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ABSTRACT

Vacuumtight cryogenic containers can easily be made from Mylar plastic sheet and metal, or from Mylar alone, for use in vacuum-insulated liquid hydrogen target assemblies. Mylar is bonded very firmly to metals or to itself by an Epon-Versamid mixture or by Armstrong A-4. These adhesives maintain strong vacuumtight joints throughout the temperature range from 300°K to 4°K. Mylar sheet has also proved satisfactory as vacuum-window material for beam ports. Fabrication of these structures is described in detail, and explosion-safety measures are mentioned. Some examples are given of structures which have been used or tested, with data on the ultimate strength of each expressed as the internal pressure required to rupture it. Helium leak testing must be carried out at 77°K or below, because Mylar is relatively impermeable to helium only at low temperatures. The primary electron beams commonly obtained from electron-linear accelerators are sufficiently intense to cause Mylar beam windows to fail under vacuum loading, probably because of radiation damage. However, the authors know of no case of radiation damage to Mylar sustained in exposure to secondary beams from high-energy accelerators.

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Vacuum-insulated liquid hydrogen targets are commonly used in conjunction with high-energy particle accelerators in the study of interactions between elementary particles. This note concerns the fabrication of the container (target) for the bombarded hydrogen and the beam-entrance windows of the vacuum system.

Background effects that arise from interaction of radiation with the target walls can be minimized by making the targets as transparent as possible. For targets designed for use in high-energy photon beams, it is particularly important to use thin material of low atomic number if electron background is important.

Mylar ($C_{10}O_4H_8$) plastic sheet has proven satisfactory for the construction of transparent cryogenic targets; and in certain applications where thick beam-entrance or -exit windows in the vacuum system are sources of background, satisfactory Mylar windows also have been fabricated. The material is sufficiently transparent to light so that liquid levels in the target may be ascertained by visual inspection instead of by means of a level indicator. Some examples of bonded targets are shown in Fig. 1.

Two adhesives have been found suitable for attaching Mylar to metals and to itself, namely, Epon-Versamid and Armstrong A-4. The first is a 50-50% mixture (by weight) of Epon No. 828 and Versamid No. 125. (See List I for manufacturers.) The surface to be bonded is cleaned with acetone and lightly sandblasted with a fine powder; the bonding agent is then smeared on the surfaces, the joint is mechanically clamped (when possible), and the part is cured at 60° C for 1 to 1-1/2 hours. Generous fillets should be allowed at Mylar-to-Mylar joints (see Fig. 2). Some joints may require two or three coatings to achieve a suitable fillet without dripping. In these cases each successive layer of adhesive should be partially cured before the next is added. This adhesive gives a mechanically strong, vacuumtight joint. In all pressure tests of targets to date, there have been no instances of joint failure. Occasionally a joint has a bubble or crack due to improper construction. This type of flaw can be patched by simply adding more Epon-Versamid adhesive and recuring. The second adhesive is a mixture of 88% Armstrong A-4 and 12% activator "E". Joints using this adhesive are prepared identically to the first, except the curing temperature and time are 165° C and 2 hours, respectively. This adhesive seems to be especially good when a Mylar-to-aluminum joint is required. Care must be used in heating pneumatically formed Mylar parts above 100° C, since Mylar has a tendency to return to its original flat shape when warmed excessively.

Epon-Versamid bonded Mylar-metal joints have proved completely satisfactory in cryogenic targets when either brass or copper have been used. Steel is also a satisfactory material, but less ideal than brass. The utility of stainless steels is borderline because they tend to crack all but the thinnest Epon-Versamid fillets when the assembly is cooled to cryogenic temperatures. Aluminum is probably the least satisfactory of the common metals because of difficulties with the adhesion of Epon-Versamid or Armstrong A-4 in cryogenic service. Cadmium is quite satisfactory in Epon-Versamid bonded Mylar-metal joints; a short length of cadmium can be used as the intermediate metal in a graded seal between stainless steel, for example, and Mylar.

