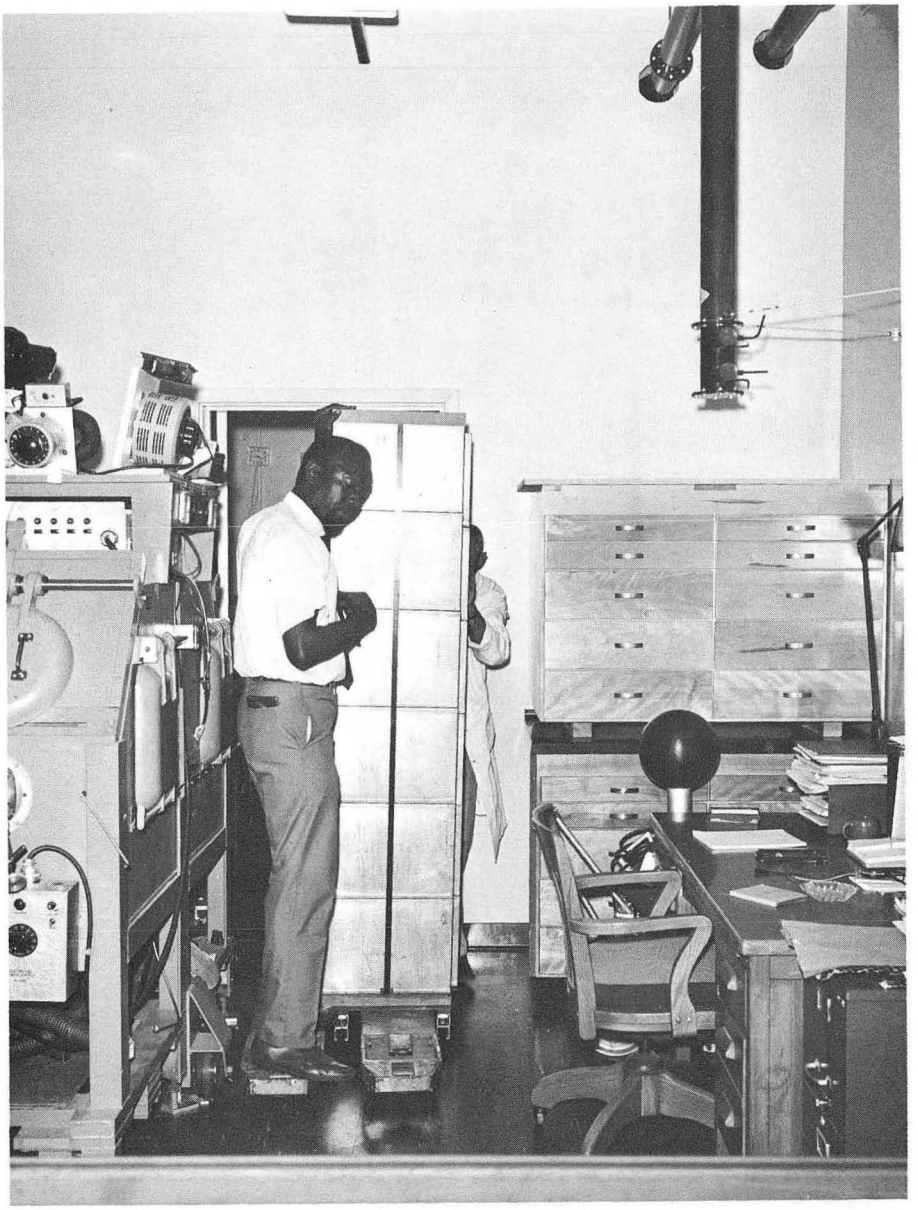
Fig. 9. First structural "unistrut" member is in place on rear concrete wall of future cell. This member was installed with self-drilling Phillips anchors. All additional framing was tied to this part.



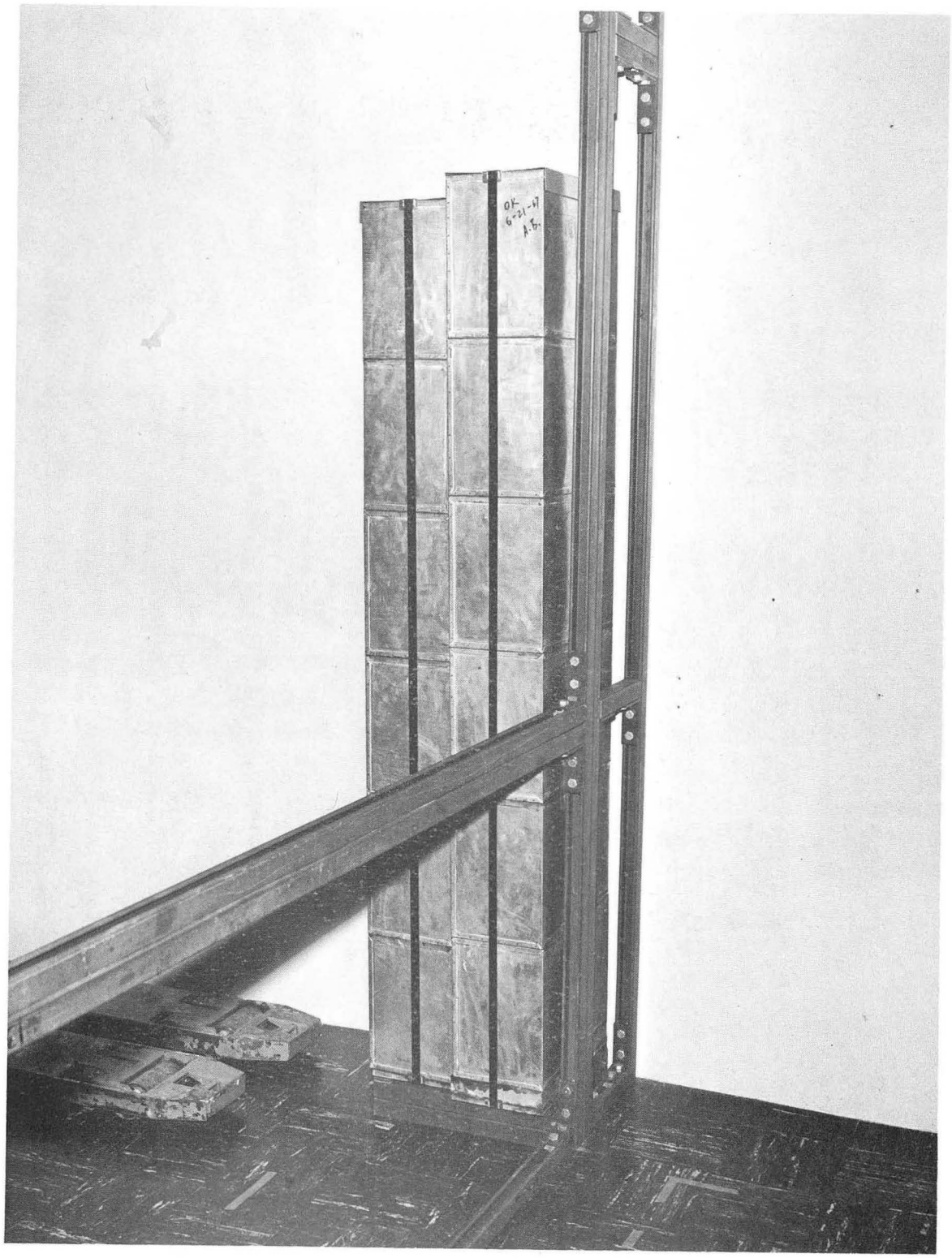
XBB 678-4867

Fig. 10. Internal frame members are in place, providing support for can stacks and window units.



