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SOME VITAL ROLES OF PLASTICS IN HIGH-ENERGY NUCLEAR RESEARCH

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James O. Turner

October 23, 1956

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ABSTRACT

A very ticklish business is the pursuit of the antiproton, the antineutron, the neutrino, and the meson. One has to learn what makes them and how they live and die; what they are like--charge, mass, spin, magnetic moment, etc. (the nuclear scientist's equivalents of color, song, habitat, and mating habits)--and what they do to other particles and materials that get in the way. Some of them live for only a few microseconds and some predicted ones haven't even been found yet. They require powerful magnets to guide them, and some require billions of electron volts for creation. This means that voltages, magnetic forces, vacua, and energies have to be pushed higher and ever higher.

This, in turn, requires ever more and more specialized nonmetallics for electric isolation, radiation detection, and containment.

Most of these have to operate under tough, exacting conditions involving

(a) vacua of around 5×10^{-6} mm,

(b) gigantic magnetic forces resulting from fields of up to 25 kilogauss continuous, and some pulsed ones many times this value,

(c) voltage gradients up to 20,000 volts per inch,

(d) heavy copper conductor cross-sections (up to 1.3 in. square),

(e) extremes of temperature--down to -424°F and up to $+450^{\circ}$F.

Thanks to the genius of the chemical and plastics industries and some adroit applications by ingenious nuclear design and materials engineers, solutions have been found to some of the knottiest of these problems, as follows:

(a) acrylic Cerenkov counters,

(b) massive polystyrene scintillator blocks for large-scale detection of radiations,

(c) expanded polystyrene and polyester film targets to hold liquid hydrogen,

(d) epoxy-potted magnetic coils for use in high-voltage application,

(e) epoxy castings for high voltage and high vacuum,

(f) coils deeply imbedded in epoxy for high-voltage application,

(g) epoxy and glass wet layups for extra mechanical as well as electrical strength,

(h) polyethylene sandbags for shielding.

SOME VITAL ROLES OF PLASTICS IN HIGH-ENERGY NUCLEAR RESEARCH

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The Radiation Laboratory at Berkeley presently boasts the highest-energy accelerator in the free world, the Bevatron. Also our old giant cyclotron is about to go back into operation after being rebuilt for greatly increased energy and efficiency. Many different kinds of nuclear particles have been produced, accelerated, transmuted, and studied in these and other accelerators here. The press recently announced the finding of the antiproton and antineutron, particles of matter created out of pure energy in experiments with the Bevatron.

A very ticklish business is this pursuit of the antiproton and the antineutron, as well as of the neutrino and the meson. One has to learn how they are created, and how they live and die; what they are like—charge, mass, spin, magnetic moment, etc. (the nuclear scientist's equivalents of habitat, color, song, and mating habits)—and what they do to other particles and other materials that get in their way when they are traveling at velocities near the speed of light. Some of these live for only a few microseconds, and some predicted ones haven't even been found yet. Guiding them requires powerful magnets, and their creation may require billions of electron volts. This means that voltages, magnetic forces, vacua, and energies have to be pushed higher and ever higher. To achieve this necessitates continuous invention and development of new ways to attack the problems.

The new techniques in turn require ever more and more specialized materials of all sorts. A vital and indispensable role in this effort is performed by plastics for electric isolation, radiation detection, and containment. These all have to operate under one or more of such tough, exacting conditions as

high radiation fluxes, with much highly penetrating gamma;
vacua of 5×10^{-6} mm and better;
gigantic magnetic forces resulting from fields of up to 25 kilogauss continuous, and some pulsed ones many times this value;

voltage gradients up to 20,000 volts per inch;
heavy copper conductor cross sections (up to 1.3 in. square);
extremes of temperature up to +450°F and down to -424°F.

Thanks to the genius of the chemical and plastics industries and some adroit applications by ingenious nuclear design and materials engineers, solutions have been found to some of the knottiest of these problems.

One of these problems is the focusing of the beam in a particle accelerator. Particles to be accelerated usually begin their journey by being ionized or stripped of electrons in what is known as an ion source or injector, which operates in the range of several hundred thousand volts. As the particles start on their journey toward the accelerating zone, their stream must be focused into a narrow beam. Figure 1 shows an electrostatic focusing lens consisting of two 6-in.-diameter cast epoxy insulating rings and a center metallic electrode, all cemented together with epoxy cement. This assembly must hold a high vacuum on the inside, and the plastic rings must withstand a voltage of 30,000 volts across their 1-inch width. Figure 2 shows the parts before assembly.

Ion sources and other pieces of apparatus frequently contain electronic tubes with heater filaments that operate at a high voltage above ground. The transformer coil that powers the filament must be insulated for this high voltage. Figure 3 shows the secondary coil of such a high-voltage filament transformer deeply imbedded in an epoxy casting. Figure 4 shows the transformer after completion.

The termination of a cable that operates at high voltage is a problem because of the high gradients encountered when the conductor emerges from its insulating sheath. Figure 5 shows a clear epoxy casting designed and built to distribute and withstand these gradients when used with a cable operating at 235,000 volts dc. Figure 6 shows an epoxy casting whose dielectric constant has been adjusted by addition of glass bead filler for use with a cable operating at a half million volts dc.

We are repeatedly faced with the problem of carrying electrical circuits through the walls of vacuum vessels operating at pressures around 5×10^{-6} mm of mercury or less. This requires bushings that

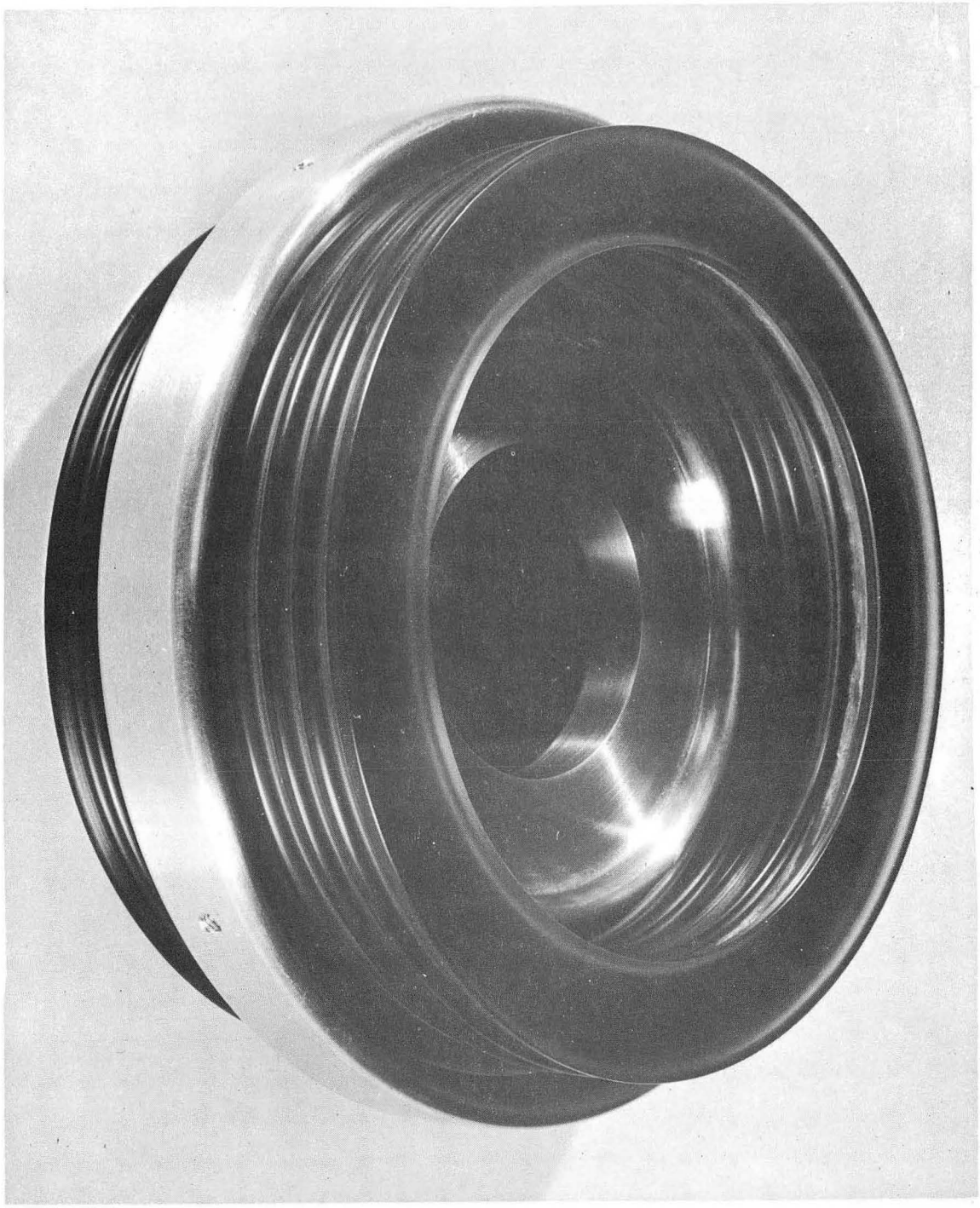

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Fig. 1

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Fig. 2

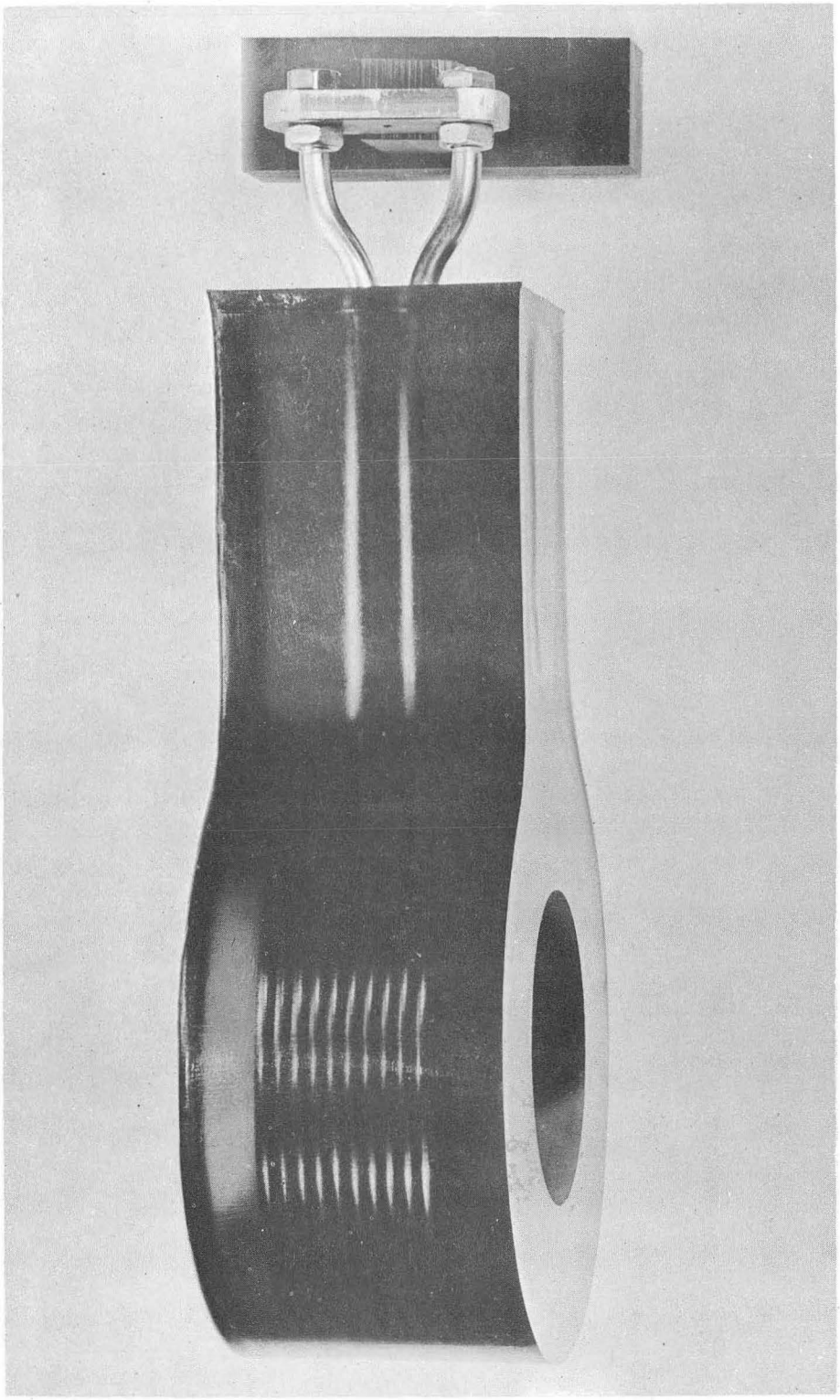

Fig. 3

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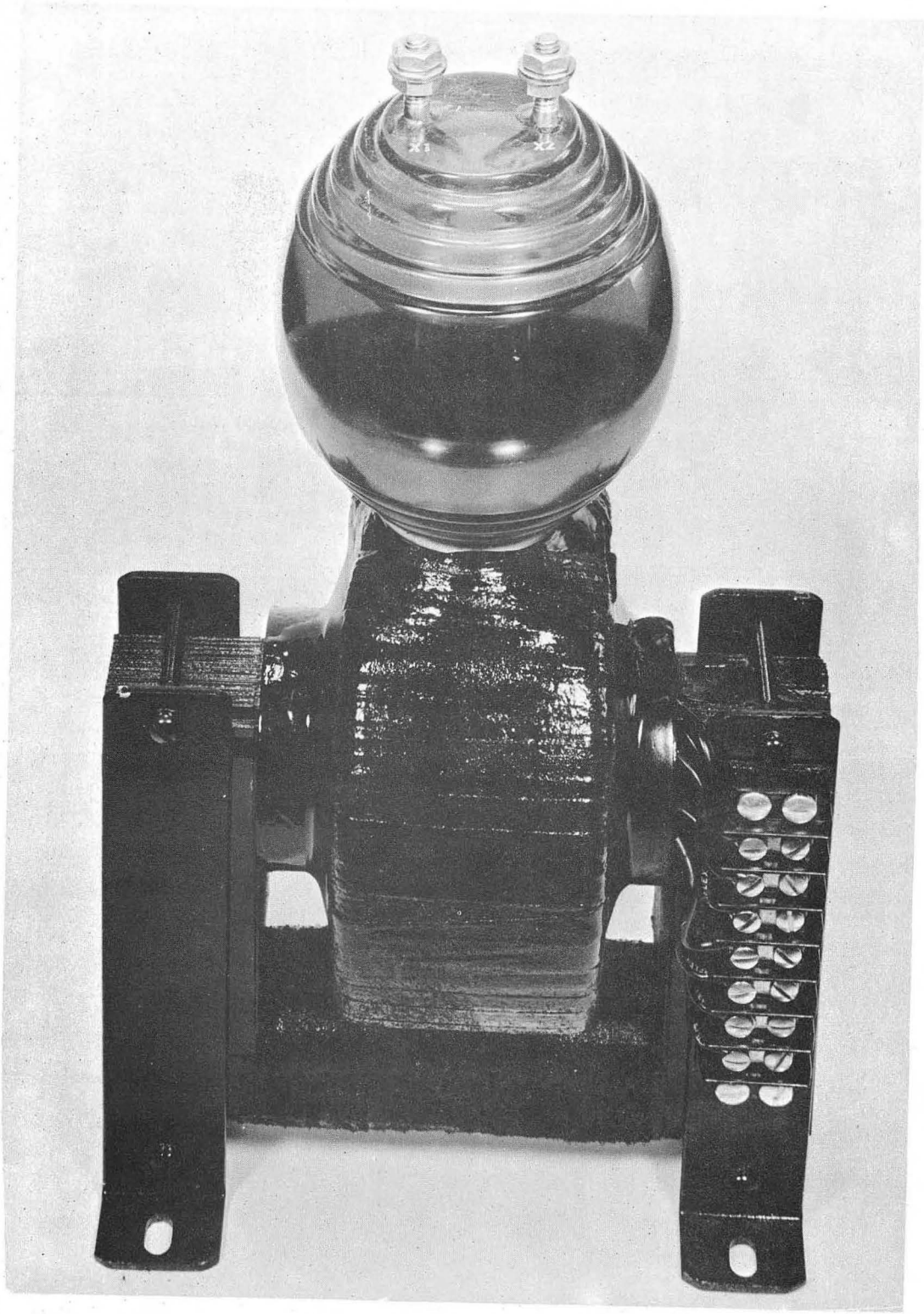