Mylar is extremely flexible (See List II for physical constants). It is therefore virtually impossible to achieve plane Mylar surfaces on a target used in a vacuum with atmospheric pressure inside the target itself. However, Mylar can be formed into stable curved shapes by pneumatically forcing sheet stock into a suitable concave die at about 200° to 220° C. Or cylinders can be formed by wrapping on a cylindrical die: single or multiple layers of sheet stock are wrapped around the die and a continuous bond is made between the stock layers. A 3/16-inch overlap should be allowed at lap joints. If a solid (rather than collapsible) cylindrical die more than 3 in. in diameter is used, the die should be lightly coated with paraffin to facilitate removal of the cylinder. Silicone grease is used as a parting agent in all other cases.

One advantage of the flexibility of Mylar becomes apparent in its use as a beam-entrance window in the vacuum tank of a hydrogen target. Under normal operation the window is flexed toward the vacuum under the external atmospheric pressure. If the hydrogen flask were to burst and suddenly over-pressurize the normally evacuated space, the Mylar would "snap through" and yield as a bubble under internal pressure. The elasticity of Mylar permits bubble yielding (in which stresses are proportional to the bubble radius) instead of plate yielding (in which stresses are proportion to the square of the radius). This is a principal reason for the strength of Mylar windows.

As an explosion-safety measure, the vacuum systems of all liquid hydrogen targets should be pretested by applying 125 psi internal pressure. This condition can be relaxed somewhat by providing adequate blow-out patches and high-conductivity vent lines. Frequently Mylar windows preform outward during such tests and then must be snapped through to sustain vacuum loading in normal operation. It should be noted that this preforming has little effect on the bursting pressure of the window, since Mylar easily sustains reversal of loading at ~~77° K~~ 300°K. In a test, a window 3 in. in diameter and 0.02 in. thick (two bonded 0.010-in. sheets) was first preformed with 125 psig and was then snapped through, after which it withstood 310 psig in the direction opposite to the original preforming pressure.

The ultimate burst pressure of flat windows, which are clamped in place without adhesive attachment to a rigid metal member, is increased slightly by providing a positive radial support for the Mylar, to prevent its slipping from between the clamping members and giving rise to wrinkles on the window surface. Screw holes through the Mylar, which allow the clamp-ring screws to give this radial support, usually suffice.

Another important property of Mylar is its high permeability to helium at 300° K and its relatively low helium permeability at 77° K. For this reason Mylar parts cannot be vacuum tested at room temperature with helium leak detectors. However, satisfactory helium-leak tests can be made on cryogenic Mylar targets after cooling (perhaps by partially filling the target system with liquid nitrogen) to 77° K. An easy and satisfactory leak test of a preliminary nature can be made at room temperature by pressurizing the Mylar system with helium gas and placing it under water for 20 to 30 minutes. The small residual helium permeability of cooled Mylar does not appear to affect the insulating vacuum under operating conditions; pressures of 1×10^{-6} mm of mercury are common in assemblies using Mylar targets.

Attempts have been made to use Mylar vacuum windows at the primary beam-exit port of electron linear accelerators, and in all cases the Mylar has very quickly been damaged (presumably by radiation) to the point of failure under vacuum loading. The authors know of no case of radiation damage to Mylar sustained even in prolonged exposure to secondary beams from high energy accelerators.

The use of Mylar in an adhesive-bound assembly at cryogenic temperatures was suggested to us by Dr. V. Z. Peterson of the California Institute of Technology. Many members of the Lawrence Radiation Laboratory staff, too numerous to acknowledge individually, have contributed significantly to the Laboratory's Mylar techniques. Their collective part in this work is gratefully acknowledged.

This work was done under the auspices of the U. S. Atomic Energy Commission.

List I. Manufacturers of products mentioned in text

Mylar - E. I. de Pont de Nemours, Inc., 9 Rockefeller Plaza, New York, N. Y.

Epon - Shell Chemical Co., Shell Building, San Francisco, Calif.

Versamid - General Mills, Inc., Mechanical Division, 1622 Central Ave., Minneapolis 13, Minn.