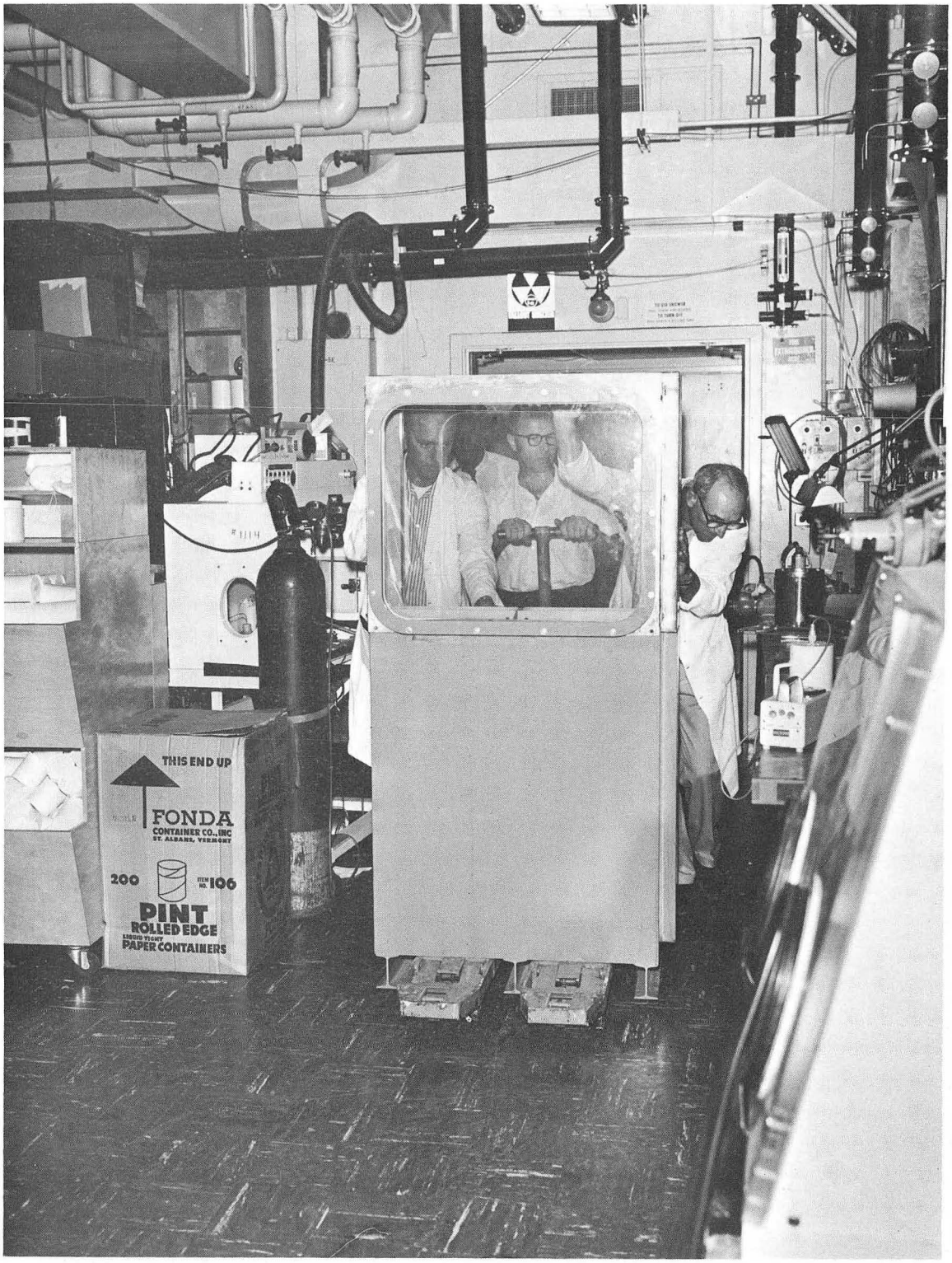
XBB 678-4871

Fig. 11. The first stack of water-filled cans is rolled into place. This is a "half-size" unit, not wide enough to ride on both forks of the pallet truck. The man is riding as a counterweight on the other fork. Note the crowded and narrow passageway through the laboratory, still providing adequate access to the cave area.



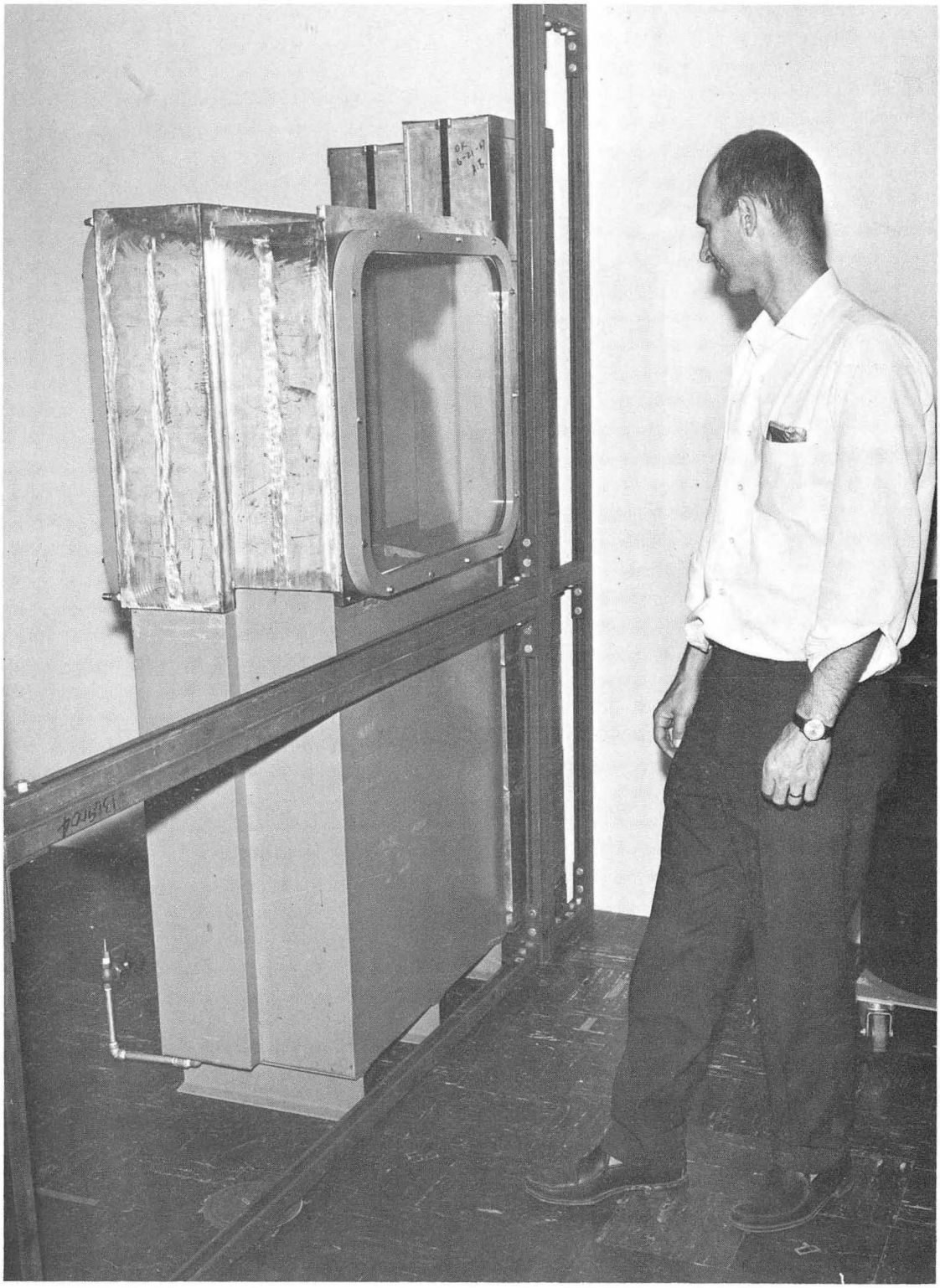
XBB 678-4872

Fig. 12. The first can stack in place, backed up against the inside frame.