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Fig. 4

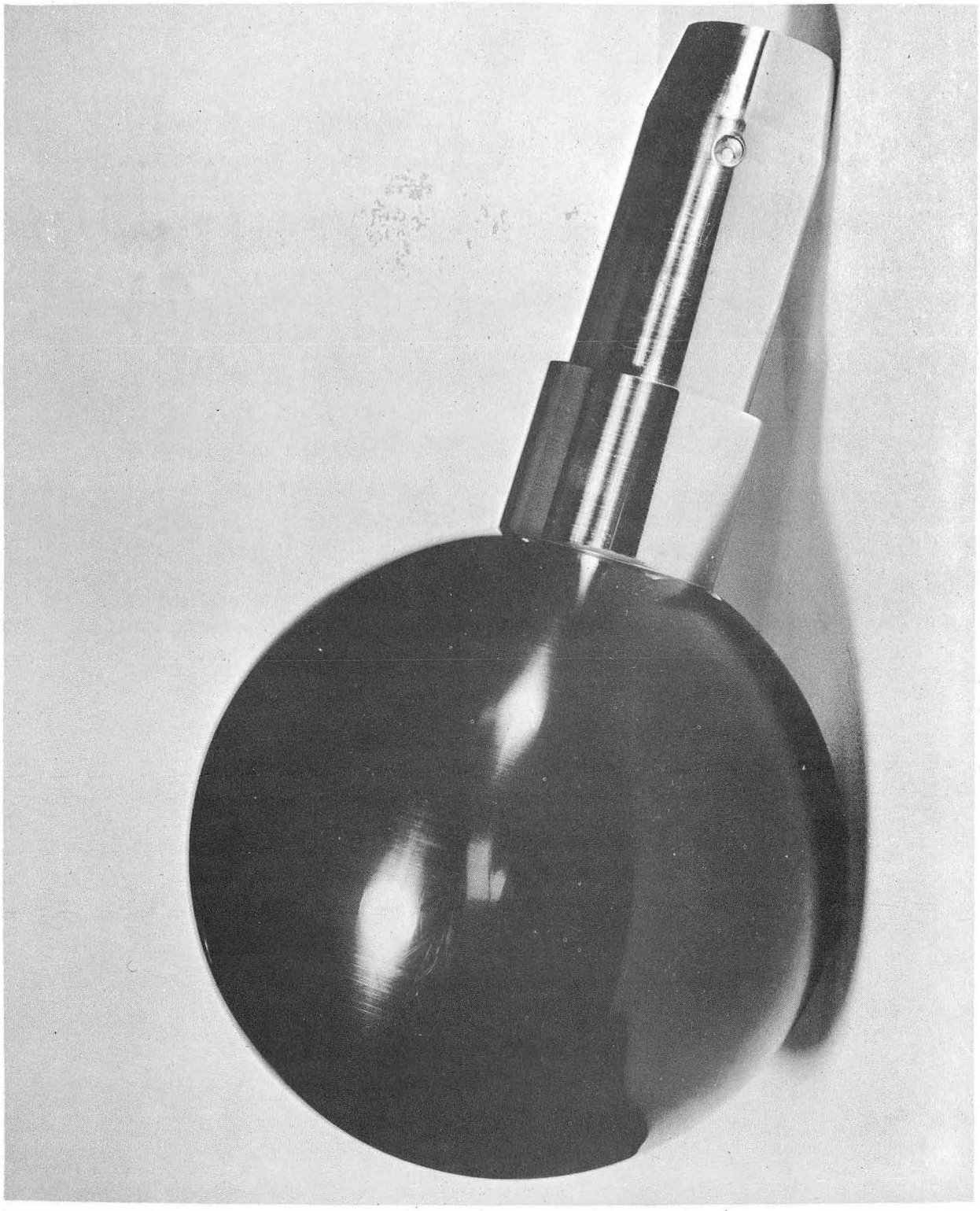

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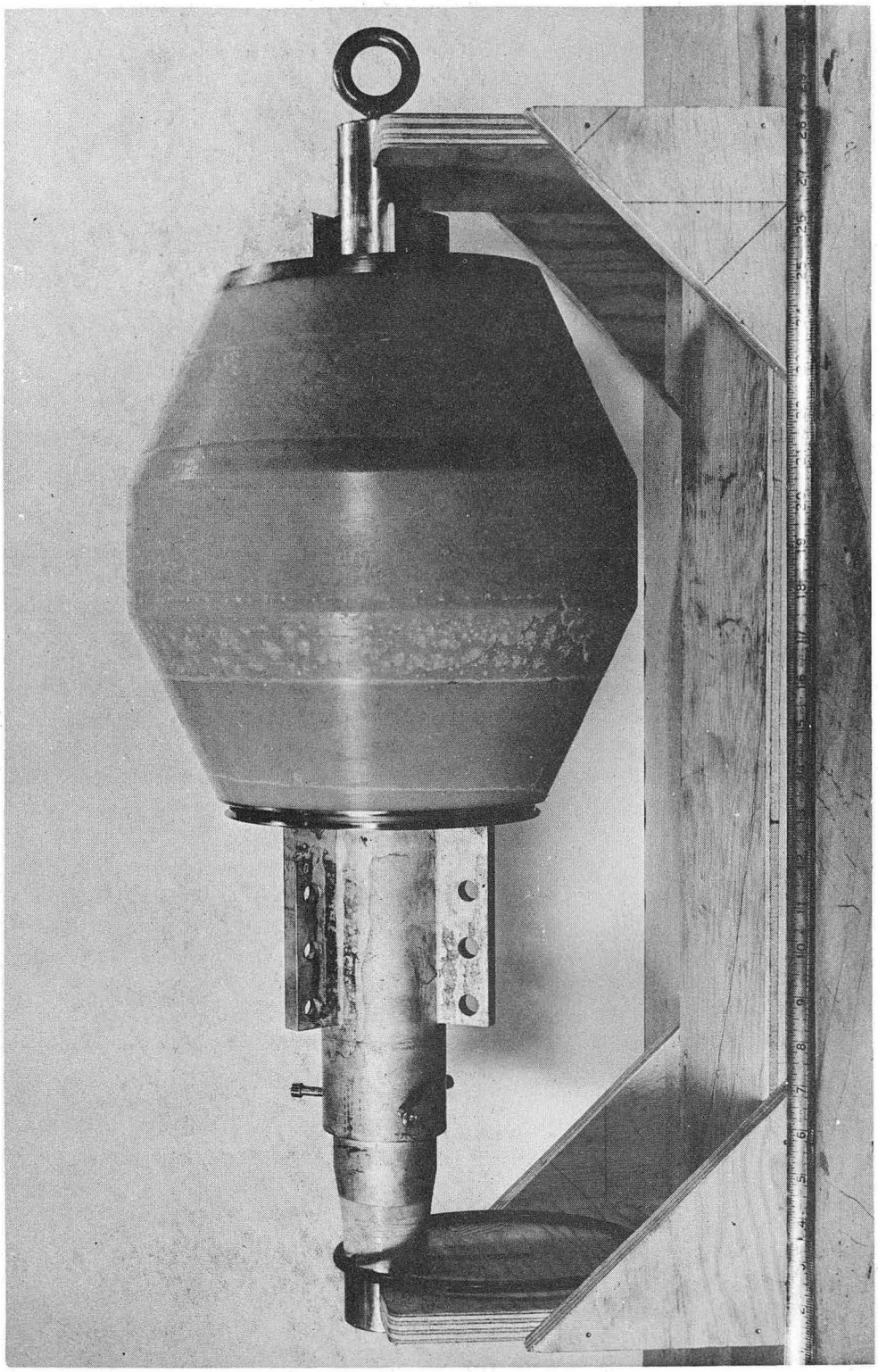
Fig. 5



ZN-1609

Fig. 6

are vacuumtight, do not outgas, and will withstand high voltage, and frequently requires that they have high mechanical strength as well. Figure 7 illustrates a bushing for such an application which has been fabricated of glass cloth and epoxy resin. Merely getting a high-voltage circuit through a grounded case sometimes becomes a problem when one is severely restricted for space. Figure 8 shows bushings constructed of epoxy resin filled with glass beads for use in transformer cases. They carry circuits ranging up to 100,000 volts to ground. Figure 9 shows the internal construction of one of these bushings.

The problem of quickly inserting a target into the accelerated beam of the Bevatron was solved by the use of a coil that would interact with the magnetic field of the Bevatron itself. Such a coil is illustrated in Figs. 10 and 11. The coil is so positioned in the magnetic field that when it is quickly energized by an external source of current it must rotate through 90° to align itself with the field, thus driving the target into the accelerated beam. These coils were constructed on a form machined from acrylic plastic. After the coil was wound, it was tightly taped with a glass cloth tape, which was then saturated with an epoxy resin and cured. The coil was then filled with epoxy resin by means of a veterinarian's syringe, after which it was cured and ready for use.

Our kind of operation requires magnets of every conceivable size, shape, and description. Some of these are used for the purpose of focusing a beam of particles, keeping it in "the straight and narrow path." Figure 12 shows a set of coils forming a quadropole focusing magnet. These coils are wound of square copper conductor with a hole in its center for water cooling. The conductor has cotton sleeving slipped over it, and is then dip-impregnated in vacuum with epoxy resin. These coils are for use inside a linear accelerator at high vacuum. Figure 13 shows the internal construction of coils similar to the focusing coils. The very high space factor obtained is evident. Figure 14 shows a coil constructed in the same manner of water-cooled square copper conductor, this time for a 60-inch-long magnet. This one was first cocooned by wrapping with glass tape and coating with epoxy resin, and then was filled by vacuum-pumping one end and pressure-injecting the resin at the other end.