Armstrong A-4 - Armstrong Products Co., 29 Argonne Road, Warsaw, Ind.

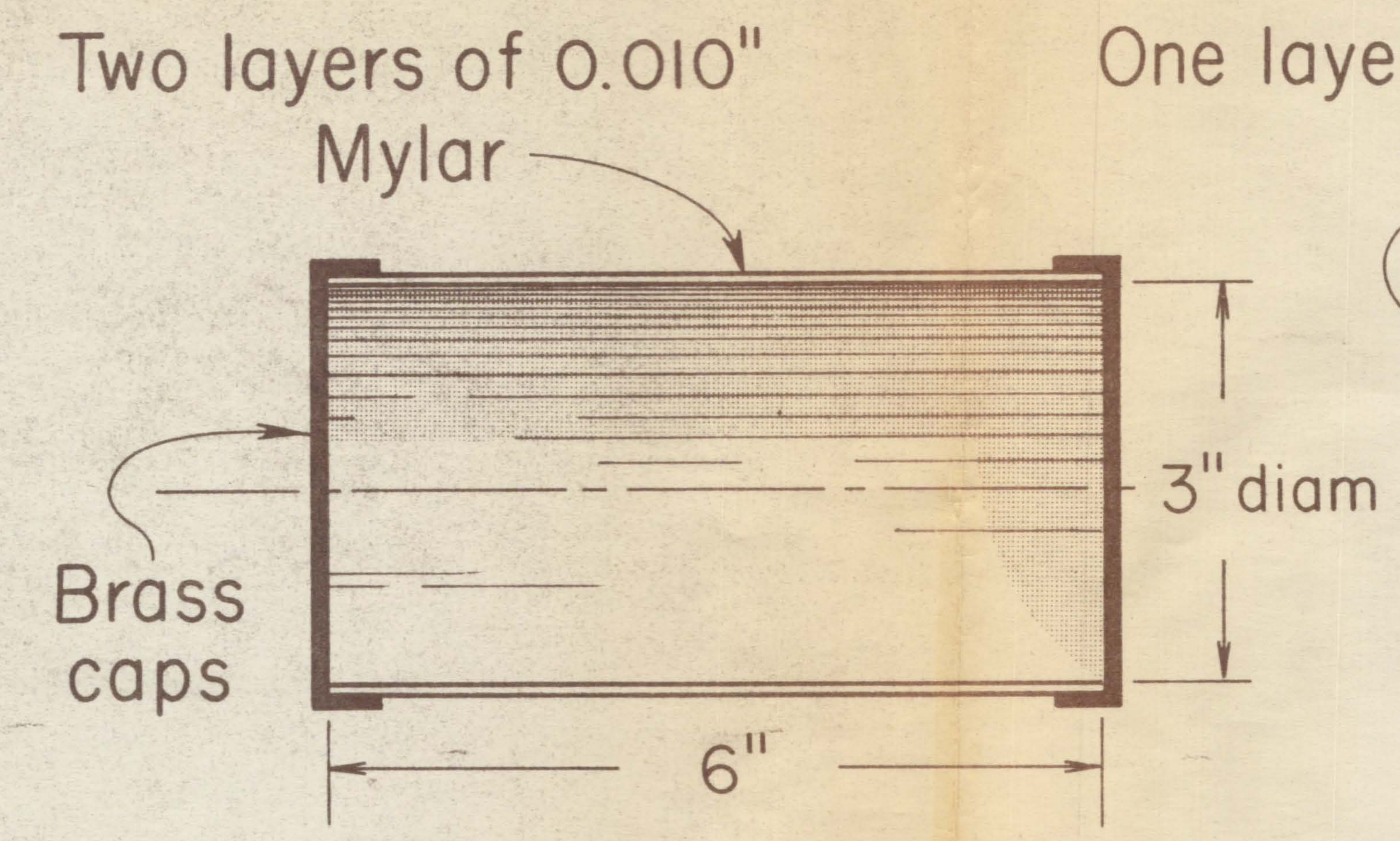
List II. Physical Properties of Mylar

1. Modulus of elasticity: 0.5×10^6 psi at 300° K
2. Ultimate strength: 16,000 psi at 77° K
3. Yield strength: 17,000 to 23,500 psi at 300° K (DuPont Data)
4. Softening Temperature: 200° to 220° C
5. Semitransparent to visible light
6. Permeable to helium at 300° K; not noticeably permeable to helium at 77° K.