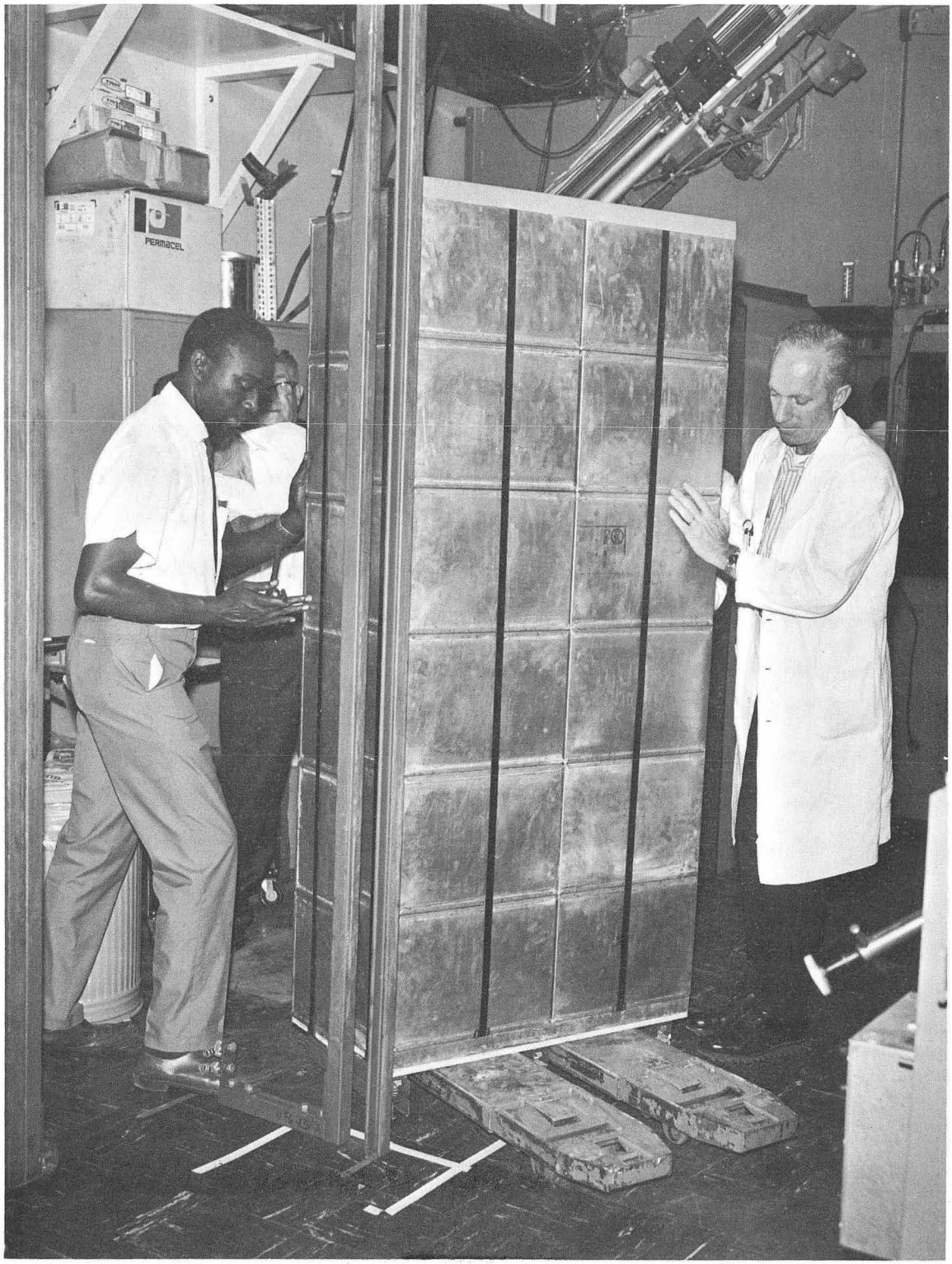
XBB 678-4870

Fig. 13. A window unit being wheeled into place.



XBB 678-4873

Fig. 14. First window unit shown in position.

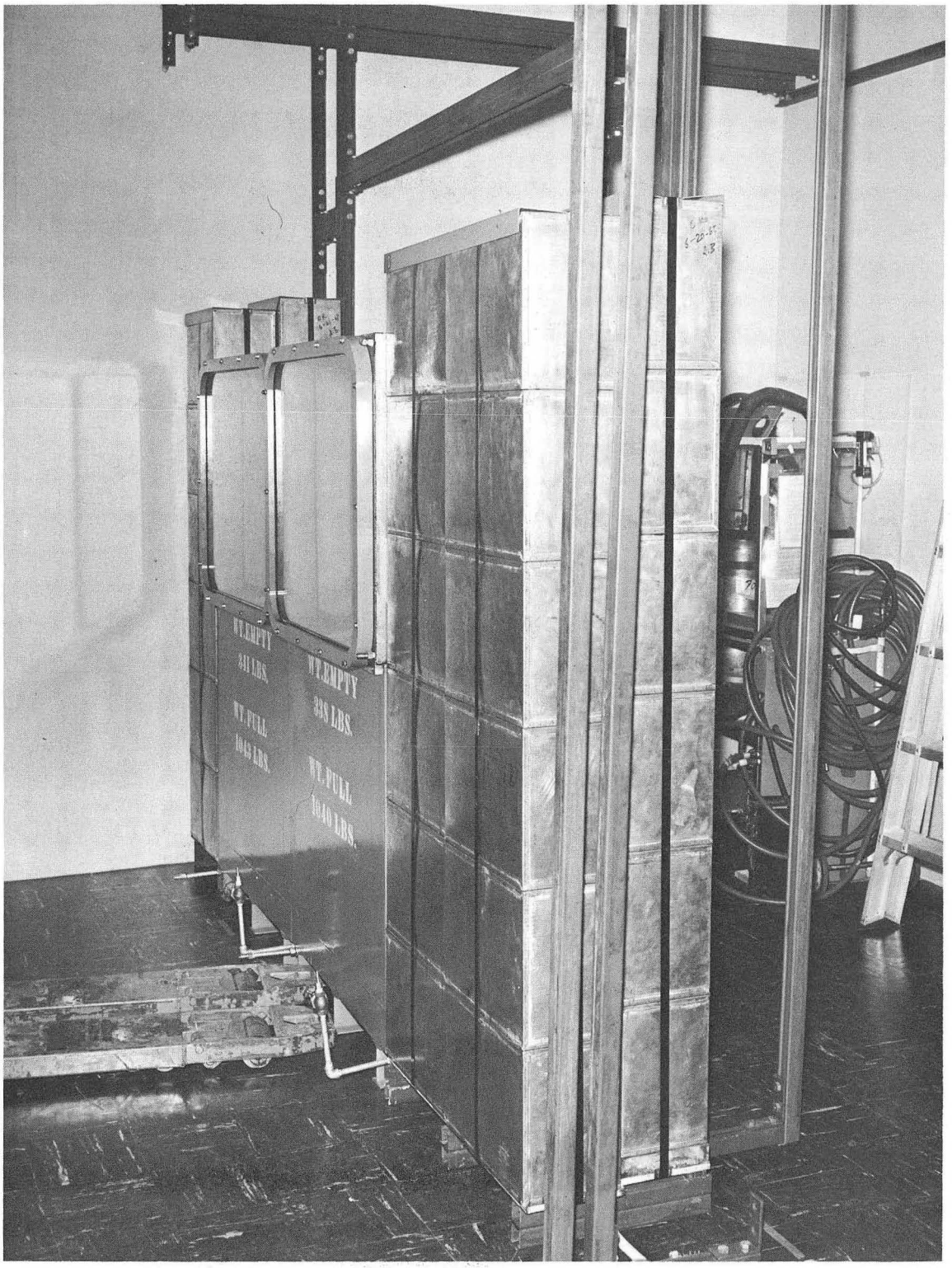


XBB 678-4864

Fig. 15. Full size can stack being maneuvered into place.