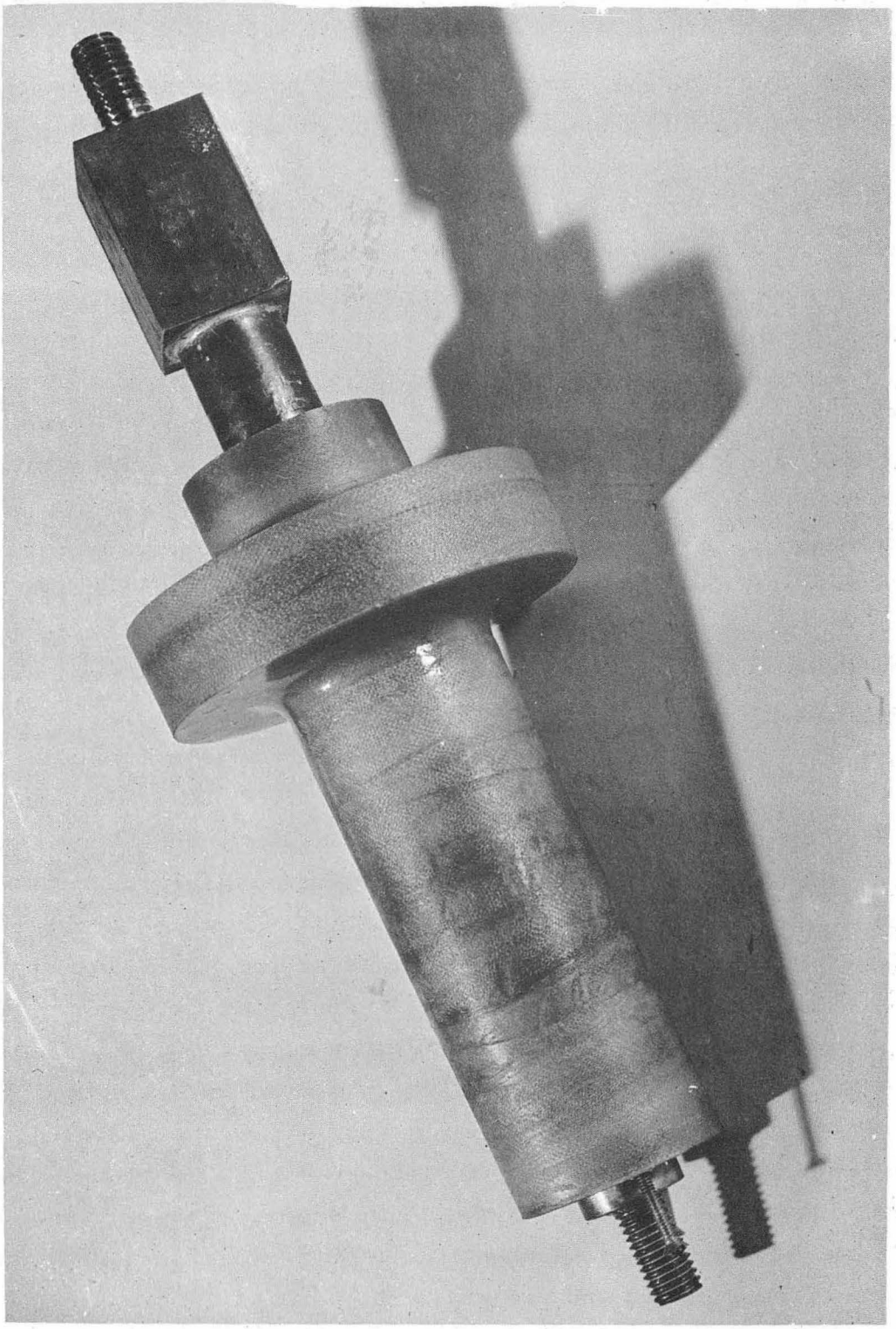


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Fig. 7

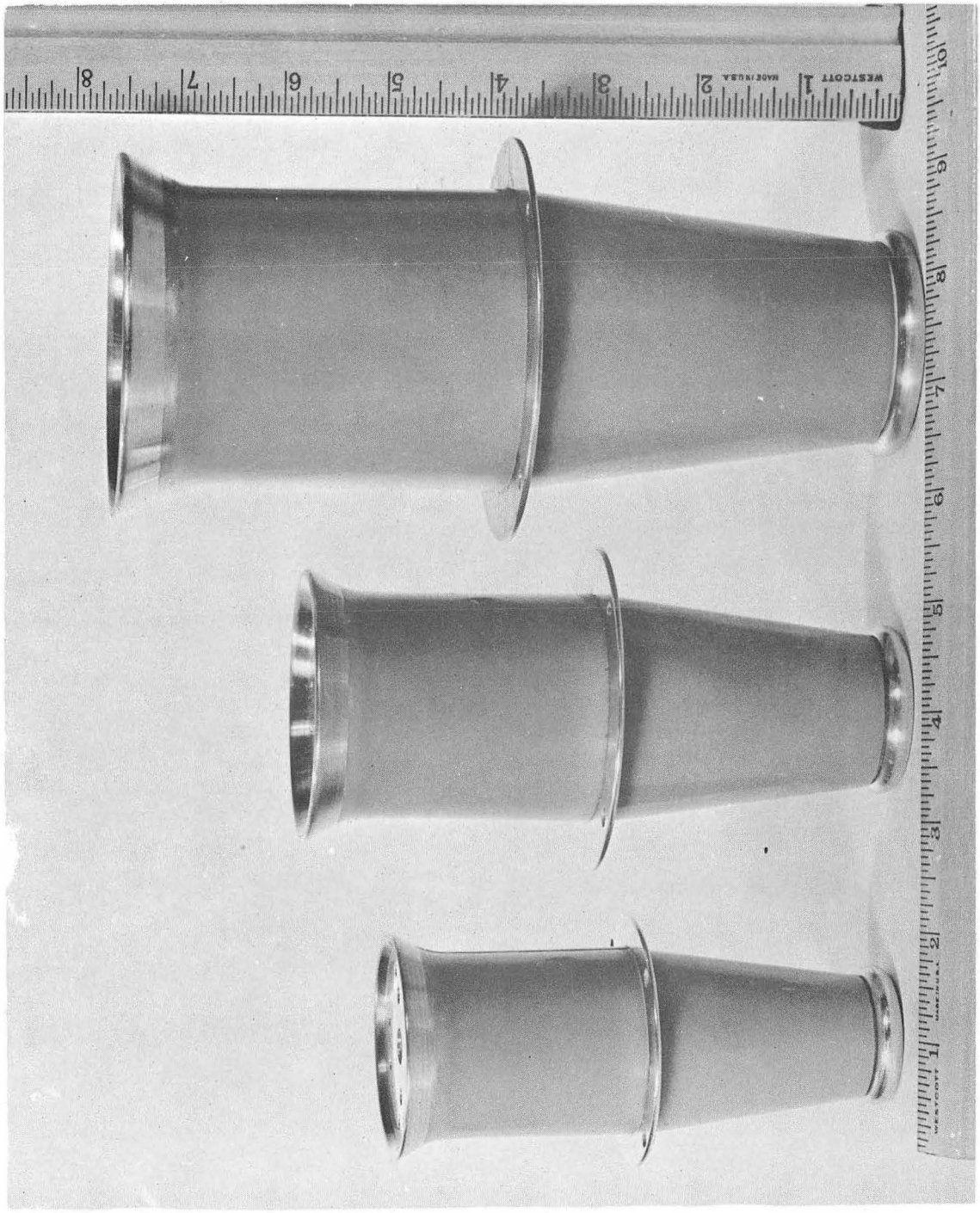

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Fig. 8

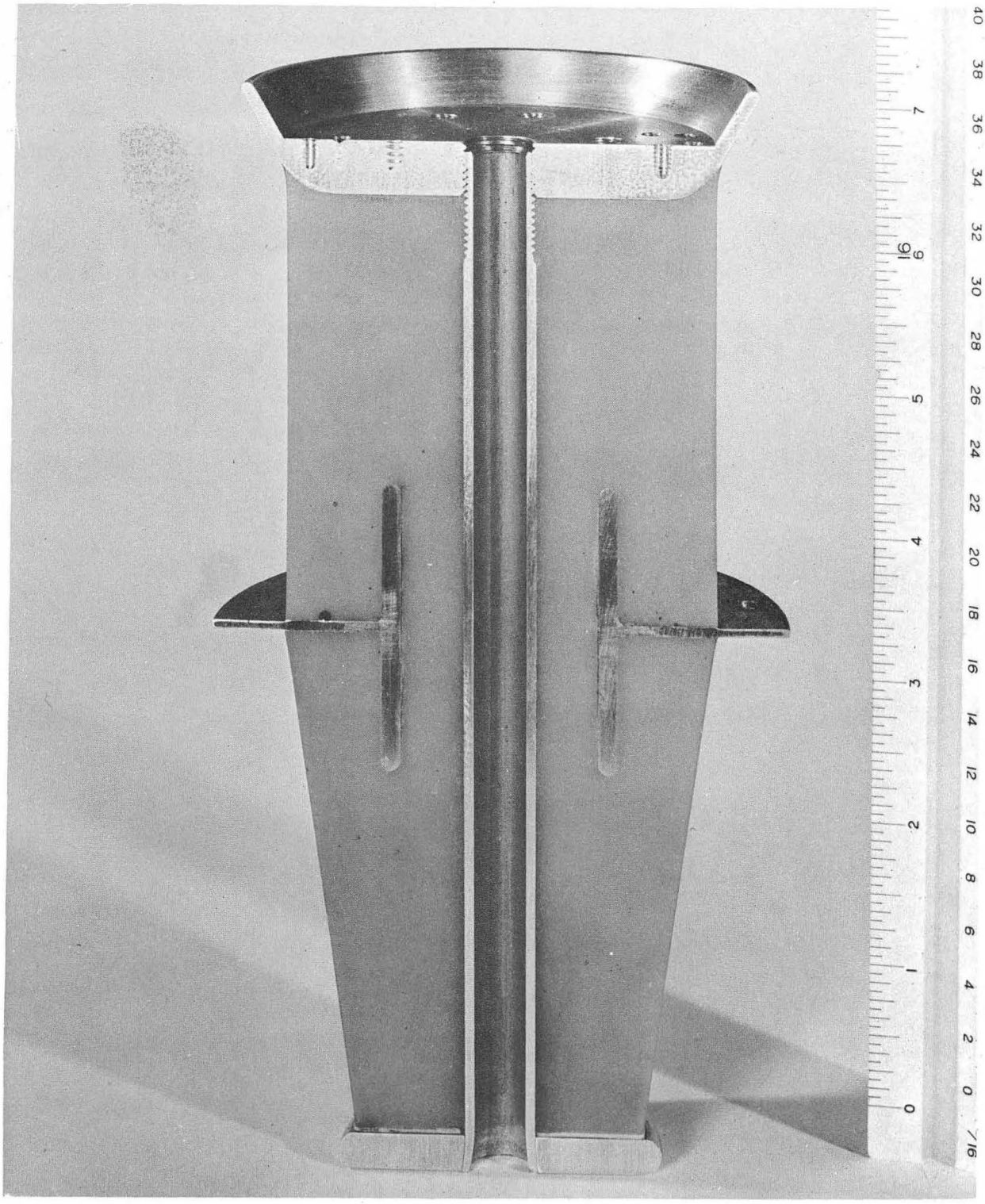

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Fig. 9

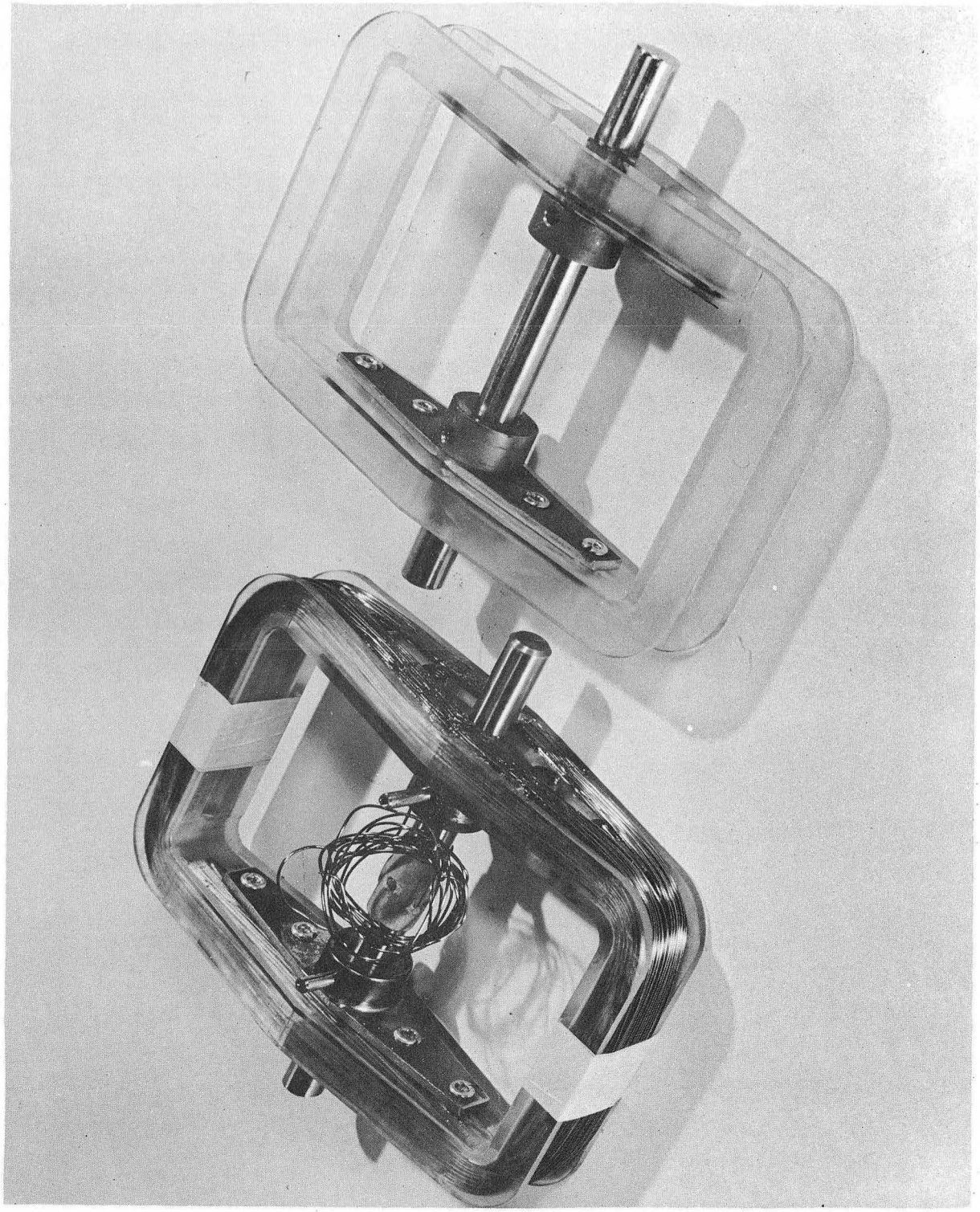

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Fig. 10

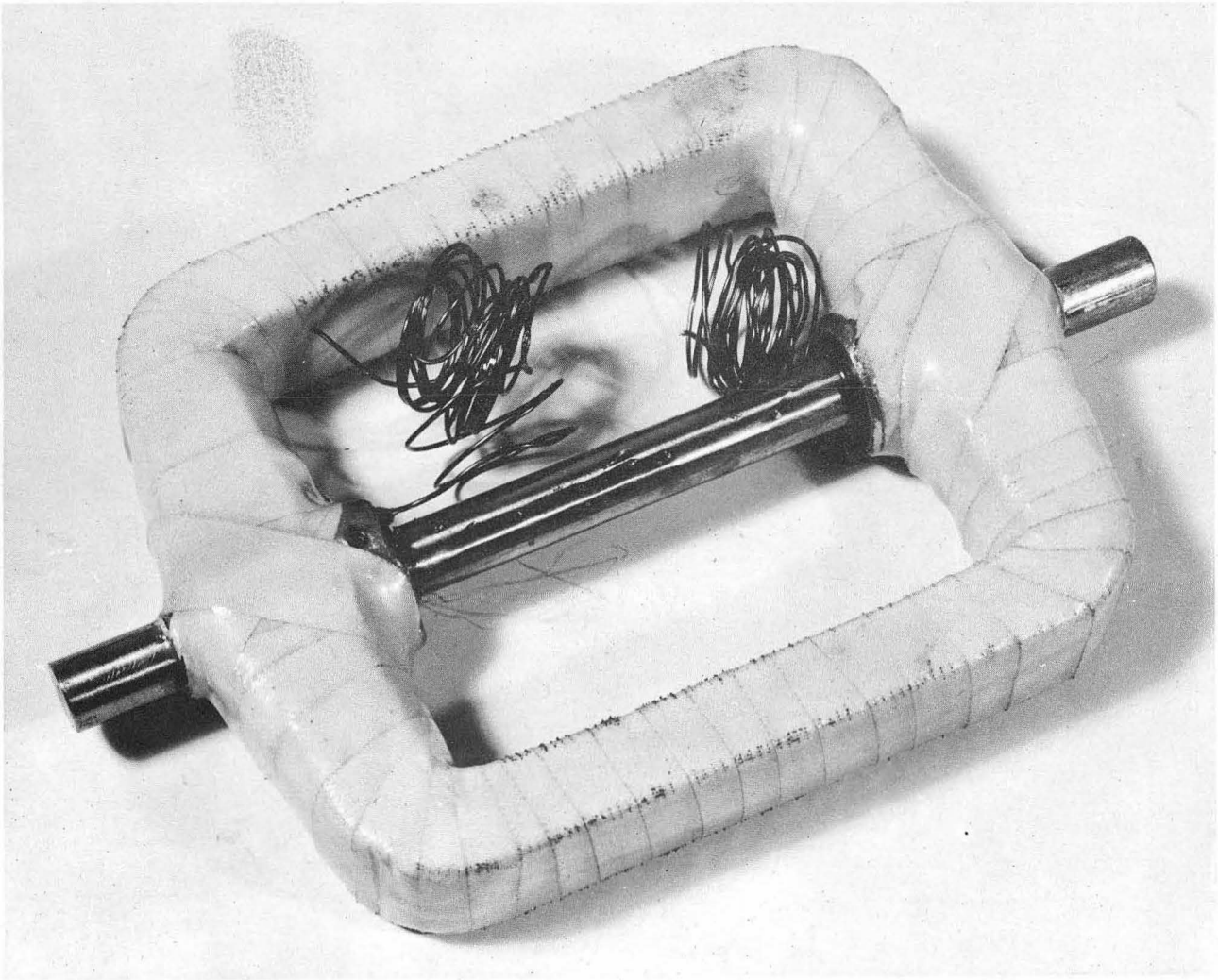

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Fig. 11

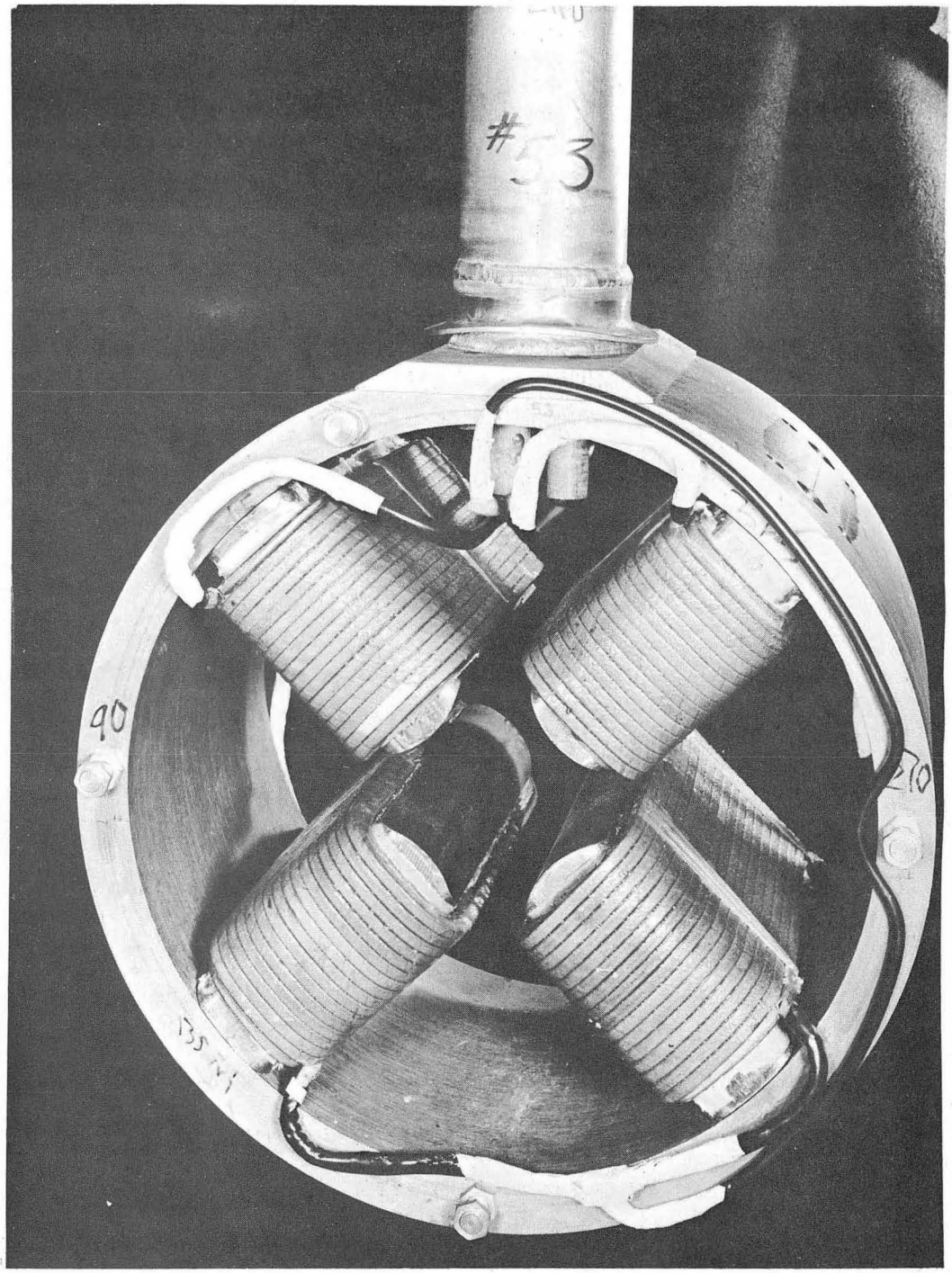

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Fig. 12

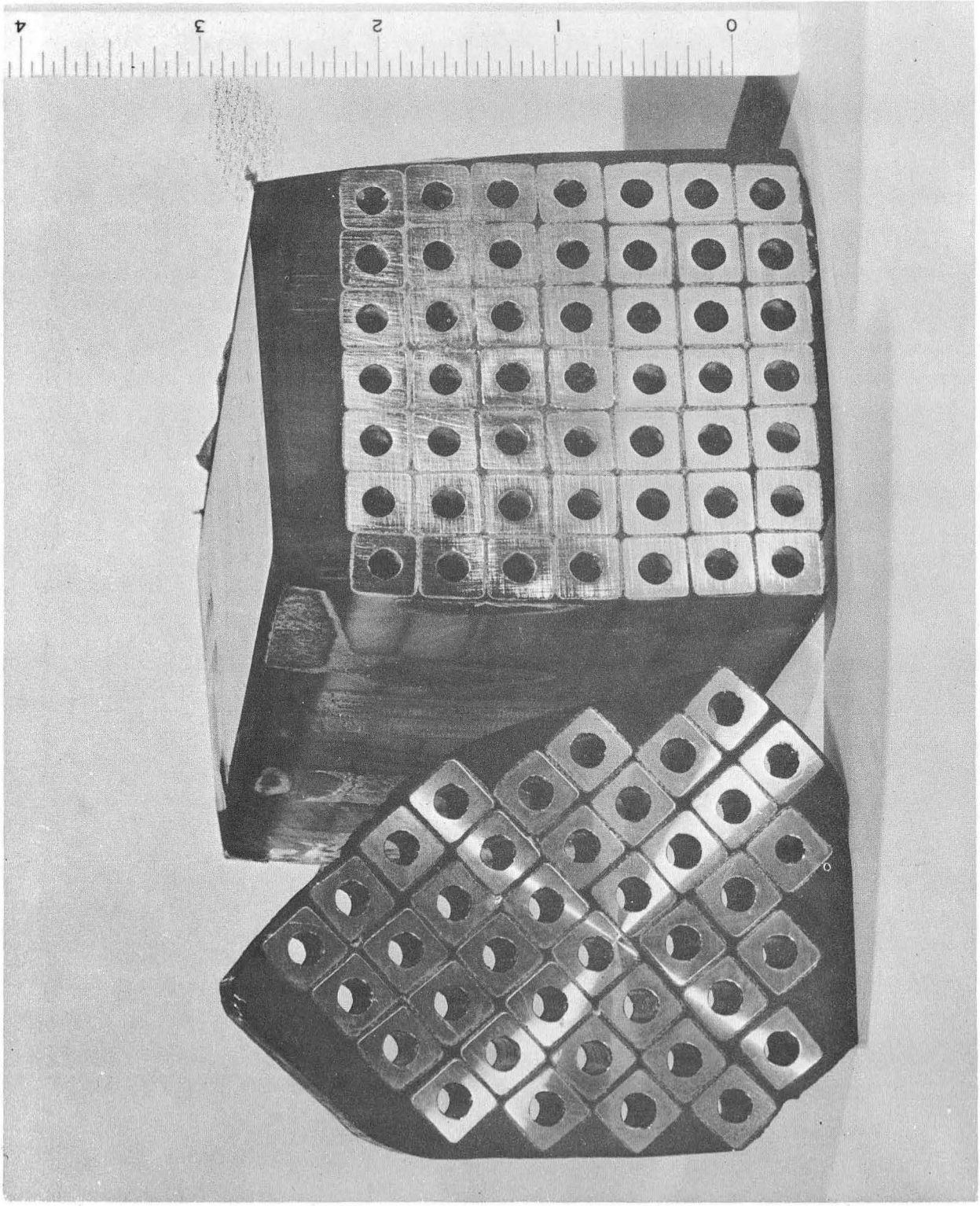

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Fig. 13

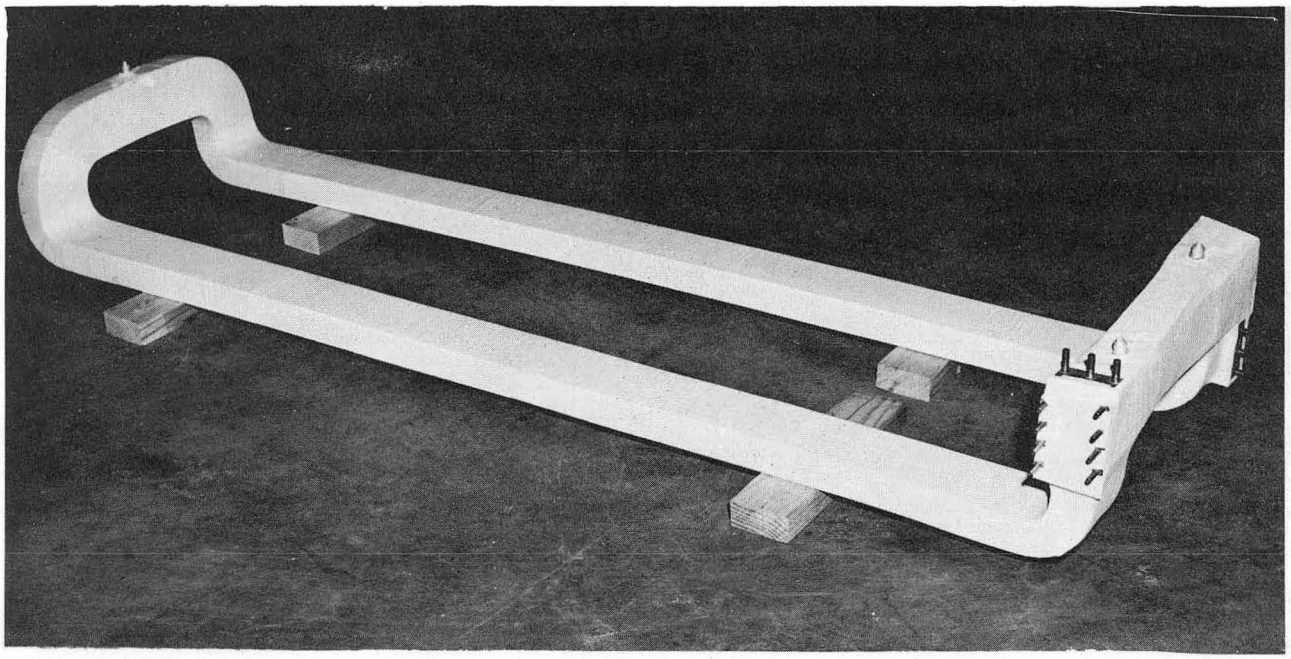

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Fig. 14

In some investigations the magnetic and other forces become exceedingly high and the copper conductor must be reinforced with something that is a nonconductor but still has the highest possible mechanical strength. Figures 15 and 16 illustrate the coils for an application of this sort, which have been constructed of 3/8-in.-square water-cooled conductor, backed up both inside and out with fiberglass roving and cloth, all epoxy-impregnated. Electrical and water connections are made to these coils by drilling and tapping into the side of the conductor near its end.

Even the lowly sandbag is a useful device when it becomes necessary to shield personnel from low-energy radiations emanating from piping. Figure 17 shows a sandbag containing wet sand, and made of heavy-gage polyethylene film sealed with a hot-air gun. Figure 18 shows how the sandbags solved a difficult problem of shielding in a very restricted space.

A great many experiments are based upon collisions of a variety of accelerated particles with protons. In order to get the highest density of protons--that is, the greatest possible number in a given volume--we make use of a considerable amount of liquid hydrogen, whose nucleus consists of a single proton. Since liquid hydrogen boils at approximately -453°F, there arises the problem of building a container to insulate it as well as possible and at the same time to obstruct the incoming beam with as little mass as possible. Figure 19 is a photograph of a sectionalized model of a container built for this purpose. It is constructed so that as the liquid evaporates, the cold hydrogen gas passes out the top of the inner container, down between the walls of the inner and outer containers, and out through the hole at the bottom. This blanket of cold hydrogen gas reduces considerably the heat reaching the inner container from the walls of the outer container. Containers of this type are presently made of expanded styrene, and we are studying the possibility of using some of the "foam in place" polyurethanes for this purpose. Figure 20 is a photograph of a polyethylene liner for a liquid hydrogen target container of a somewhat different shape. The main body of this liner is constructed of 20-mil material, with an insert or window of 2-mil material near the bottom. Sometimes these liquid hydrogen targets have to be used inside the vacuum envelope of the accelerator. In