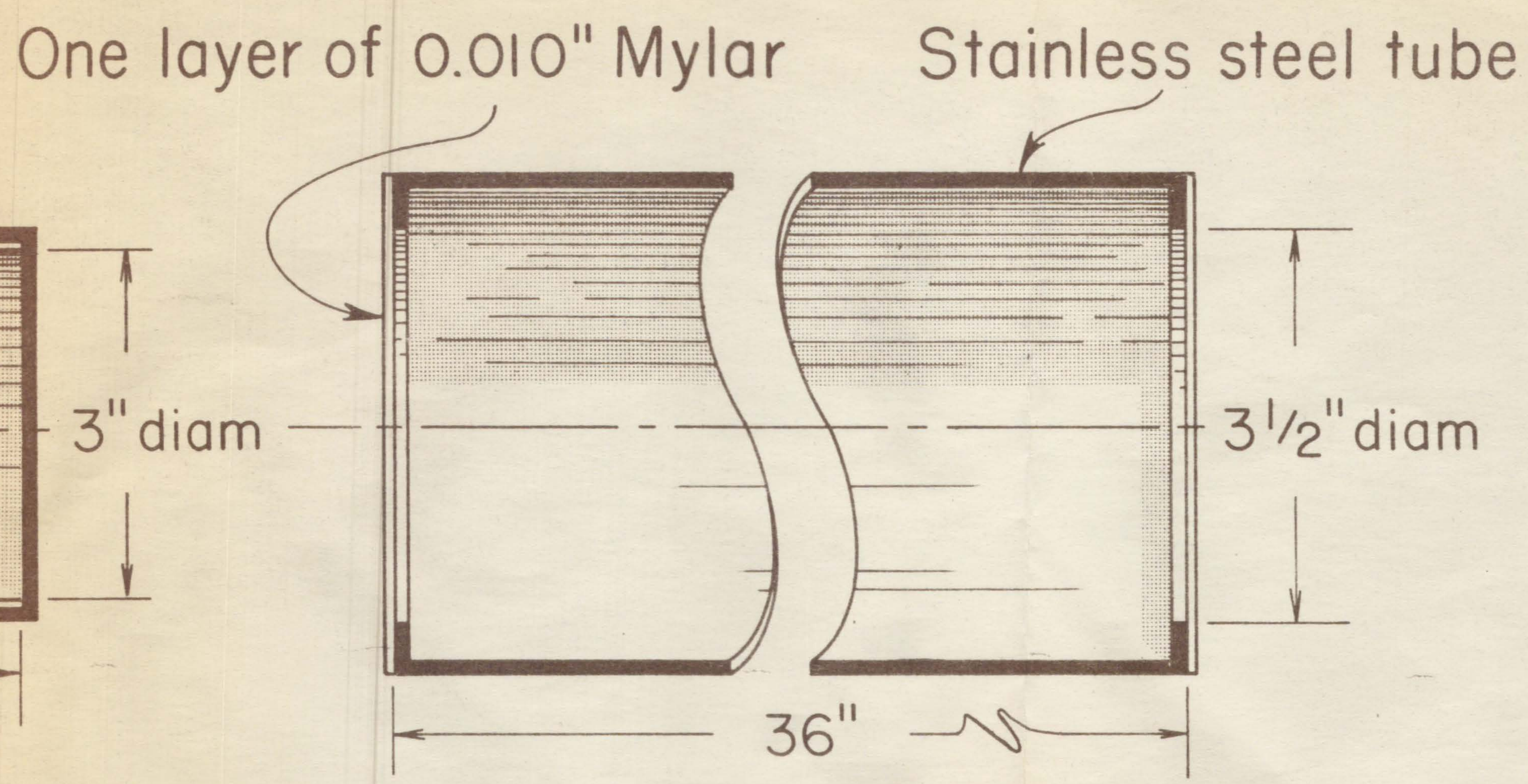
FIGURE LEGENDS

Fig. 1. Recent target configurations. The burst-pressure differentials at 77° K for the targets were: (a) 80 psi; (b) 