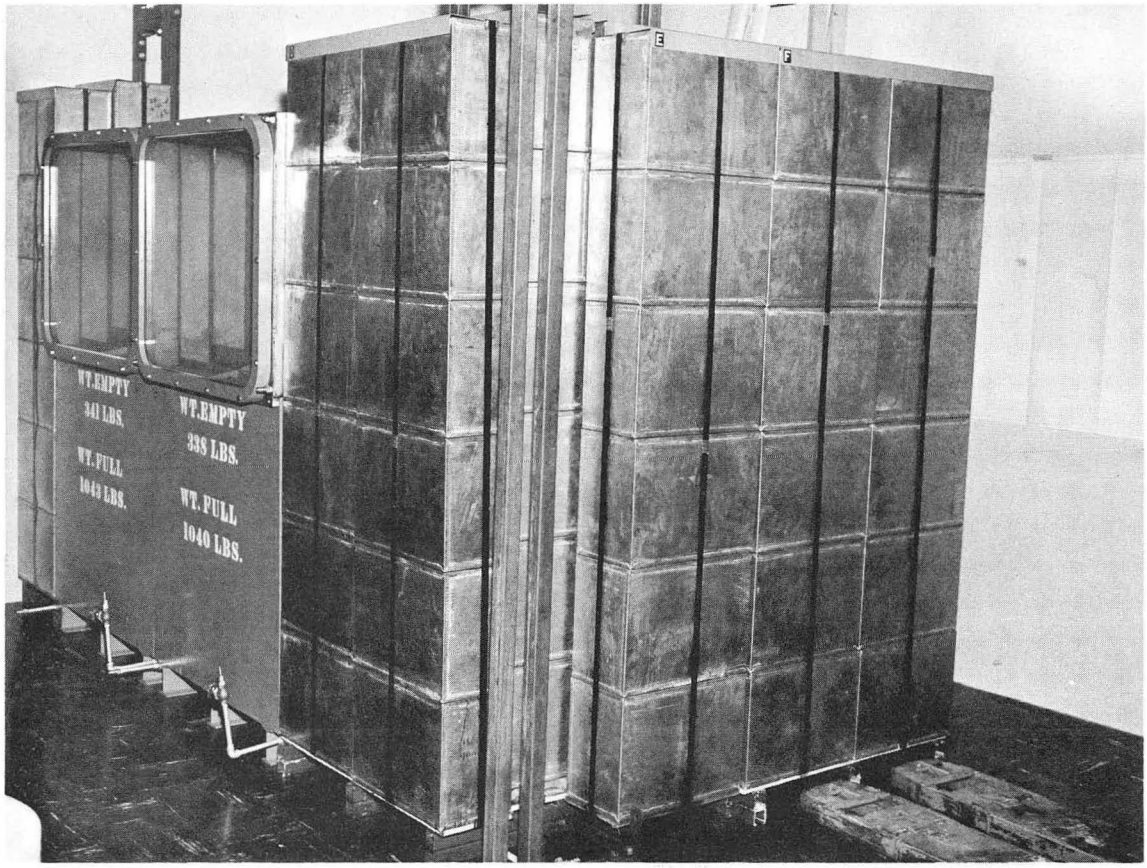
XBB 678-4876

Fig. 16. Can stack in position.



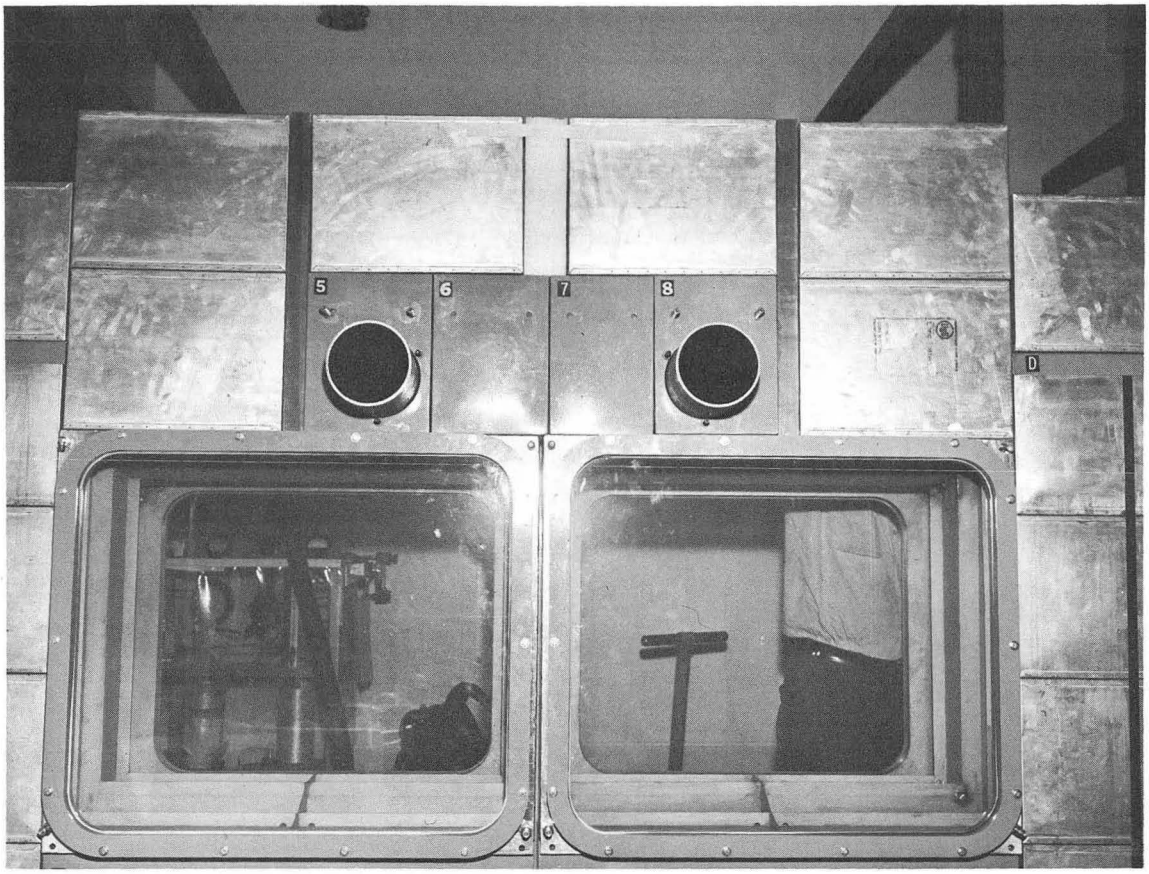
XBB 678-4877

Fig. 17. Front water shielding in position.



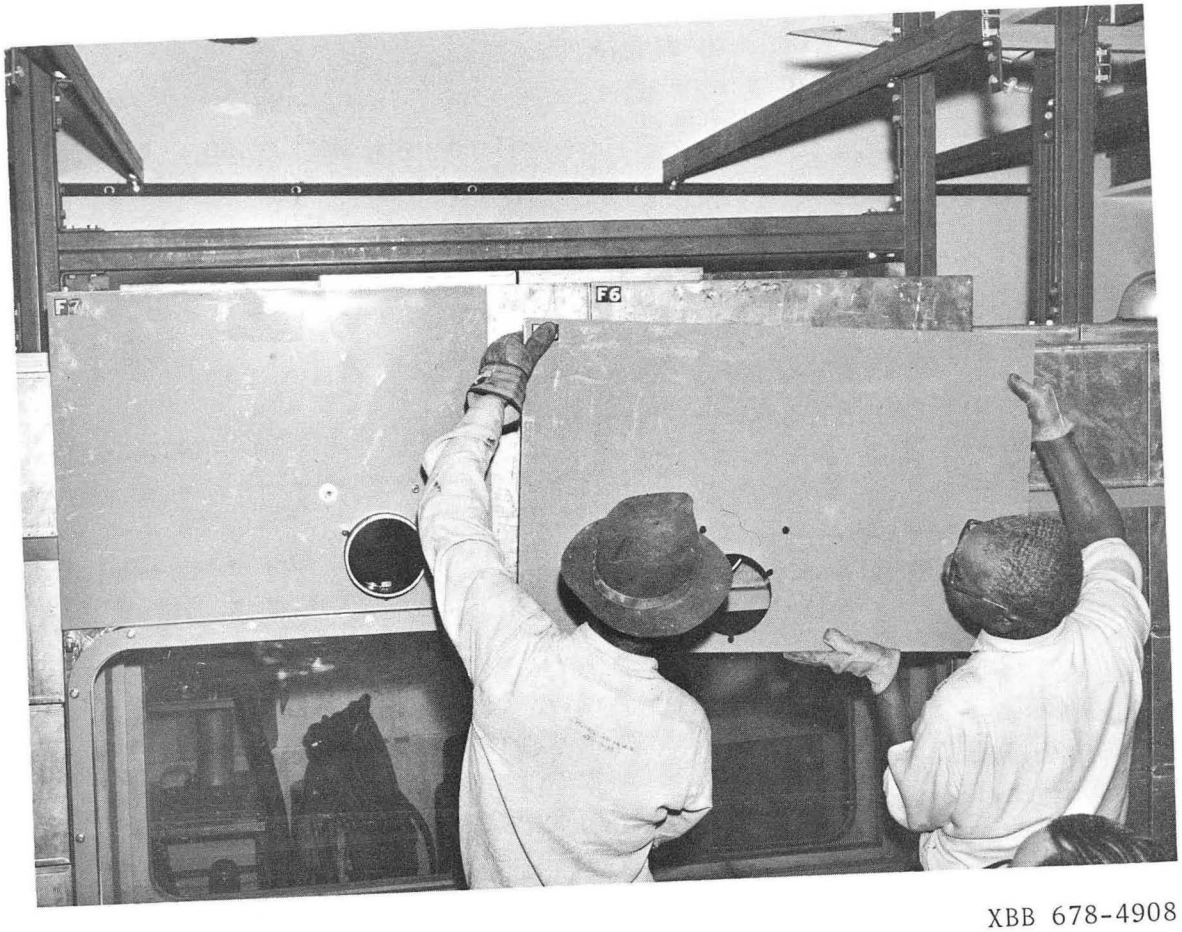
XBB 678-4880

Fig. 18. Front and side water shielding in place.