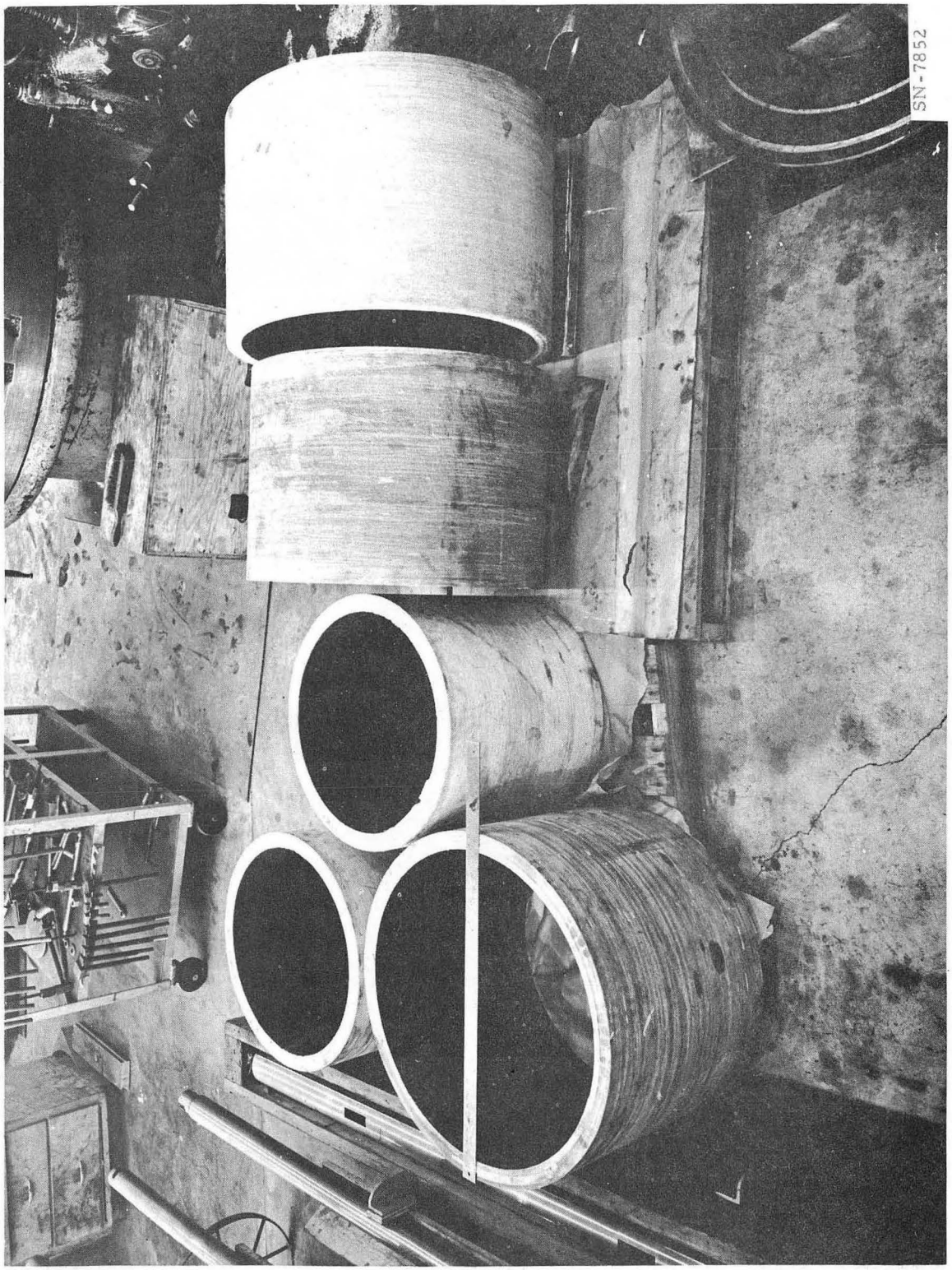

Fig. 15

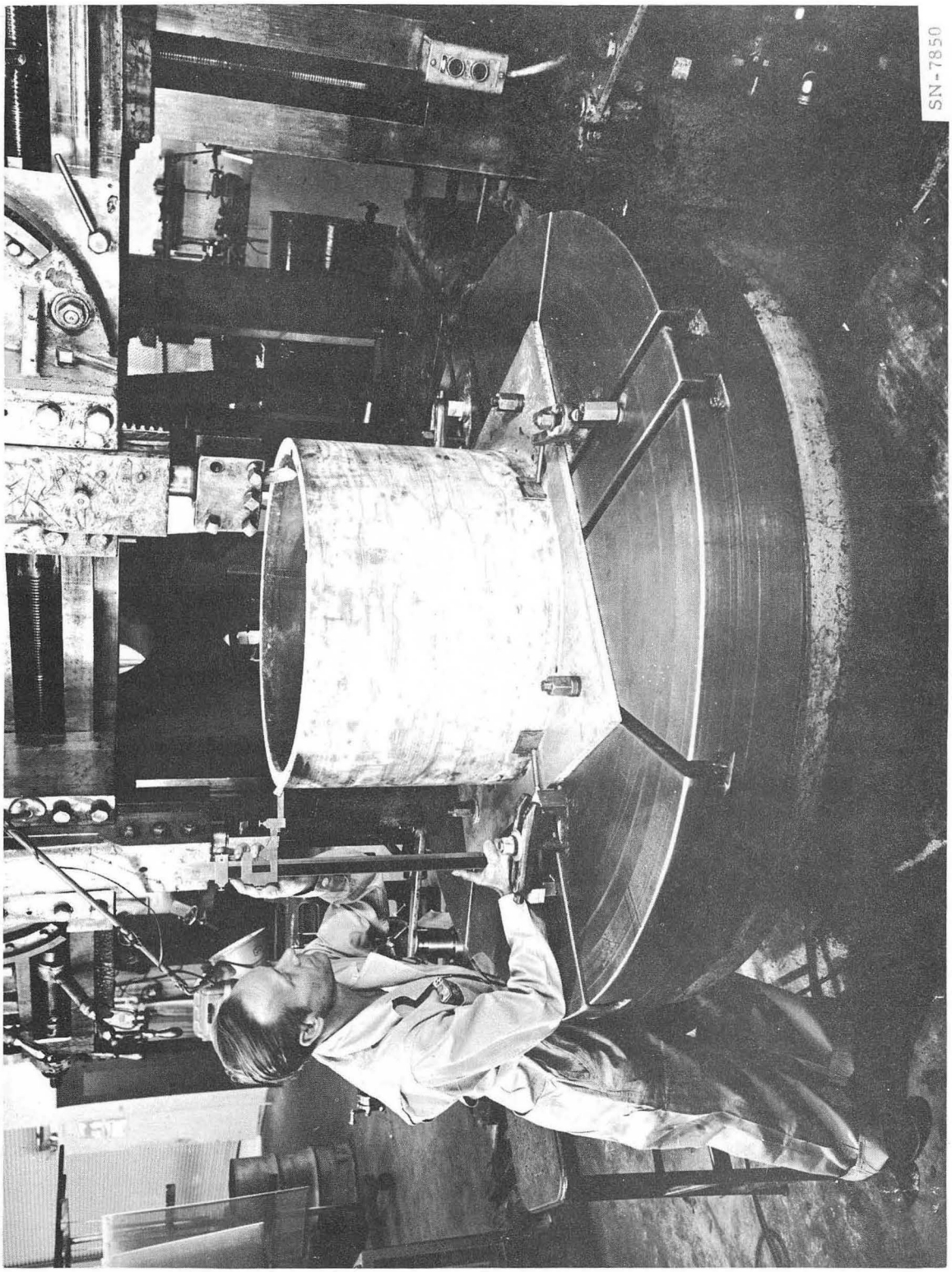

Fig. 16

ZN-1613

Fig. 17

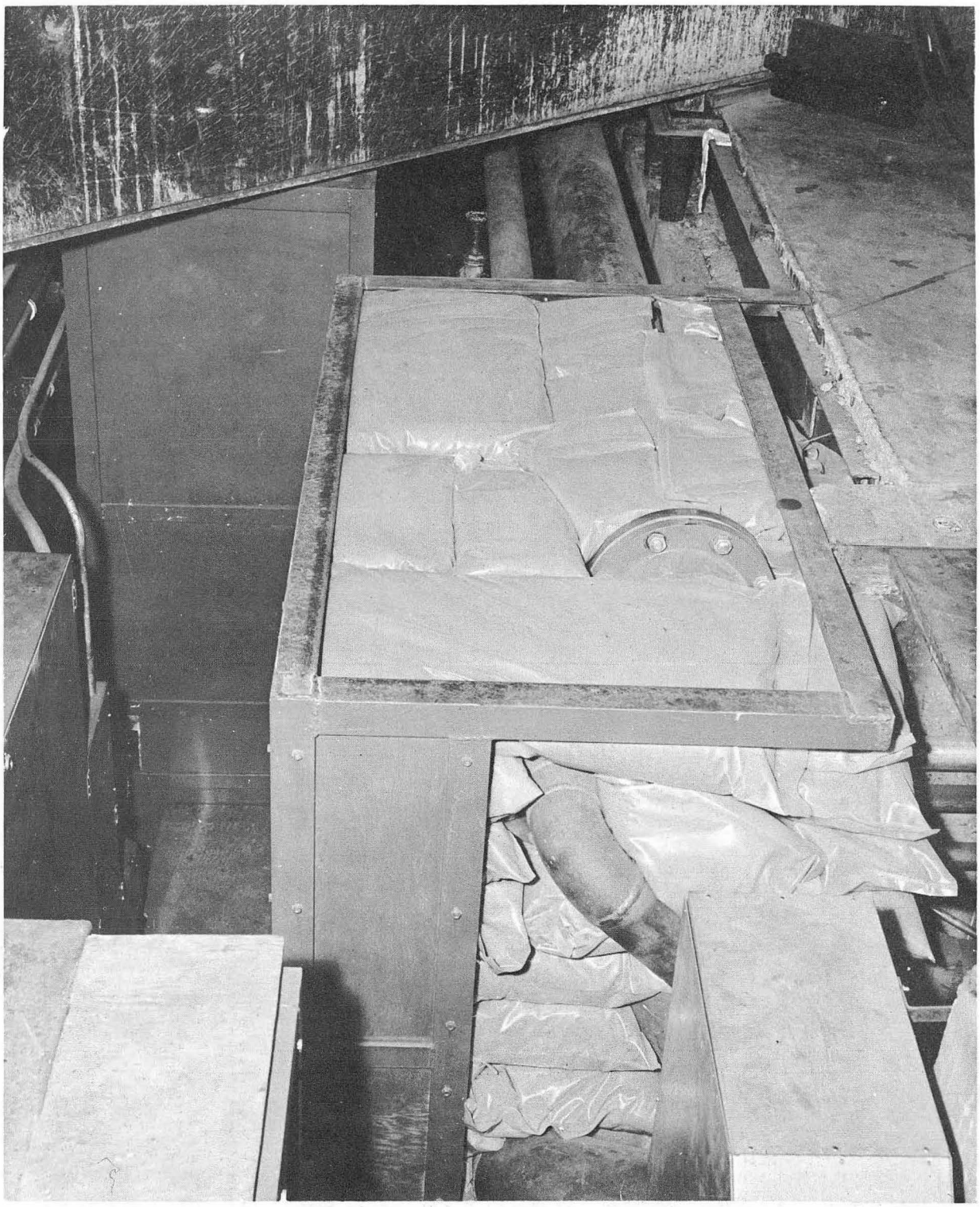

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Fig. 18

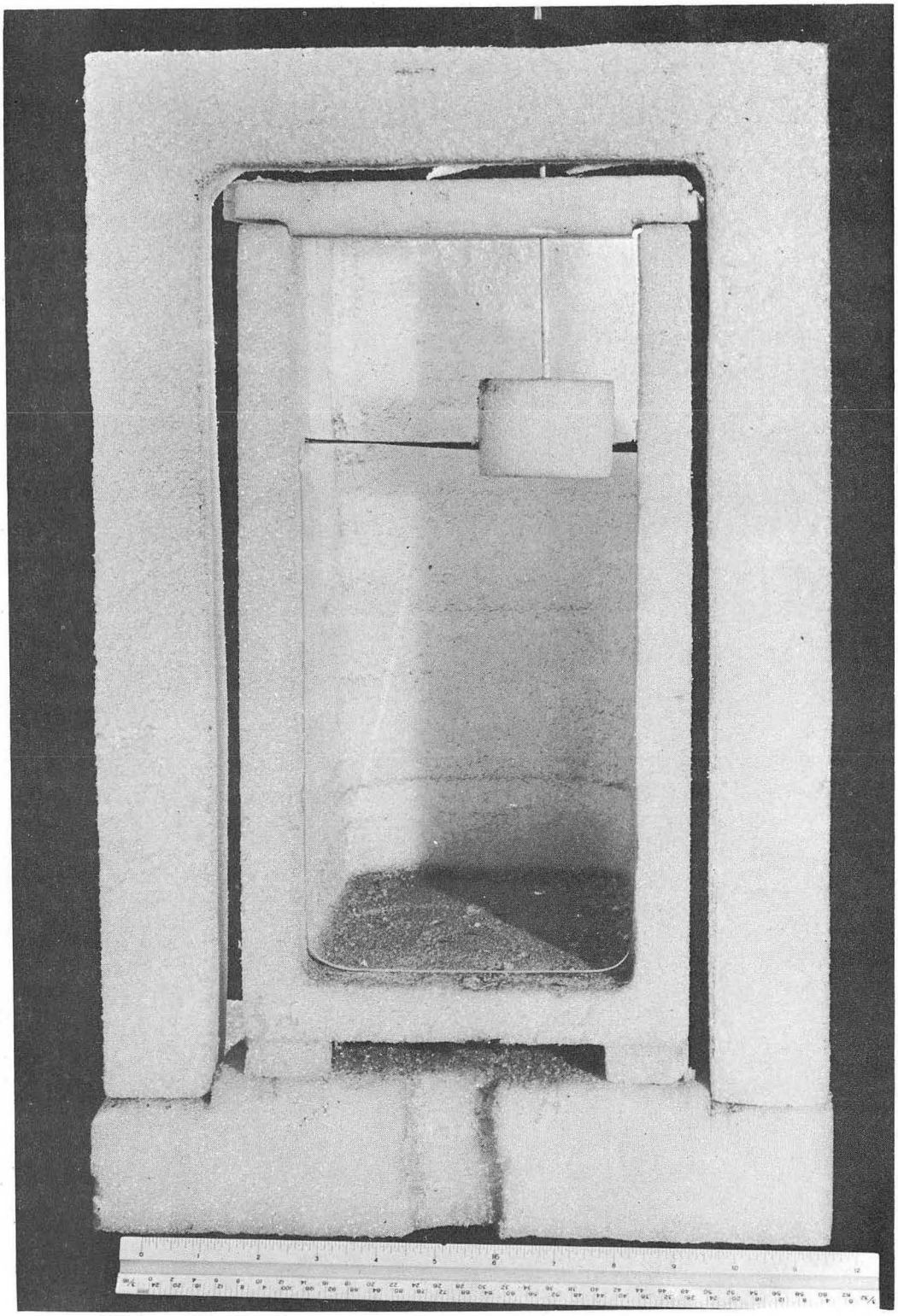

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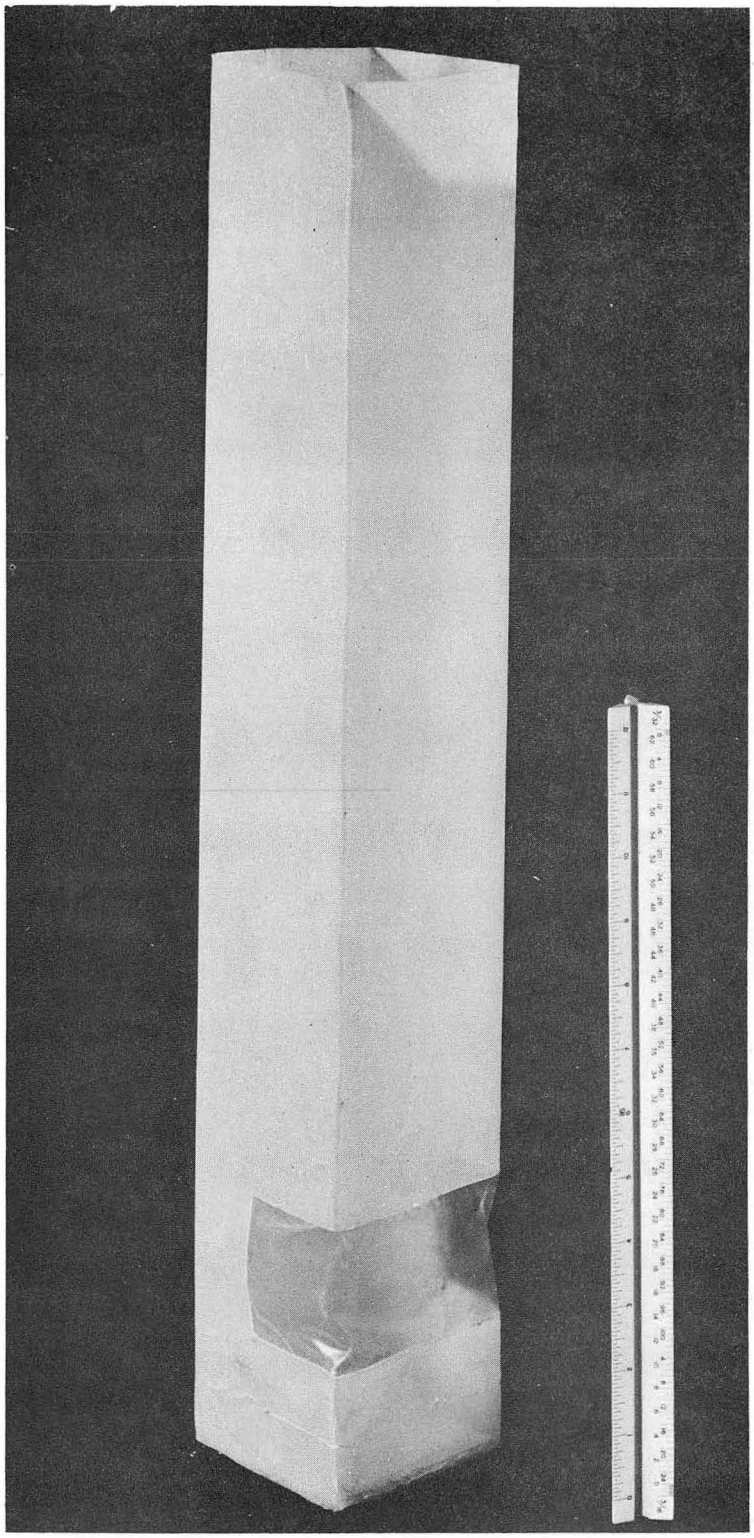
Fig. 19



ZN-1601

Fig. 20

this case we exchange one problem for another. There is no longer any need for heavy insulating walls, but now we must construct a vessel that is completely vacuumtight, and of a material which does not outgas. Figure 21 shows a liquid hydrogen target container for use in a vacuum. This one is constructed of 7.5-mil polyester film cemented to brass with an epoxy adhesive.

The large-scale detection and counting of radiations is a problem unavoidably associated with large-scale nuclear research. A material that lends itself most admirably to accomplishing this purpose is the plastic fluor, or scintillator, which emits visible light under the influence of radiation. As the magnitude of this problem increased, it became necessary to develop a technique for producing these fluors in ever larger and more massive blocks. Figure 22 shows a block of this material alongside a glass bottle that is used as a mold. The manufacture begins with styrene monomer, to which is added an "activator" which is 2 to 3% by weight, and a "shifter" which is approximately 0.03% by weight. This material is poured into the bottle, which is then placed in an oil bath, heated by means of steam coils. The activator and shifter dissolve in the styrene, which is then polymerized by a very carefully controlled elevated temperature. After polymerization, the bottles are removed from the oil bath and quickly incased in a heavy mass of fiberglass insulating material. They are allowed thus to cool slowly for several days, after which the bottle mold is broken and the plastic ingot is ready for machining. Figure 23 is a close-up view of one of these polystyrene fluors after machining. Figure 24 shows a recently constructed mold, which is much larger, and has a slight draft so that the ingot can be removed by sliding out one end. A section sliced from one of the ingots made from this large mold is shown in Fig. 25.

For actual use, this fluor material is fabricated and shaped in a variety of ways. One technique involves pressing out slugs of this material to form wide, flat sheets. Figure 26 shows on the right a slice from one of the ingots, ready for pressing. To its left is shown the same material after it has been pressed out by the application of gentle heat and pressure into a sheet 12 in. square by 0.25 in. thick. Figure 27 shows an assembly that utilizes a number of these sheets.

