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Summary

The thermal insulation system of the Langley 0.3-Meter Transonic Cryogenic Tunnel is described. The insulation system is designed to operate from room temperature down to about 77.4 K, the temperature of liquid nitrogen at 1 atmosphere. A detailed description is given of the primary insulation system which consists of glass fiber mats, a three-part vapor barrier, and a dry nitrogen positive-pressure purge system. Also described are several secondary insulation systems required for the test section, actuators, and tunnel supports. An appendix briefly describes the original insulation system which is considered inferior to the one presently in place. The time required for opening and closing portions of the insulation system for modification or repair to the tunnel has been reduced, typically, from a few days for the original thermal insulating system to a few hours for the present system.

Introduction

It is generally recognized that one of the more important parameters in aerodynamic research and design is the nondimensional simulation parameter called the Reynolds number. Typically, wind tunnels are designed to operate at the Mach number and Reynolds number of interest in a particular flight or fluid flow regime. At transonic speeds, duplication of the appropriate flight Reynolds numbers has proven to be very difficult in wind tunnels, requiring large facilities, high pressures, and excessively large amounts of power. The high pressures also lead to very high model loads, which greatly compromise model design. A new wind-tunnel testing technique, described in references 1 through 4, makes use of a test medium at cryogenic temperatures (150 K or less) to alleviate the problems mentioned above as well as to create new aerodynamic research opportunities.

This combination of cryogenic and wind-tunnel technologies has resulted in new cryogenic wind tunnels for both aerodynamic and fluid mechanics research. Although the successful combination of these technologies has existed for only slightly more than a decade, most technically advanced countries either are operating, constructing, or planning cryogenic wind-tunnel facilities. The largest and oldest cryogenic wind tunnel currently involved in aerodynamic research is the Langley 0.3-Meter Transonic Cryogenic Tunnel (0.3-m TCT). (See refs. 2 and 3.)

The 0.3-m TCT is a state-of-the-art transonic wind tunnel capable of being operated over a wide range of pressures and Mach numbers at temperatures from slightly above ambient to temperatures near that of liquid nitrogen at 1 atmosphere, 77.4 K. When operating at cryogenic temperatures, the 0.3-m TCT not only exhibits unprecedented efficiency in obtaining high Reynolds numbers at transonic Mach numbers but also represents a new and unique application of cryogenic engineering.

Many of the techniques used in the successful construction and operation of the 0.3-m TCT have been reported in the technical literature, both to point out mistakes and to document successful new approaches. Reference 4 is a bibliography citing references which contain data from the 0.3-m TCT as well as other cryogenic wind tunnels.

One area of cryogenic technology that is particularly deserving of documentation is the thermal insulation system used for the 0.3-m TCT. (The Langley 0.3-Meter Transonic Cryogenic Tunnel was originally known as the Pilot Cryogenic Tunnel.) References 5 through 10 contain information relative to the thermal insulation of several types of cryogenic wind tunnels as well as addressing the subject of thermal insulation as it relates to the conversion of conventional ambient temperature tunnels to cryogenic operation. The thermal insulation presently in use for the 0.3-m TCT is a second-generation external insulating system and has been operated successfully since early in 1979.

It is the purpose of this report to document the history, technical details, and some of the reasoning associated with the design of the thermal insulation system for the 0.3-m TCT.

Description of the Langley 0.3-m TCT

Physical Layout

As noted in reference 4, there are a number of different types of cryogenic wind tunnels. The 0.3-m TCT is a closed-circuit single-return tunnel, meaning it is basically a continuous closed circuit of pipe that changes shape and cross-section area as required to fulfill different functions around the circuit. The 0.3-m TCT is arranged so that the circuit is vertical with the model testing section located at the top of the loop, as shown in figure 1. The pipe size is typically 1 meter in diameter and the distance around the tunnel circuit is approximately 22 meters. The maximum height of the tunnel is approximately 4 meters. Although several test-section shapes have been built and can be used with the 0.3-m TCT, the typical test-section size is roughly 0.3 meter. (By convention, the size of a test section is given as the diameter of a circle which would have the same cross-sectional area as the area of the actual test section, regardless of the actual dimensions or shape of the test section.)