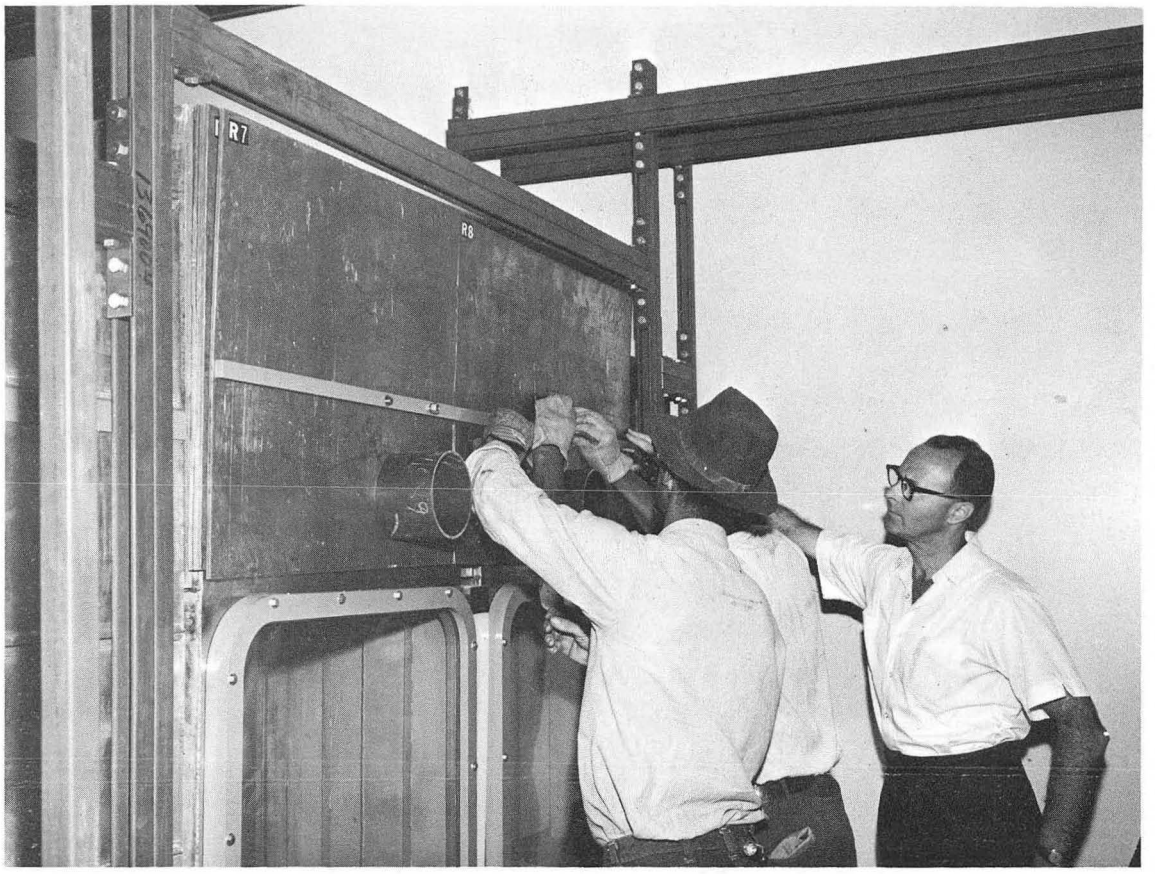
XBB 678-4884

Fig. 19. Top tanks and additional water-filled modular cans are placed on top of window units and can stacks. Two pieces of steel tubing--having a slightly larger outside diameter than the master-slave manipulators--are inserted in the through-tanks. These tubes act as guides and temporary supports, while lead laminations are being attached to the tanks. Note the screws projecting from the tanks. Four screws hold the bar that clamps lead laminations to the tanks. Three screws around each manipulator opening hold mounting flanges.



XBB 678-4908

Fig. 20. Lead laminations being installed above windows.

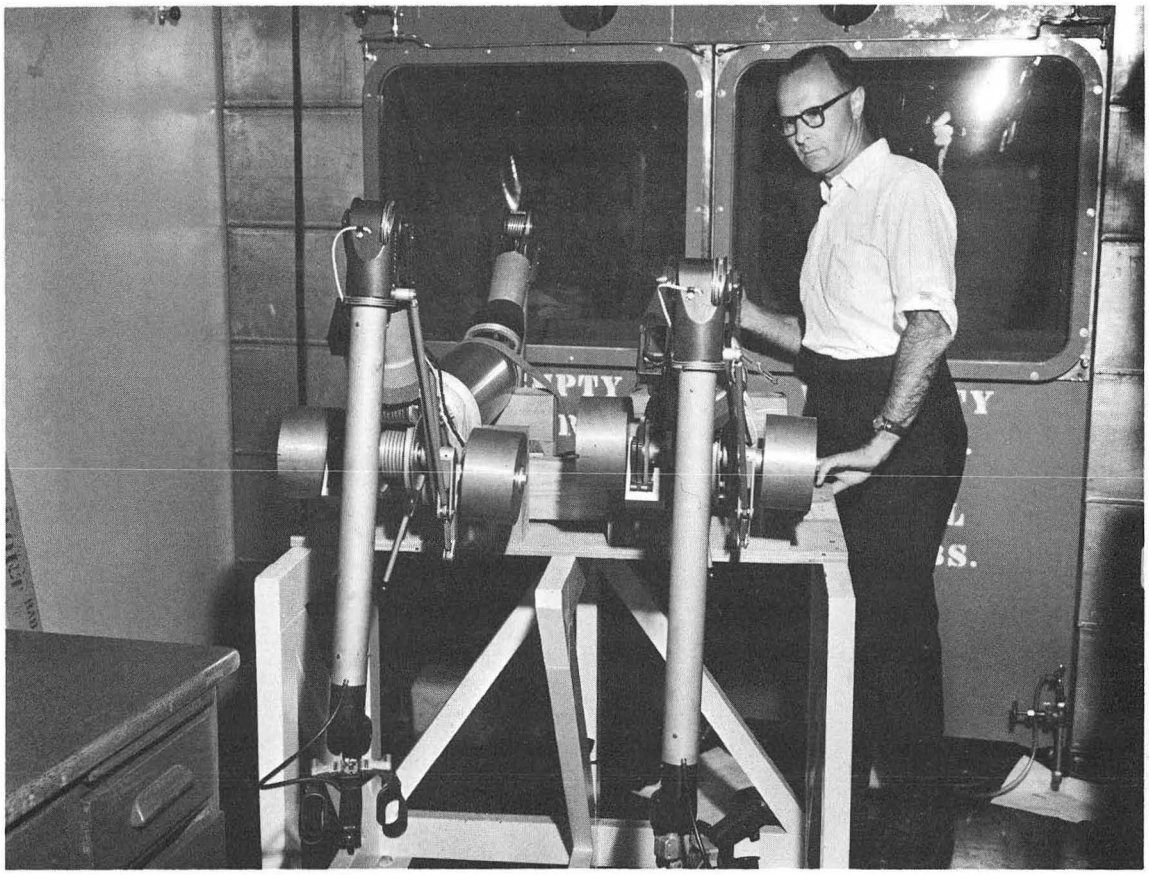


XBB 678-4910

Fig. 21. Clamp bar being fastened over lead laminations.

XBB 678-4907

Fig. 22. Guide tubes are removed, leaving well-aligned and unobstructed openings for the manipulators to slip through.