ZN-1603

Fig. 21

Fig. 22

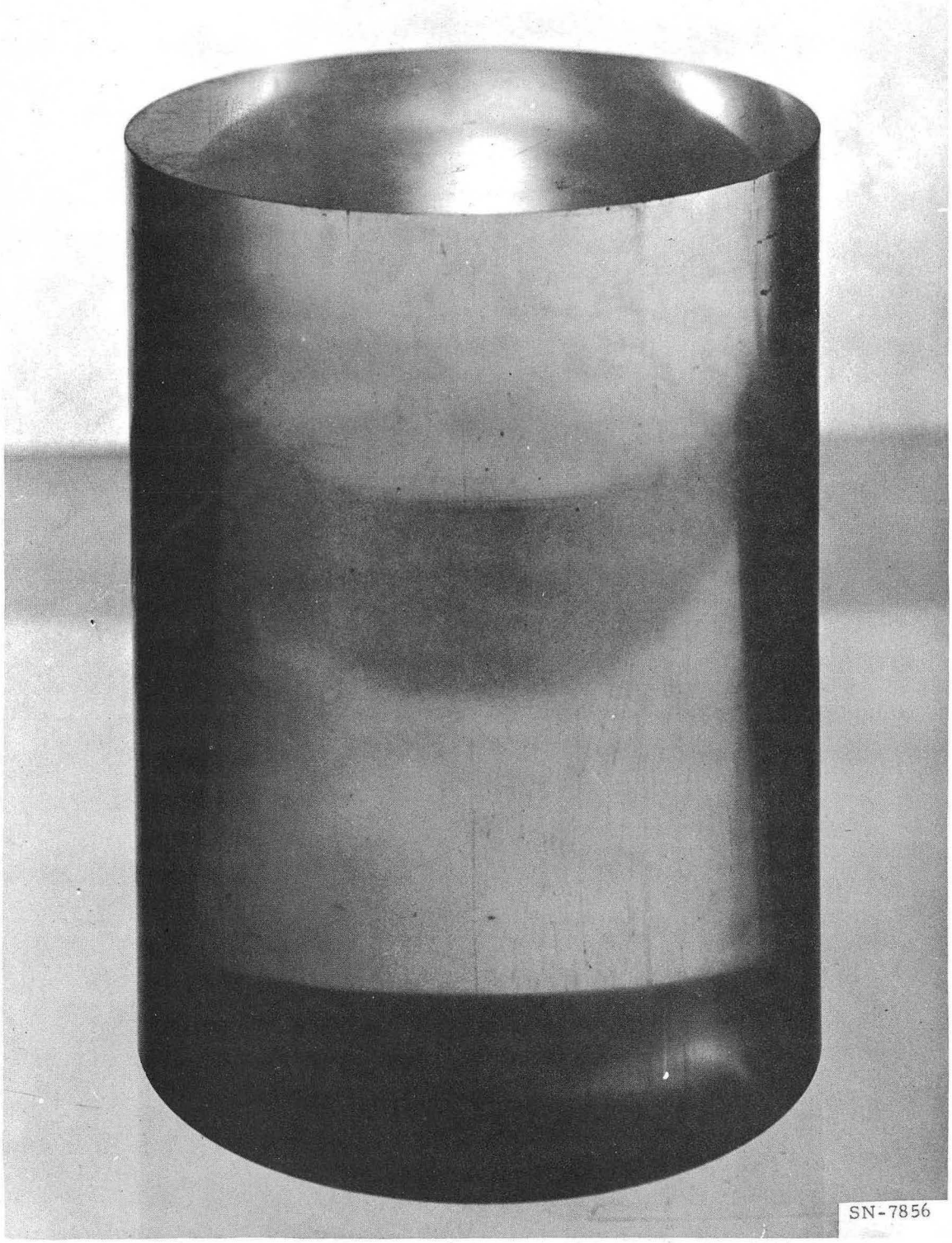


Fig. 23

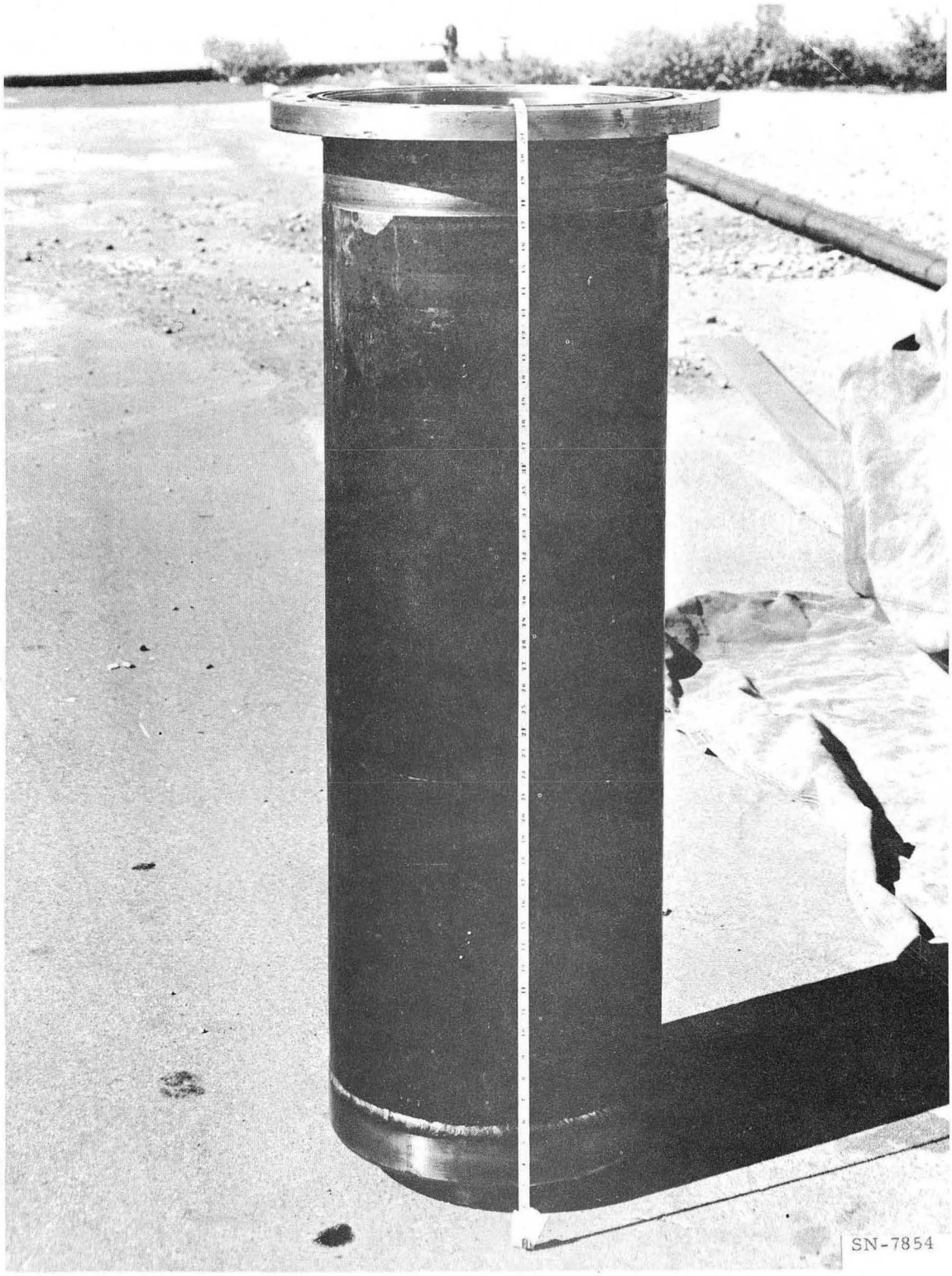


Fig. 24

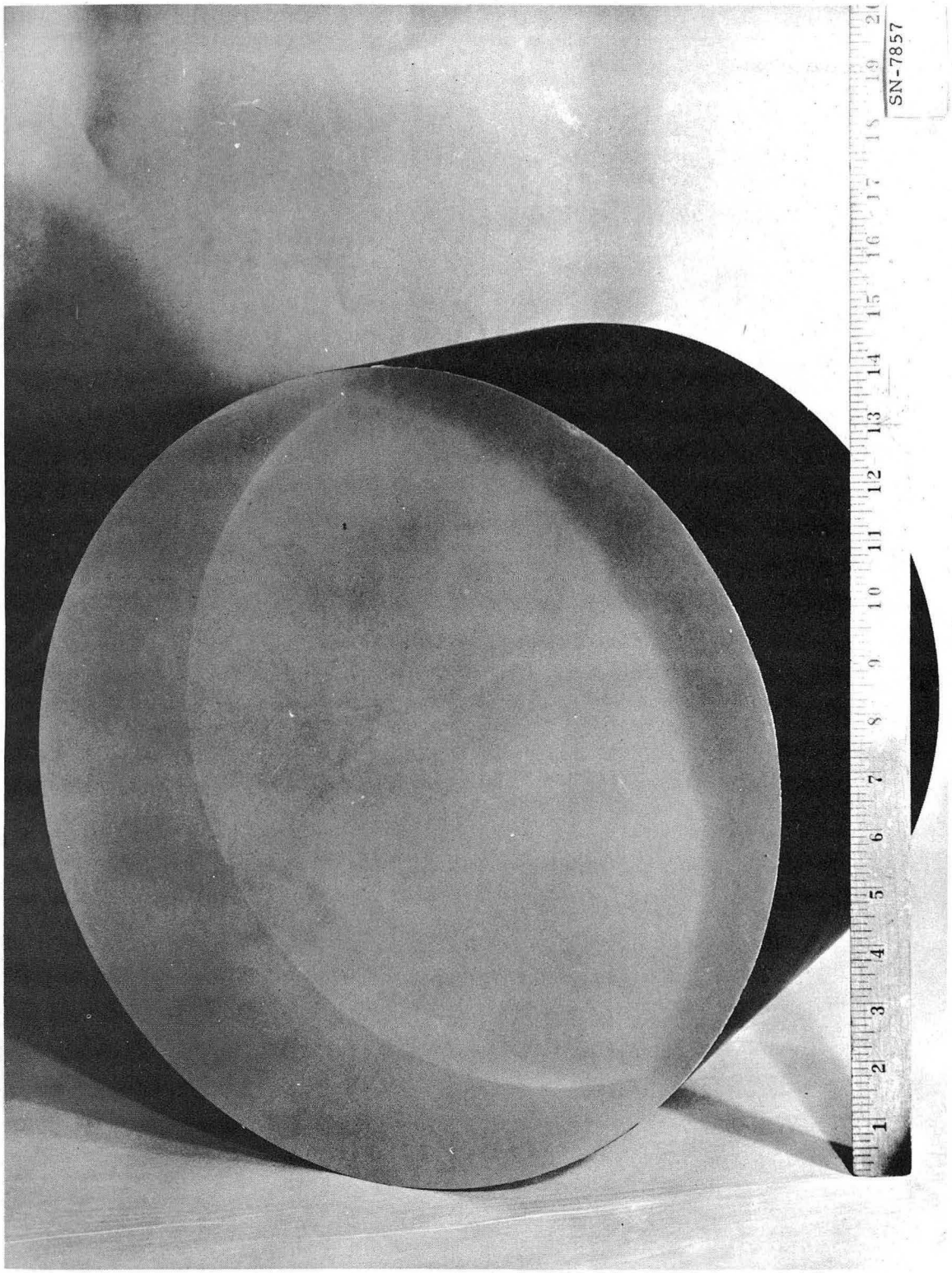


Fig. 25

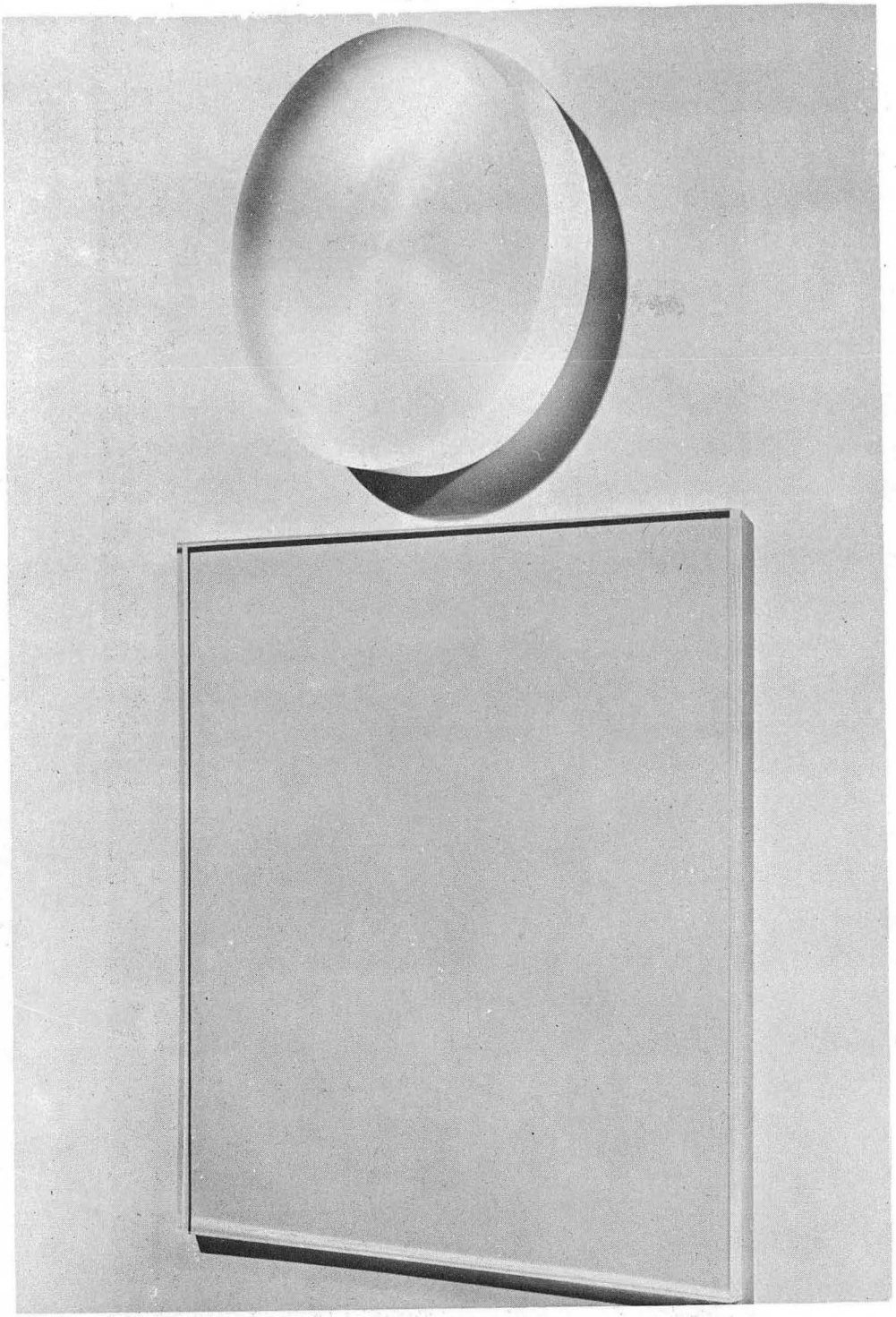


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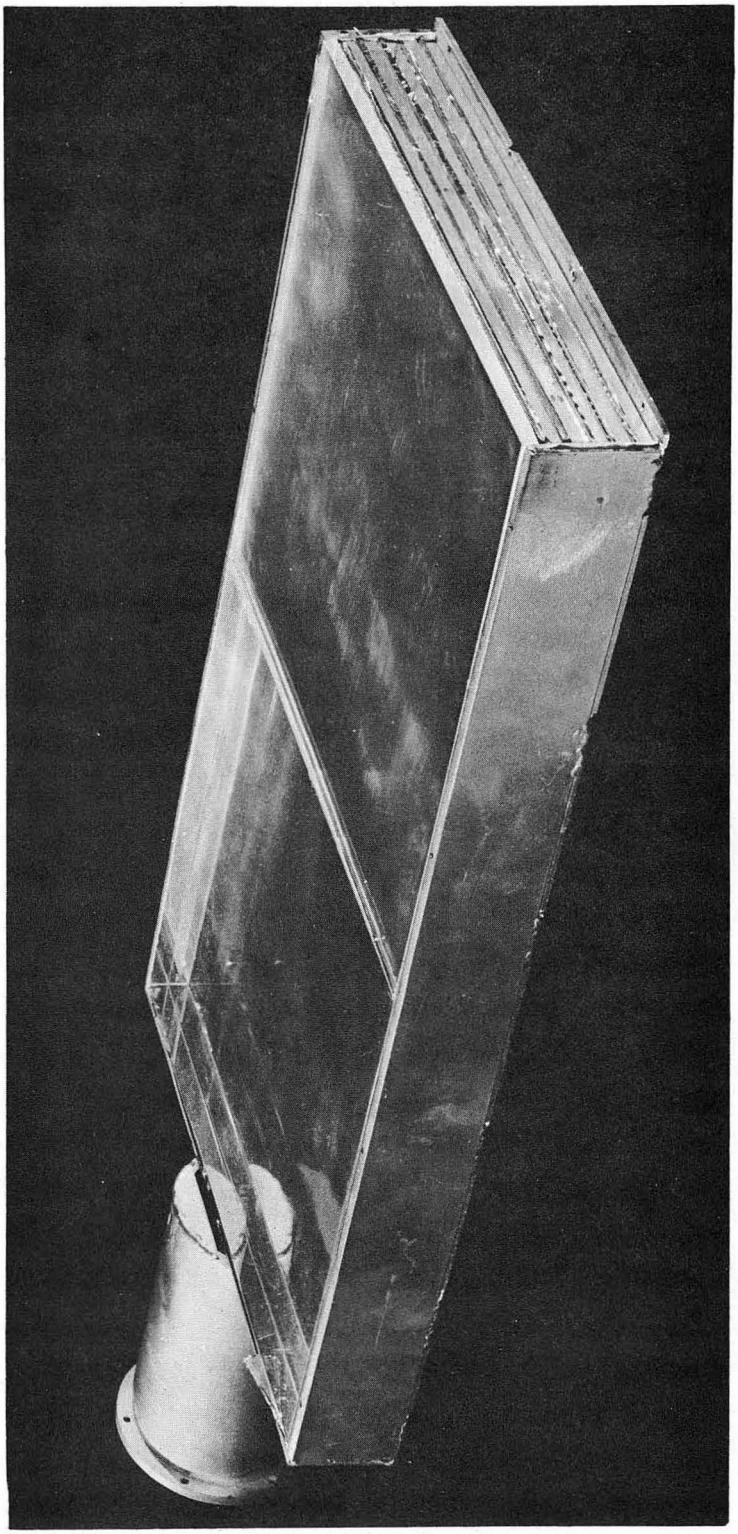
Fig. 26



ZN-1604

Fig. 27

The near end consists of a stack of six of these sheets interleaved with lead sheets approximately 1/32 inch thick. Cemented to the left-hand edge of this stack of fluor plates and lead is a block of acrylic plastic, and beyond that is seen the housing for a photomultiplier tube. The photomultiplier tube looks through the acrylic light pipe at the edges of the fluor sheets, and thus receives light from their scintillations. This assembly is one of many similar cells that are to be stacked up into a large assembly for an antineutron experiment. The axis of the beam or radiation is at right angles to the plane of the fluor sheets. Figure 28 illustrates a somewhat similar application, but without any interleaving lead sheets. The fluor material on the left in this case is 12 in. square by 1 in. thick, and is cemented to a tapered acrylic light pipe. Again, the photomultiplier tube is positioned so that it looks through the acrylic light pipe at the edge of the plastic fluor.

When accelerated particles traveling near the speed of light in vacuum or in air enter a material of appreciably greater density, they find themselves traveling actually faster than the speed of light in that particular medium. Under these conditions they produce a visible glow known as a Cerenkov radiation. This phenomenon is utilized in a number of ways. Figure 29 shows a piece of apparatus using a square of acrylic plastic to detect and count high-velocity particles by means of Cerenkov radiations. Here again, photomultiplier tubes look at the edges of the detecting material through acrylic light pipes.

Another device for the detection and analysis of high-energy particle reactions is a cloud chamber. One form of this device contains an atmosphere of hydrogen gas saturated with methyl alcohol vapor at a pressure of somewhat more than 500 pounds per square inch. This poses the problem of how to construct windows through which to illuminate the chamber for taking pictures. Glass is unsatisfactory because of high mechanical and thermal shocks involved. A satisfactory solution was arrived at by the use of a polyester casting. Figure 30 shows two stages in the manufacture of these windows. The material is cast in the form of a ring, which is machined to size and then cut into four 90° segments, polished, and grooved for gaskets.

The newest development for the high-speed analysis of high-energy particle reactions is the bubble chamber, in which the speeding