Starting at the top of the tunnel circuit with the test section and going clockwise, the next tunnel component is the high-speed diffuser, followed by the first turn, the constant-diameter fan approach leg, the second turn, the fan contraction, the fan section, the fan diffuser, the third turn, the constant diameter return leg, the fourth turn, the settling chamber, the screen section, and finally, the contraction leading to the test-section entrance. Although for structural reasons most of the sections of the tunnel are round, the test section presently installed in the 0.3-m TCT is rectangular, necessitating pieced, welded transitional sections leading from the beginning of the contraction to the test section and from the test section to the diffuser.

Liquid Nitrogen Supply System

Liquid nitrogen is stored at atmospheric pressure in two 212 000-liter insulated tanks located next to the building which houses the wind tunnel. The tanks and the associated plumbing are shown in figure 2. The liquid nitrogen is pumped at rates up to about 500 liters per minute at pressures up to 9 atm absolute. The liquid nitrogen transfer line from the pump to the tunnel is an overhead copper line with an outside diameter of 6.35 cm. This line is insulated by a rigid urethane foam with an aluminum protective wrapper which has a moisture barrier on its inner surface.

The liquid nitrogen is injected into the tunnel through four nozzles that feed from the supply line by tee joints. The supply line itself is arranged to form a continuous loop from the storage tank to the tunnel back to the storage tank. In this way it is possible to avoid two-phase flow in the supply line that could exist under conditions of low flow rate into the tunnel if the supply line was simply terminated at the tunnel. The four injection nozzles are arranged at 90° intervals around the high-speed diffuser with the flow through each nozzle being regulated by an appropriate control valve. Two of the four injection nozzle locations can be seen in the photograph of figure 3.

Typical Operating Mode

For a closed-circuit wind tunnel where the gas in the tunnel recirculates, as in the 0.3-m TCT, a necessary requirement is the removal of the heat generated by the fan as it reenergizes the flow to compensate for the losses encountered around the circuit. Cooling, as well as control of test gas temperature, is accomplished in the 0.3-m TCT by injecting a controlled amount of liquid nitrogen into the tunnel circuit. The liquid nitrogen is injected perpendicular to the flow in the tunnel as a spray of droplets which evaporate to cool the flow as it continues around the circuit. Since the pressure in the tunnel will rise as the injected liquid nitrogen is evaporated and warmed, gaseous nitrogen must be continuously exhausted from the circuit to maintain a fixed value of tunnel pressure. This is accomplished by exhausting to the atmosphere the excess gaseous nitrogen through three exhaust pipes fitted with regulating valves. In order to allow operation at the lowest possible stagnation pressure, the exhaust pipes are located at the large end of the tunnel just upstream of the third set of turning vanes (fig. 1).

The velocity of the gas around the tunnel circuit is controlled by varying the speed of the drive fan. By proper selection of the pressure, temperature, and fan speed, the desired values of Mach number, Reynolds number, and dynamic pressure can be maintained in the test section. One of the main advantages of the cryogenic wind-tunnel concept is that temperature can be varied independently of both Mach number and pressure; thus, Reynolds number can be varied independently of Mach number and dynamic pressure.

The range of temperature variation for the 0.3-m TCT, as well as for many other cryogenic wind tunnels, is from about 340 K down to near the temperature of liquid nitrogen at 1 atmosphere, 77.4 K. This cryogenic temperature capability necessitates the tunnel insulation system which is the subject of this paper.