95 psi; (c) >35 psi; (d) 80 psi. All targets shown used Epon-Versamid joints.

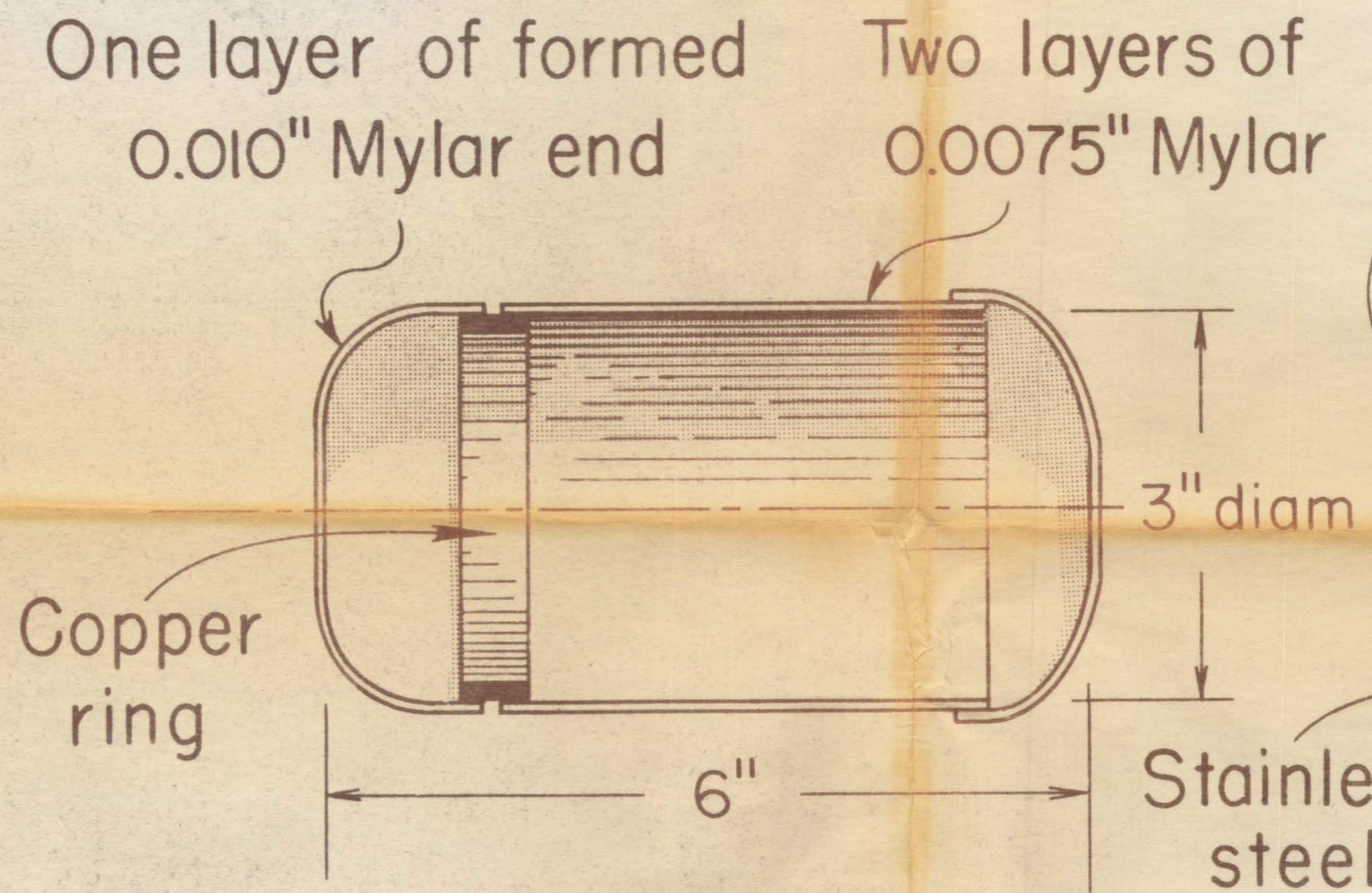
Fig. 2. Detail of a typical Mylar-to-Mylar joint.