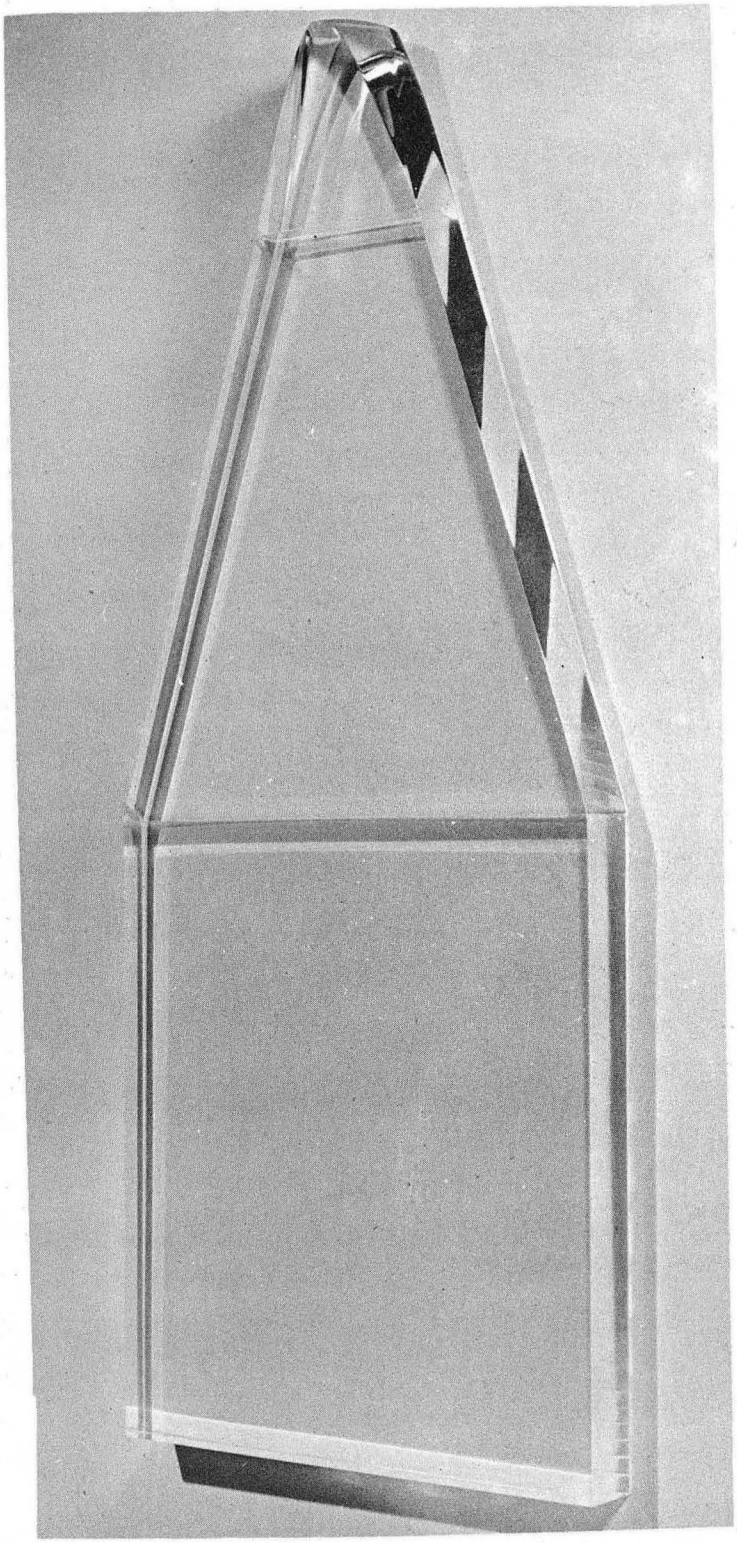


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Fig. 28

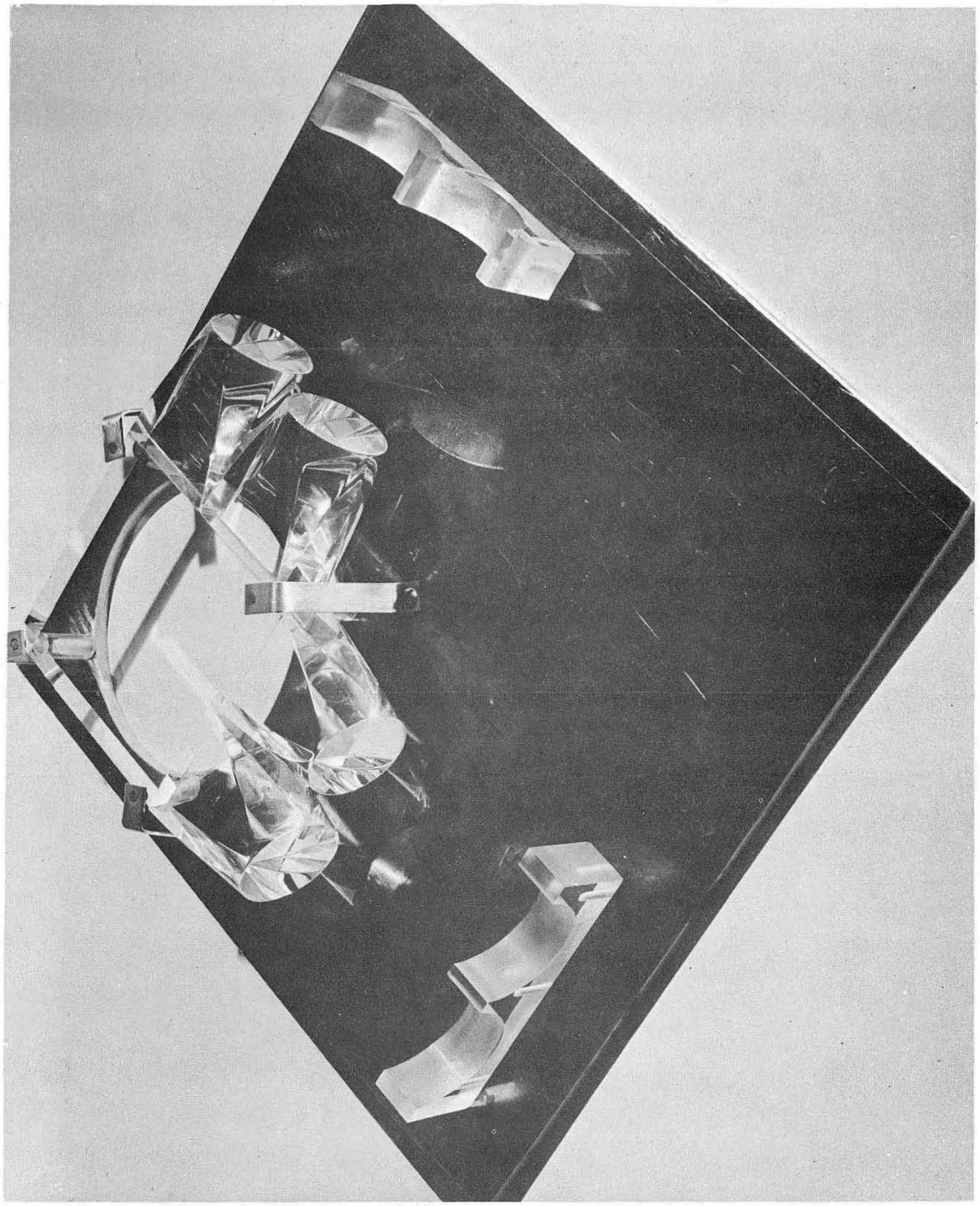

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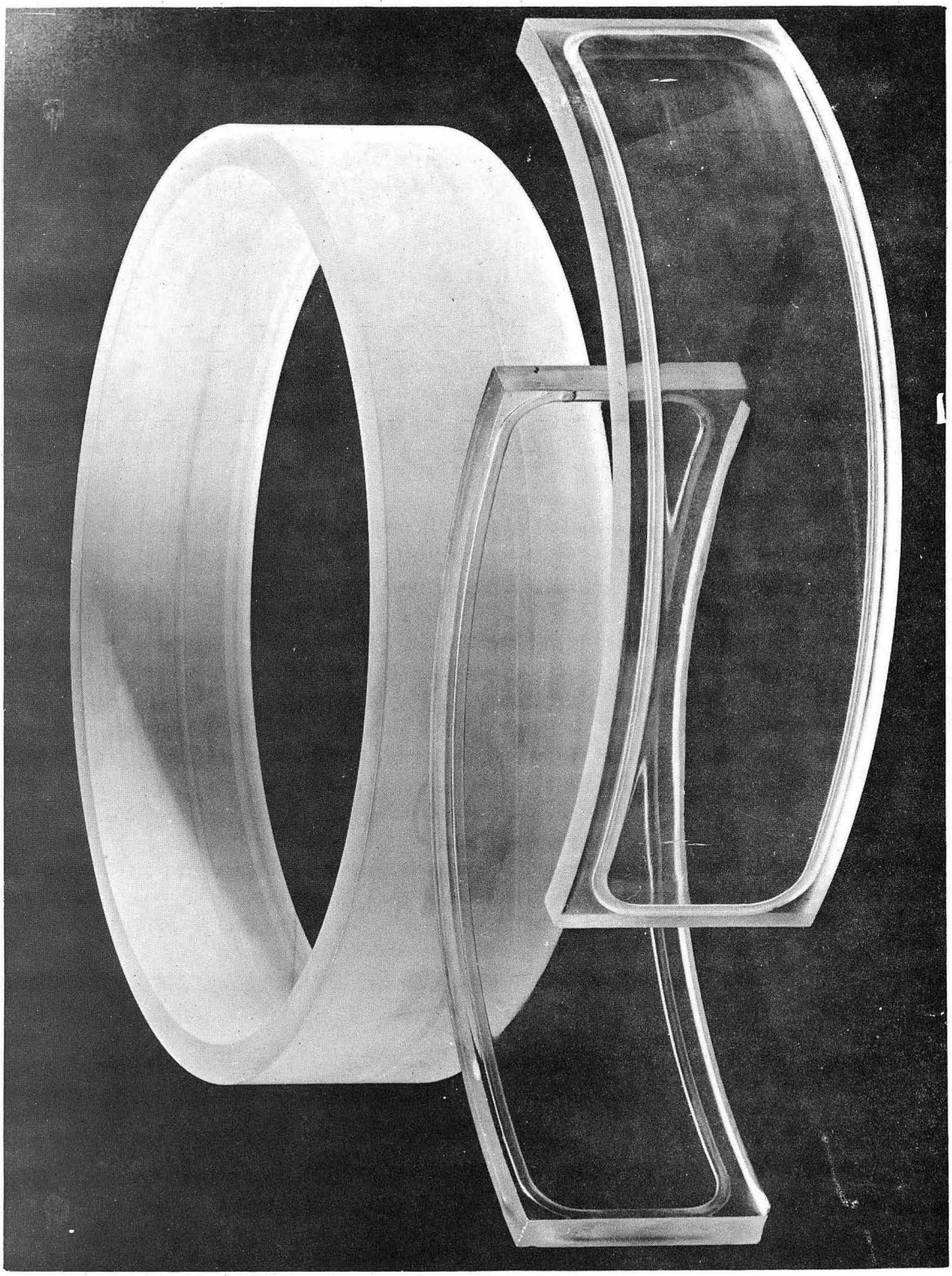
Fig. 29



ZN-1620

Fig. 30

particle leaves a trail, or track, of vapor bubbles in a liquid. The tracks are made to curve by strong magnetic fields and are photographed for precise measurement and analysis. Figure 31 shows such a device, which is now under construction, and which will use liquid hydrogen for the active medium. To create a strong magnetic field, there will be two coils, each with 190 turns of 1.3-in.-square copper conductor with a 1-in.-diameter cooling-water hole in the center. The conductor will be wrapped with two layers of 0.002-in. polyester film tape; the turns will be separated by a 0.020-in.-thick continuous strip of a polyester and fiberglass mat and asbestos laminate; between the layers or "pancakes," will be two thicknesses of this material; and the coil will be insulated from the surrounding steel by two layers of 0.062-in. polyester and fiberglass cloth laminate.

Many other examples could be cited involving vinyls, silicones, fluorocarbons, nylons, and so on and on. This paper can illustrate only a selected few, but these serve to illustrate how much the continual flow of new plastics materials and ideas have helped to further scientific research. We hope the industry and its brains will keep them coming!

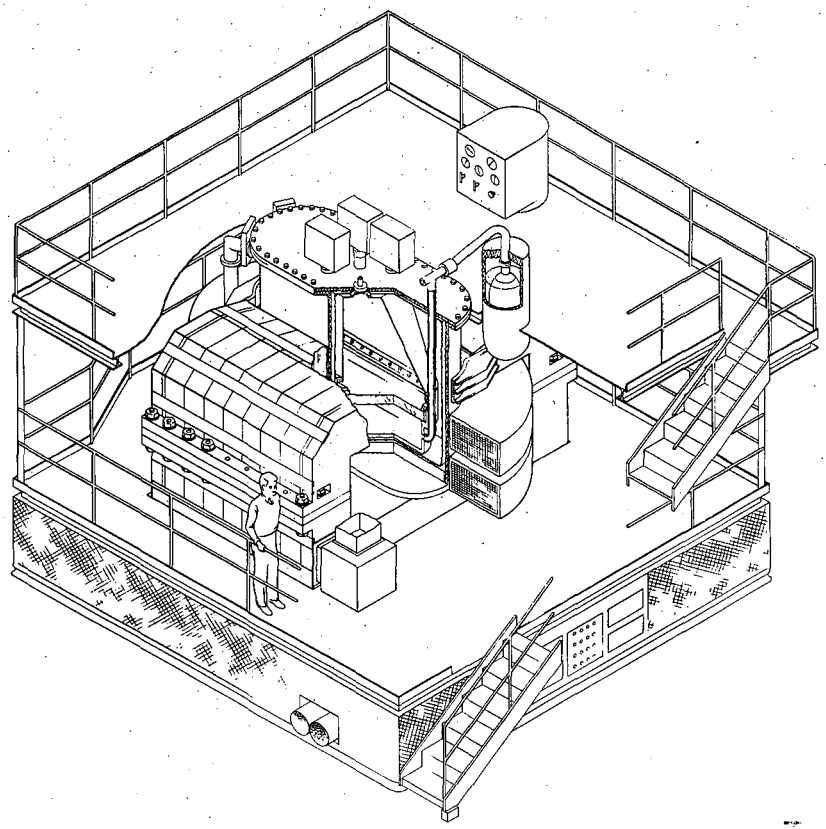


Fig. 31

LEGENDS

Fig. 1. Electrostatic lens with cast epoxy insulating rings.

Fig. 2. Epoxy rings and metallic electrode for electrostatic lens.

Fig. 3. Epoxy-embedded secondary coil of high-voltage-filament transformer. Ten turns No. 10 wire.

Fig. 4. Completed high-voltage isolating filament transformer. Test voltage, secondary to ground, 60,000 rms volts, 60 cycles.

Fig. 5. Clear epoxy casting (10 in. diam.) for cable pothead for use at 235,000 volts dc.

Fig. 6. Epoxy casting approximately 12 by 18 in. with glass bead filler for cable pothead for use at 500,000 volts dc.

Fig. 7. Bushing of glass cloth and epoxy resin for high-vacuum vessel.

Fig. 8. Bushings of glass-bead-filled epoxy for high-voltage transformer cases; 60-cycle rms flashover voltages, left to right, 62,000; 75,000; and 100,000.

Fig. 9. Sectioned view of transformer-case bushings.

Fig. 10. Two stages in the fabrication of the "flip" coil for plunging a target into the internal Bevatron beam. Approximately 6 by 8 in.

Fig. 11. Flip coil after completion.

Fig. 12. Focusing-magnet coils of water-cooled copper conductor; epoxy impregnated; used in high vacuum.

Fig. 13. Sections from two coils wound of square copper conductor, cotton-tape wrapped and embedded in epoxy. Conductor approximately 5/16 in. square.

Fig. 14. Coil of water-cooled square conductor for 60-in.-long analyzing magnet, impregnated by vacuum-pumping one end and pressure-injecting epoxy resin at other end.

Fig. 15. Coils of 3/8-in.-square conductor backed up inside and out with fiberglass roving and cloth, all epoxy-impregnated.

Fig. 16. Roving- and cloth-reinforced coil being machined.

Fig. 17. Sealing sandbags of 10-mil polyethylene with hot-air gun.

Fig. 18. Polyethylene sandbags for shielding, packed around pipes carrying radioactive liquids.

Fig. 19. Sectionalized model of expanded styrene container for liquid hydrogen used as target for highly accelerated nuclear particles.

Fig. 20. Polyethylene liner for liquid hydrogen target container.

Fig. 21. Target of 7.5-mil polyester film and brass to contain liquid hydrogen inside vacuum chamber.

Fig. 22. Polystyrene scintillating fluor and mold.

Fig. 23. Polystyrene fluor after machining.

Fig. 24. Large-size mold for polystyrene fluor.

Fig. 25. Section sliced from large polystyrene fluor.

Fig. 26. Two stages of fluor fabrication for special experimental setup. Finished plate is 12 in. square by 0.25 in. thick.

Fig. 27. Completed cell for antineutron experiment: a stack of fluor sheets interleavened with lead, an acrylic light pipe, and a photomultiplier housing.

Fig. 28. Fluor block and acrylic light pipe. Fluor is 12 in. square by 1 in. thick.

Fig. 29. Acrylic Cerenkov counter (without photomultipliers).

Fig. 30. Cast polyester windows for 35-atmosphere cloud chamber. Ring before cutting and polishing is approximately 20 in. (o.d.) by 4.5 in. wide, with a 1-in. wall.

Fig. 31. General arrangement of 72-inch liquid hydrogen bubble chamber.