Insulation System Requirements for the 0.3-m TCT

Economic Requirements

Insulation efficiency. Many cryogenic systems require highly efficient thermal insulation for economical operation (ref. 11). However, in a transonic cryogenic wind tunnel such as the 0.3-m TCT, the major usage of liquid nitrogen is to remove from the flow an amount of heat equal to the amount of heat added by the fan. With the simple insulation system described in this paper, the liquid nitrogen required to offset the heat due to conduction, from the ambient room air into the tunnel circuit at a tunnel operating temperature of 100 K, is estimated to be only about 1.5 percent of the liquid nitrogen used to offset the fan heat. Thus, a perfect insulation system for the 0.3-m TCT could save no more than 1.5 percent of the liquid nitrogen and only then during the time when the tunnel is operating at the lowest temperatures.

Since the 0.3-m TCT is routinely operated over the entire temperature range from roughly 80 K to 340 K, the actual maximum savings in terms of liquid nitrogen consumption due to a more sophisticated insulation system would be considerably less than 1.5 percent. These requirements, however, are pertinent only to tunnels very similar in size and type to the 0.3-m TCT; for example, if a particular tunnel had a very limited thermal cycle life and it was desired to keep it cold even when not in use, then a more efficient insulation system than described herein might be very cost-effective. In a similar vein, very large tunnels which require large amounts of liquid nitrogen for cool down of the tunnel structure may also require more efficient insulation if it is desired to maintain a low temperature between work shifts.

System cost. Factors contributing to the cost of a thermal insulation system are materials and labor required to install the system; system operation and control; and the cost of opening and closing the system as required for maintenance, inspection, modification, and repair to the structure of the tunnel. Based on experience with the original insulation system for the 0.3-m TCT, of the factors listed above, the installation cost, which is a fixed cost, may be far outweighed by the rest of the costs which recur throughout the life of the tunnel.

Materials for the thermal insulation system should be readily available conventional materials that are compatible with liquid nitrogen temperatures. In addition, by their very nature, conventional materials tend to require less labor to install and do not require highly skilled technical specialists for their installation. The cost factor that is possibly unique to cryogenic wind-tunnel insulation systems arises from the necessity for relatively frequent access to the tunnel structure; thus, frequent opening and closing of the insulation system is required. Once again, the selection of conventional, and therefore easily worked materials, minimizes this cost.

One potentially costly feature unique to purged insulation systems is the operation and control of the purging system. This cost must, of course, include the cost of the purge gas itself. However, purging costs may be minimized for the 0.3-m TCT due to the availability of a practically unlimited supply of dry nitrogen as storage tank boil-off gas, which is normally lost to the atmosphere in a cryogenic storage facility. Purging costs may be further reduced at the 0.3-m TCT by the use of simple, readily available automatic components for the purge control system.

Productivity. Since the construction of a wind tunnel typically requires a large capital investment, it is desirable to maintain productivity at a high rate in order to maximize the return on the investment. An efficient thermal insulation system can aid productivity by making it possible to stop the tunnel at the end of the work day and restart the tunnel at the beginning of the next work day with a minimum cool-down and stabilization time. In keeping with the general desire to maximize productivity, an additional requirement for a thermal insulation system is that it can be returned to operational status after being opened with minimum lapsed time.

Safety Requirements

Reference 12 contains an extensive discussion of safety requirements for working with cryogenic fluids or devices. Among the basic safety requirements that a tunnel insulation system must satisfy is the need to prevent contact between personnel and extremely cold surfaces. For cryogenic systems operating below the temperature required to condense oxygen from the atmosphere, there is an additional requirement for isolating the cryogenic surfaces from the atmosphere in order to avoid creating an explosion hazard due to the formation of liquid air. A lesser hazard is also avoided if the thermal insulation is sufficient to prevent the condensation of water vapor from the atmosphere which can, under some circumstances, lead to slick, unsafe working conditions.

For the 0.3-m TCT, which is constructed of aluminum, it is also a requirement that the insulation not trap water or oxygen-rich condensed air in such a manner as to corrode the surface of the pressure shell. Additionally, the material used for insulation must not chemically attack the surface or degrade the integrity of the pressure shell in any manner. The 0.3-m TCT could operate for many years without the need to remove the insulation from some sections. Thus, damage to the pressure shell due to even slow rates of corrosion might go undetected for long periods of time; this would lead, in the worst case, to rupture of the pressure shell. Additionally, when possible, the insulation materials should be noncombustible.