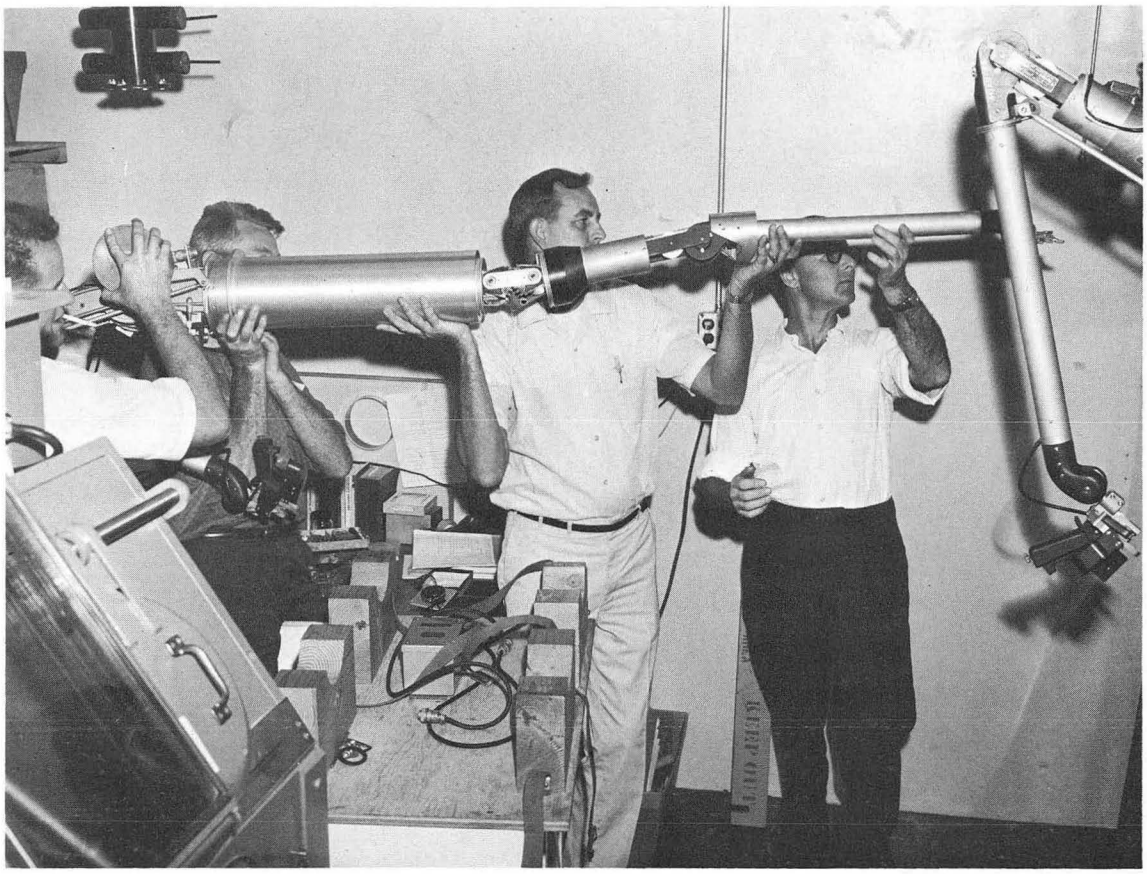


XBB 679-5246

Fig. 23. Two Central Research Laboratories, Inc., model "H" master-slave manipulators are wheeled into position on special dolly.

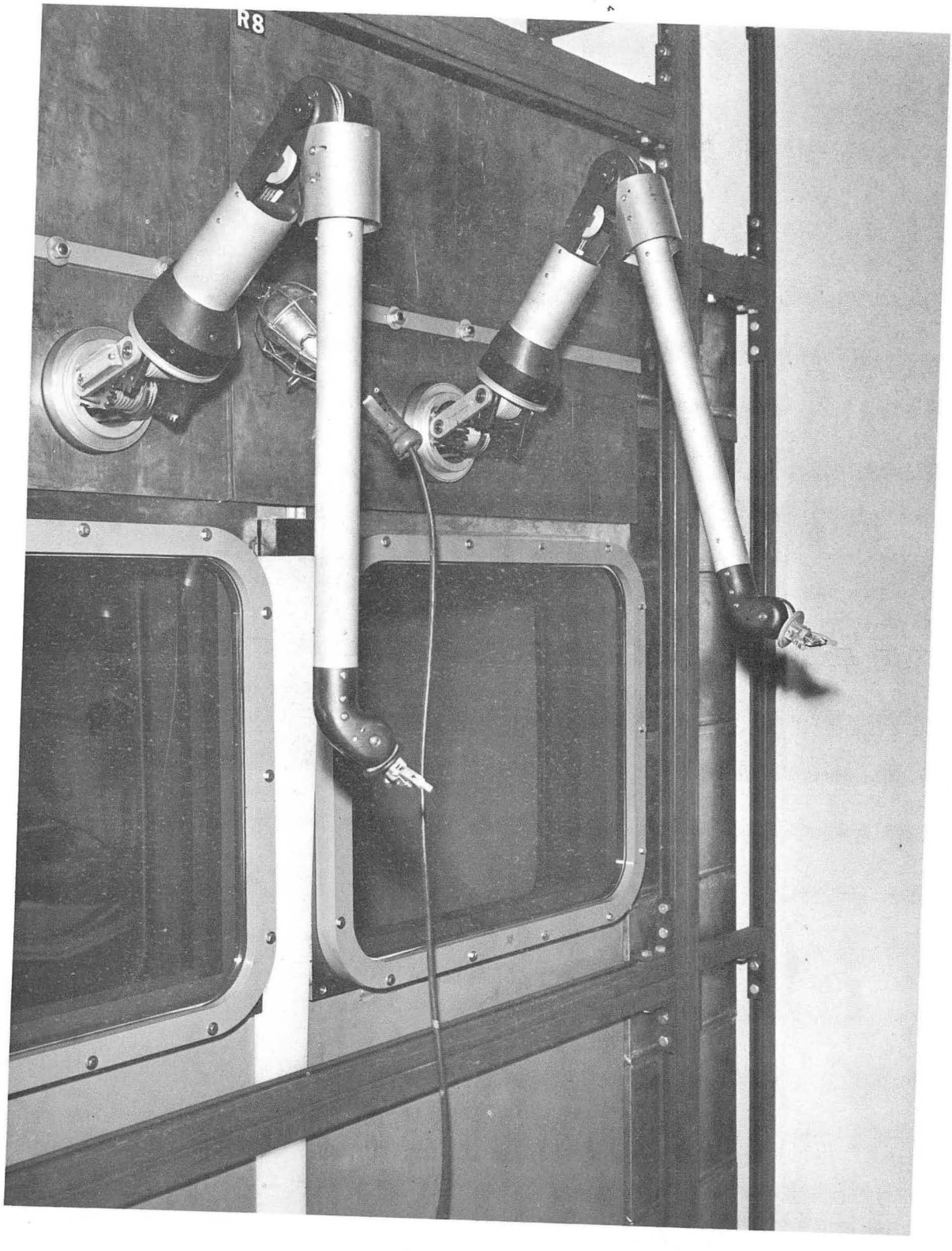
XBB 679-5239

Fig. 24. Manipulator mouting flanges are installed over lead laminations.