Two layers of 0.010"
Mylar
Brass
caps
3" diam
6"

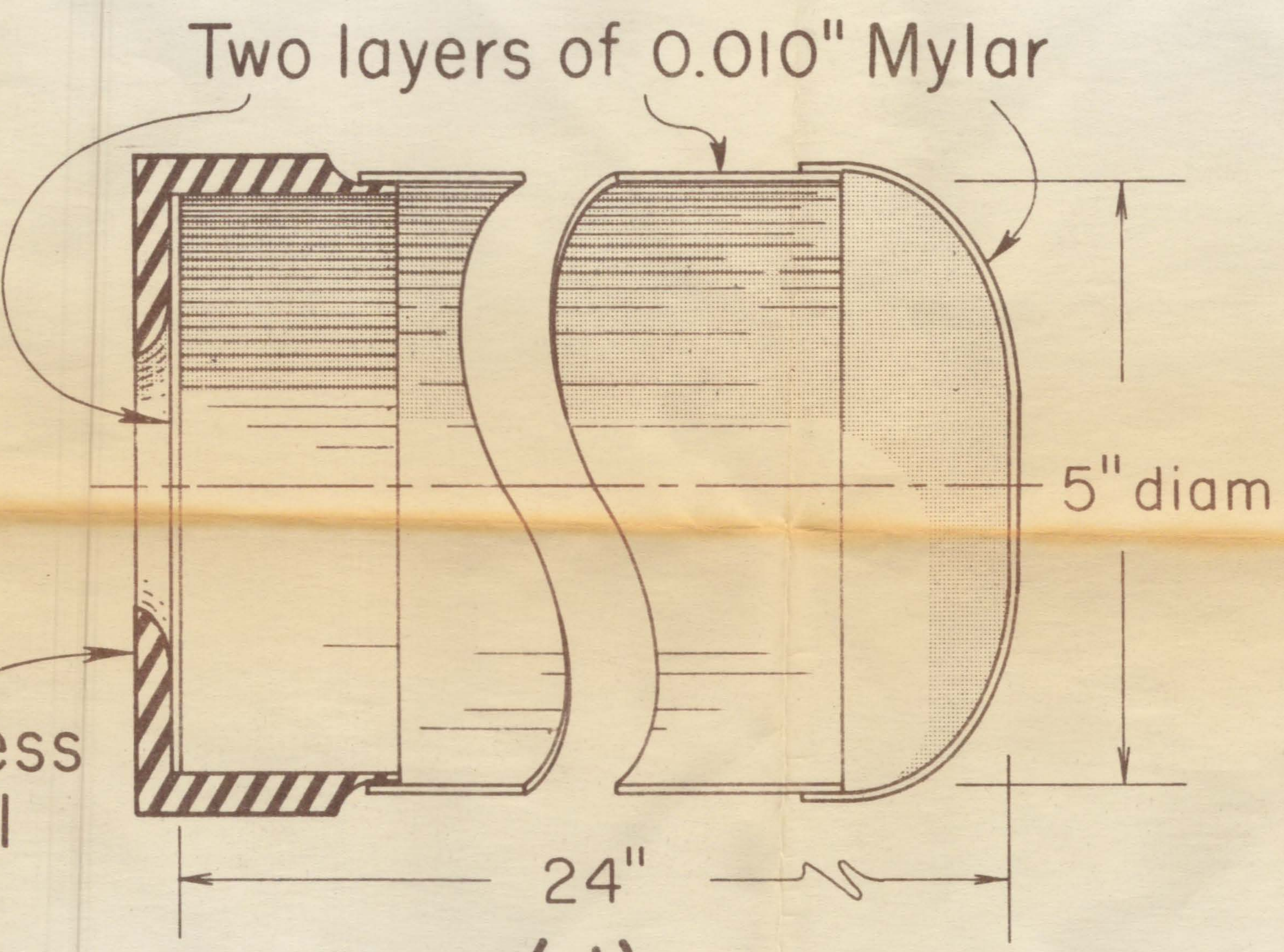
(a)