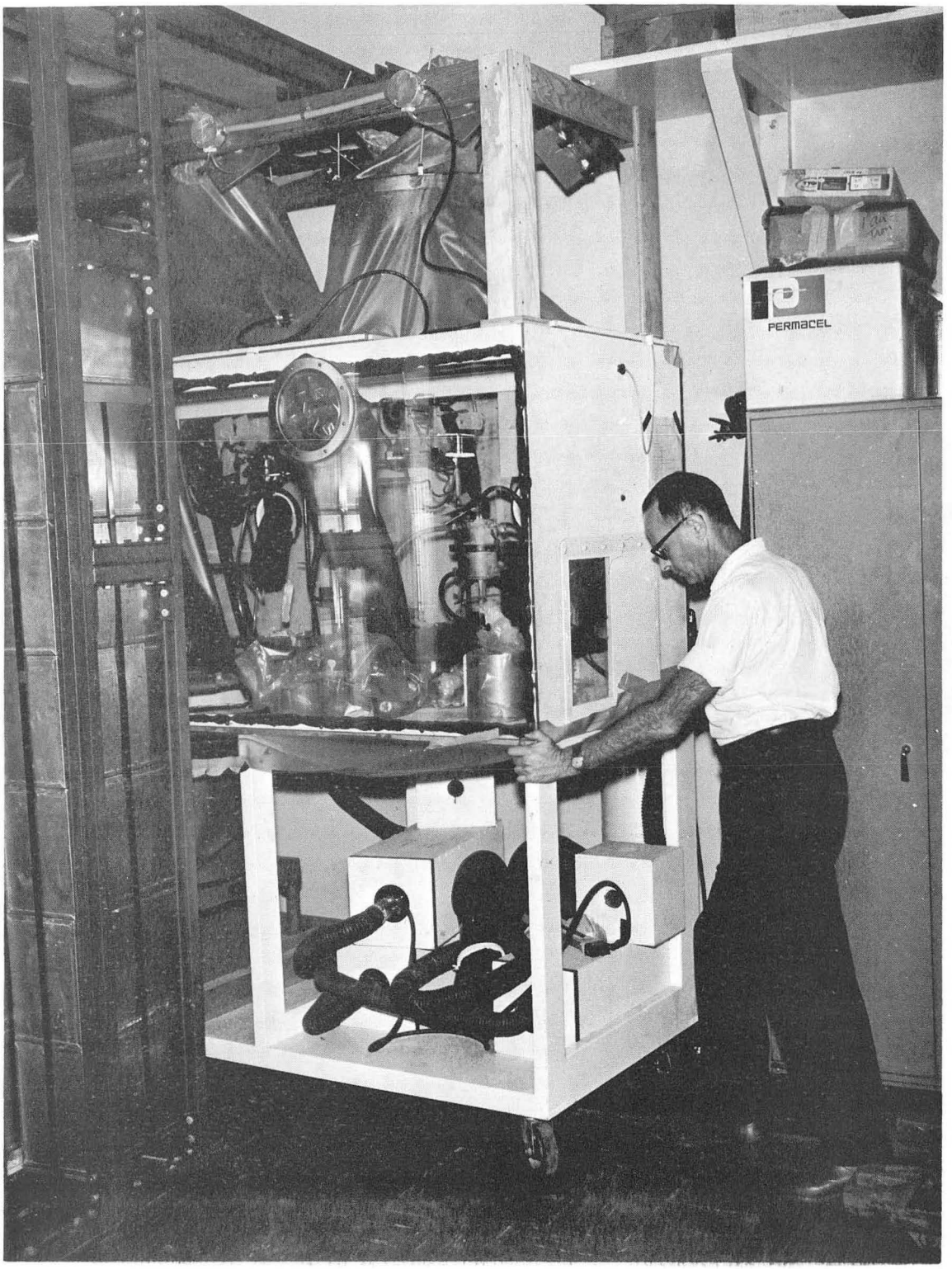
XBB 679-5240

Fig. 25. Manipulators are inserted and fastened to flanges.



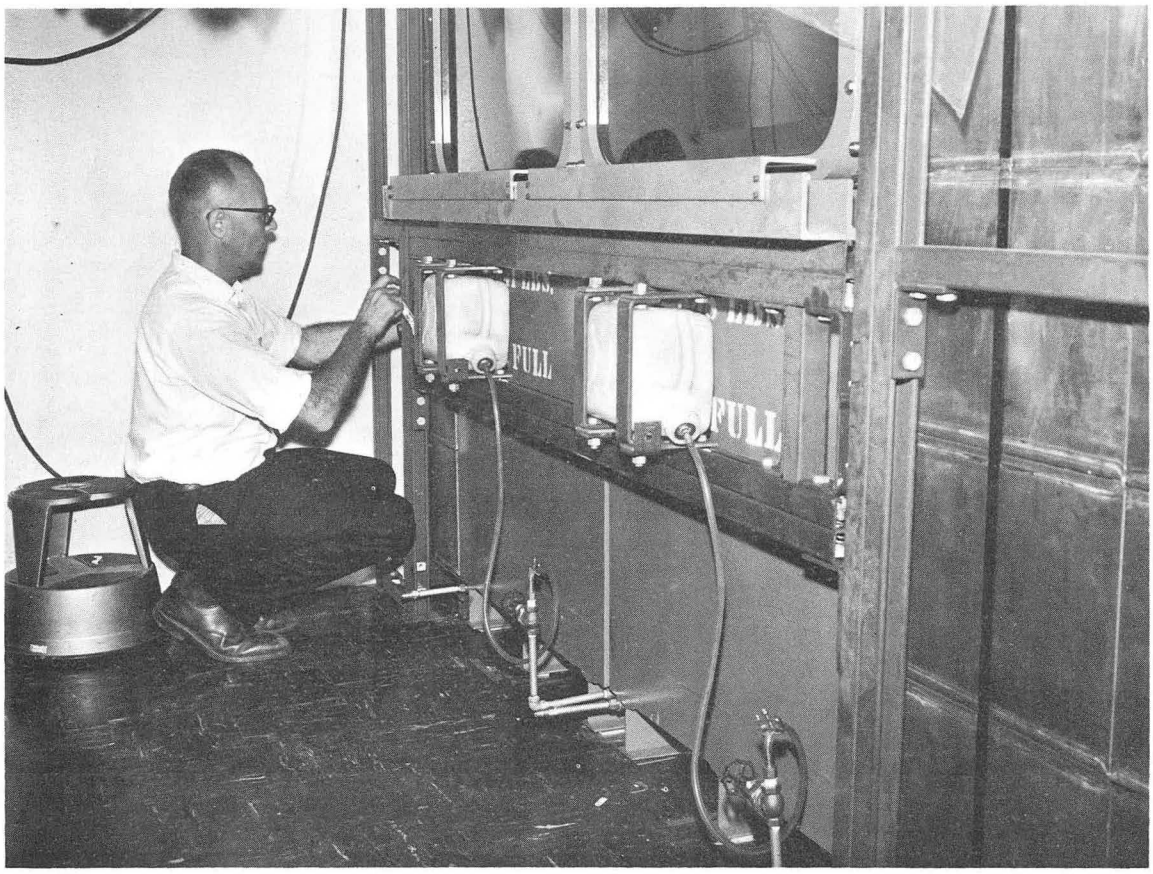
XBB 679-5247

Fig. 26. View of manipulator slave ends, prior to insertion into chemistry enclosure.



XBB 670-6003

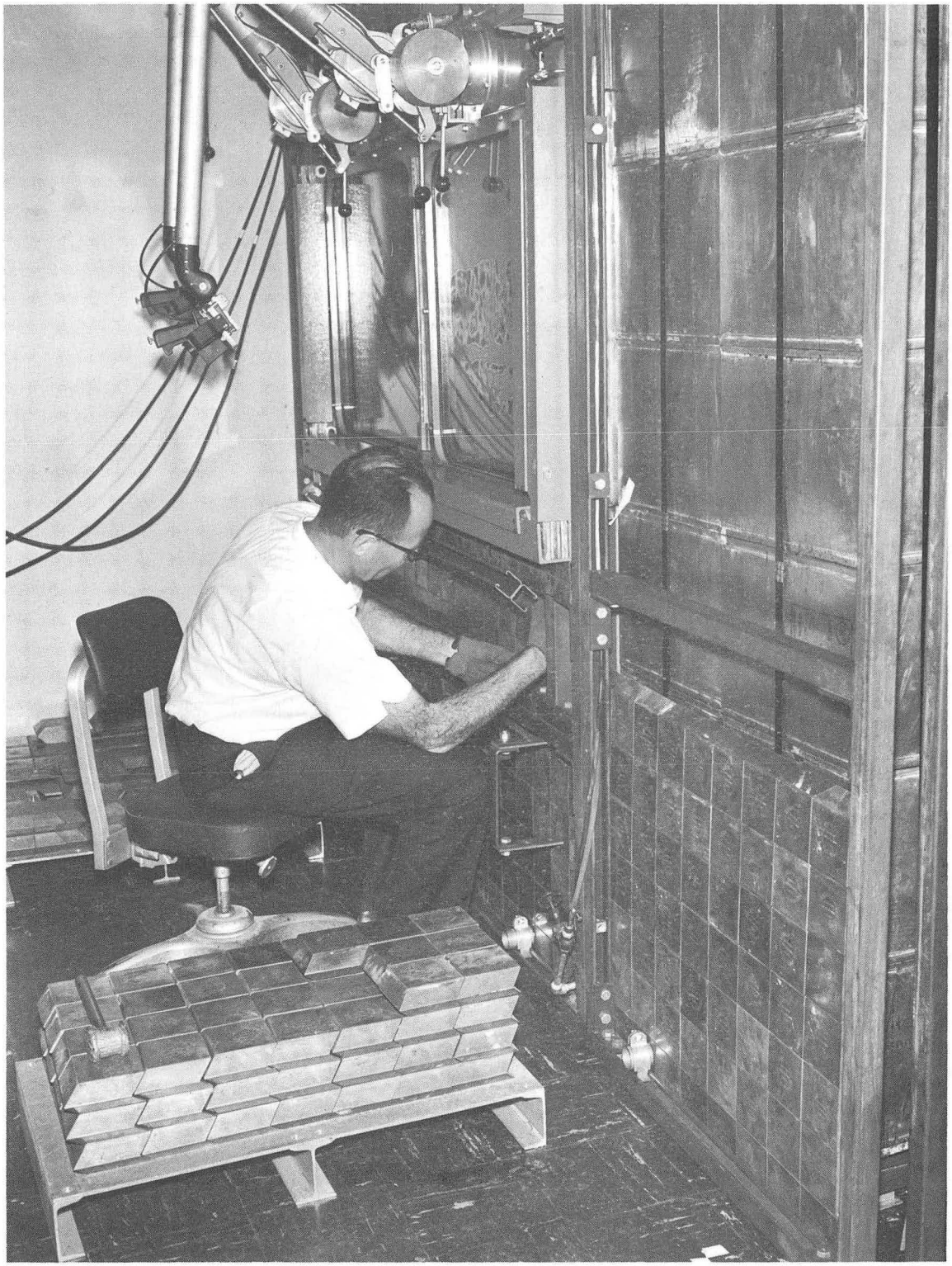
Fig. 27. After removal of side access panel, enclosure is wheeled into place behind shield.