One layer of 0.010" Mylar
Stainless steel tube
3 1/2" diam
36"

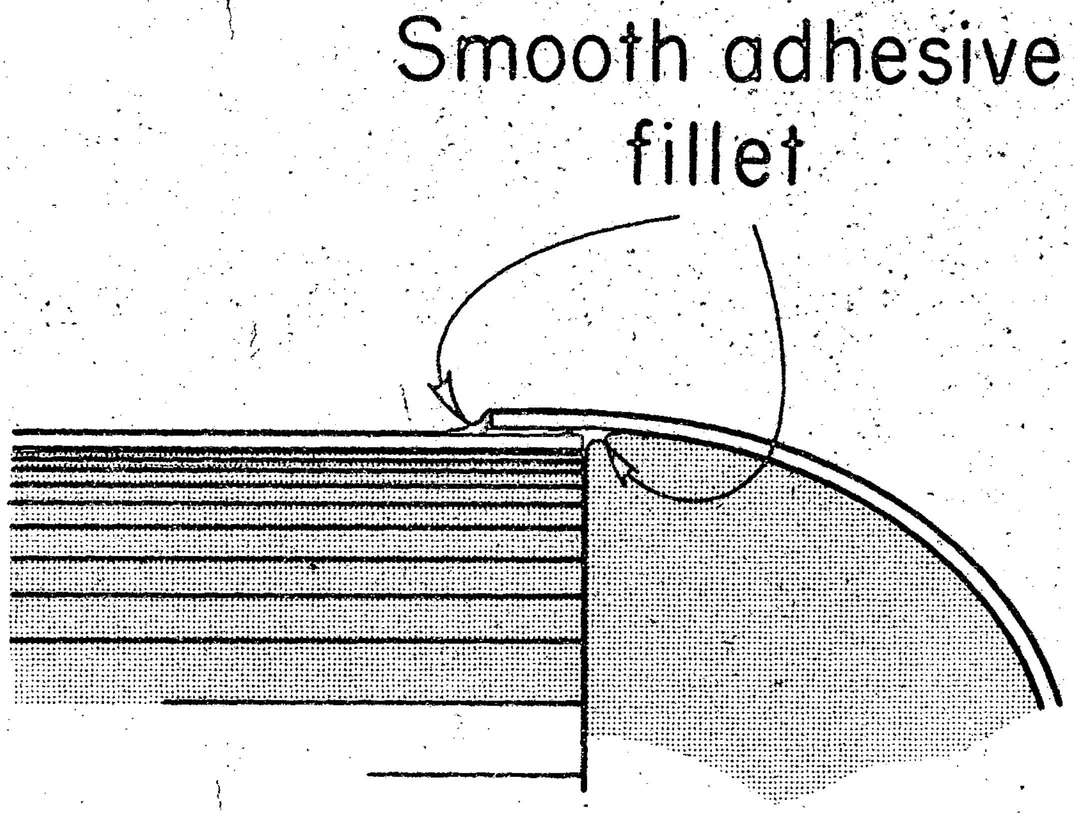
(c)


One layer of formed
0.010" Mylar end
Two layers of
0.0075" Mylar
3" diam
Copper
ring
6"

(b)


Two layers of 0.010" Mylar
5" diam
Stainless
steel
cap
24"

(d)


Smooth adhesive fillet