XBB 679-5440

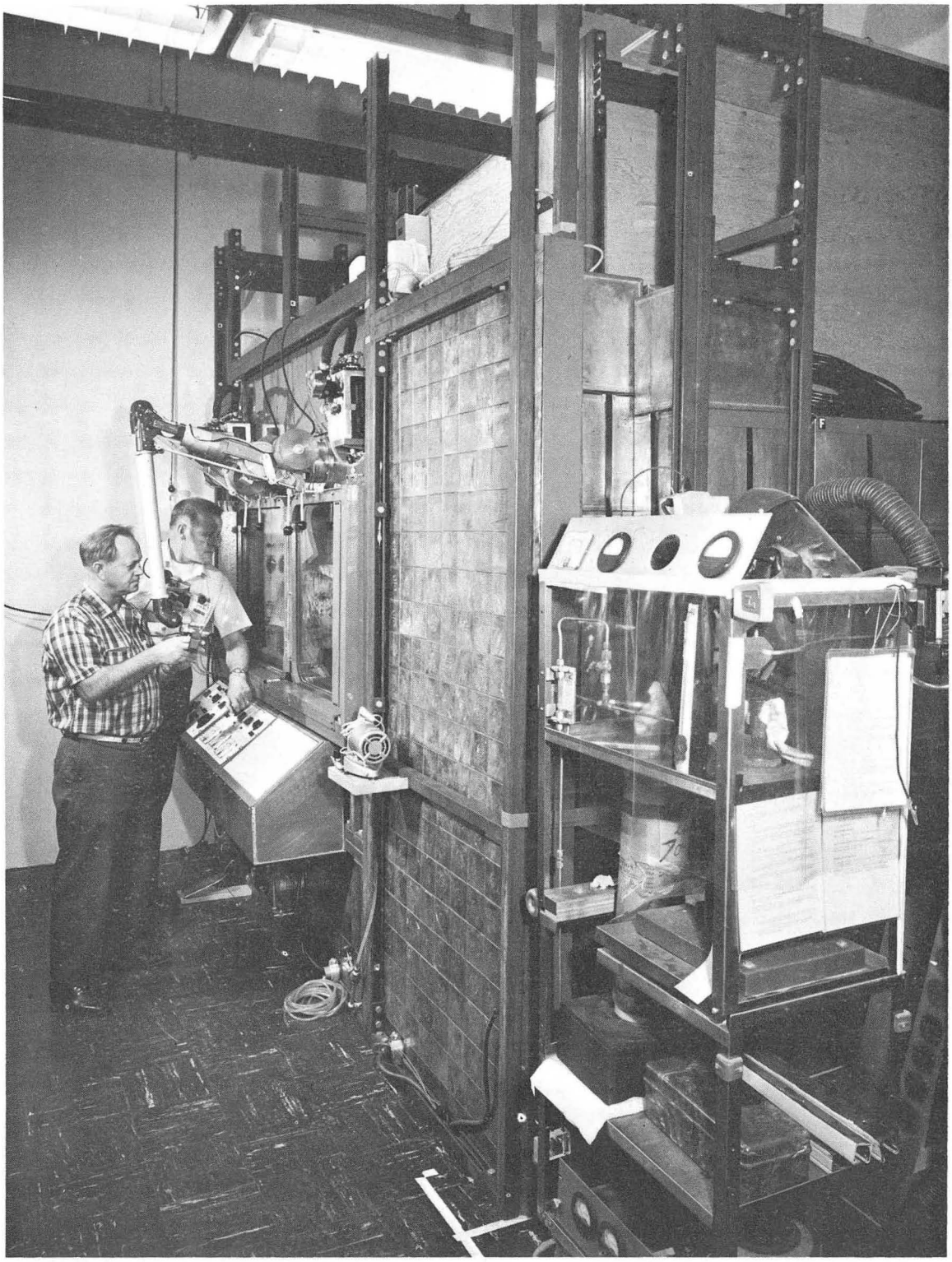
Fig. 28. Front frame structure is being installed, to retain lead bricks during and after assembly.

Polyethylene jugs shown are surge tanks for bottom tanks.



XBB 6710-6050

Fig. 29. Graviner lead bricks being stacked between water cans and front frame.



CBB 6710-6301

Fig. 30. Completed cave including electrical control panel.

Test and Operation of Cave

As mentioned earlier, this cave was designed to provide a specific level of protection. To verify the actual attenuation obtained from the assembled shield, a source of approximately 50 μg of ^{252}Cf was placed in the enclosure. At a distance of 20 in. in air a neutron survey meter gave a reading of 350 mrem/hr.

Rosemary J. Barrett[3] calculated the theoretical dose rate at the outer surface of the shield to be 2.81 mrem/hr. Actual readings obtained at various points on the front cave surface varied between 1.8 and 3 mrem/hr, a rather good correlation with the computed data.

Other noteworthy readings of 6.4 and 8 mrem/hr were observed at a distance of 8 feet from the front surface, indicating some neutron scattering due to the unshielded cave top. A high reading of 18 mrem/hr existed at the rear access opening, where normally no personnel would be located.

When 100 mCi ^{60}Co was used as a gamma source, very good attenuation was obtained through the front shield. Readings on the front cave surface were generally less than 1 mR/hr at 86 cm from the source, as against 128 mR/hr at 1 meter in air.

On the side of the cave, with water shielding alone, the reading went up to 5 mR/hr.

At the time of this writing no operating experience, beyond the tests described, can be reported. This cave, including its special chemistry enclosure, is held in readiness for the analysis of radioactive samples from underground nuclear detonations at the Nevada test site.

In conclusion, I would like to say that the cave described met all requirements presented at the outset of this project.

The use of modular "building blocks" seems to offer a practical solution to the problem of creating a low-cost flexible shield that can be erected or dismantled in a short period of time.

ACKNOWLEDGMENTS

This project benefitted from the skills and energies of a number of people, whose names were listed in the December 1967 issue of "The Magnet."[8] I appreciate all the help received, but want to single out James T. Haley and Robert M. Latimer, in particular, for suggesting some of the concepts ultimately used, and the LRL Nuclear Chemistry Department, under Dr. Isadore Perlman, for the financial support granted. I also wish to thank Rosemary J. Barrett, Peter S. Bringham, Richard P. Grill, and Jensen Young for reviewing this paper prior to its issuance.

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3. Rosemary J. Barrett (Lawrence Radiation Laboratory), personal communication, 1966.

4. E. W. Sidebotham and T. Standen, Preliminary Report on Shielding Economics, U. K. Atomic Energy Authority Industrial Group, Report No. IGE-R-13.

5. American Standard Basis for the Coordination of Dimensions of Building Materials and Equipment, (American Standards Association, Inc., 1957), A62.1-1957, or the latest revision thereof.

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8. Modular "Cave" -- Flexible New Idea for Hot Chemistry, The Magnet Vol. 11 [12], Dec. 1967.

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