Operational Requirements

Test-section access. The 0.3-m TCT thermal insulation system must allow free and repeated access to the test-section area for model and instrumentation changes and maintenance. In a typical model change, the test section is opened by removing an aluminum plenum lid which serves as a portion of the pressure shell. The relatively large size of the components and the frequency of test-section entrance (approximately three times each week) lead to a requirement of rugged durability for the insulation in this region.

Modification. As mentioned earlier, the 0.3-m TCT is the first of its kind and continual modification to the tunnel is the rule. For this reason, the thermal insulation system should be easily removed and replaced or modified with the minimum of downtime or special equipment. Clearly, a vacuum Dewar-type thermal insulation system is not a viable candidate for the insulation of this facility.

Auxiliary equipment. In addition to test-section access and facility modifications, a cryogenic-wind-tunnel thermal insulation system must also accommodate the numerous pressure shell penetrations required for a wide variety of auxiliary equipment. For the 0.3-m TCT, pressure shell penetrations are required for electrical power leads, instrumentation leads, liquid nitrogen supply lines, gaseous nitrogen exhaust pipes, drive systems for angle-of-attack struts, wake momentum survey rakes, windows for visual access, tunnel supports, the fan drive shaft, and any future innovations required in the performance of the facility research function.

Description of the 0.3-m TCT Thermal Insulation System

The thermal insulation system presently used on the 0.3-m TCT was selected based on the aforementioned requirements as well as experience gained with the earlier system described in the appendix. The present insulation system is actually a combination of insulation subsystems as required by the particular section of the tunnel being insulated. The main insulation system for the tunnel is a simple glass fiber wrap covered by a vapor barrier and slightly inflated by a continuous dry nitrogen purge. The following sections describe each part of the thermal insulation system of the 0.3-m TCT. Considerable detail is given in the hope that it may be of practical use to those needing to insulate a cryogenic device similar to the 0.3-m TCT.

Insulation of Cylindrical Sections

Insulation material. The cylindrical sections of the tunnel were wrapped with four successive mats of spun glass fiber insulation (Pittsburgh Corning Temp-Mat). In the uncompressed state, each mat had a thickness of approximately 2.5 cm and a density of approximately 176 kg/m^3. The mats contained no material other than the glass fiber. Each mat is held together by fiber interlocking which was accomplished during manufacture by repeatedly punching blunt needles through the thickness of the mat. This type of material was selected rather than the more conventional bonded glass fiber mats in order to avoid the introduction of any combustible material into areas cold enough to condense oxygen from the atmosphere.

The insulation was supplied in rolls of 122 cm width, which is less than the length of a typical tunnel section; thus, circumferential butt joints were necessary as well as the butt joints parallel to the axis of the cylinders. Since there were four layers of insulation, it was possible to stagger the joints to avoid having more than one joint at any given location. Each layer of insulation was held in place by copper wire or thin aluminum bands.

A photograph of a typical installation is shown in figure 4. In addition to the four layers of glass fiber mat, an outer layer of woven glass fiber cloth was applied and secured by a tightly wrapped spiral of a 15-cm-wide strip of woven glass fiber cloth. The combined compressive action of the copper wire or aluminum bands and the cloth strips resulted in a total insulation mat thickness of approximately 7.6 cm and, with the added woven cloth, a total insulation system thickness of approximately 8 cm.

Vapor barrier. The woven glass cloth layer and spiral wrapped strip described in the previous section formed a stable foundation for the vapor barrier system. The vapor barrier covering the insulation, as sketched in figure 5, consists of three separate layers applied as a liquid by brush to the spiral wound glass fiber cloth. The first layer (Eagle Picher Chem-Elast 2819R coating) is a two component urethane elastomer which serves as a flexible, tough, impact resistant coating which bonds well to the glass fiber cloth. This layer is reasonably impermeable to water vapor and serves as a base for subsequent layers of the vapor barrier system.

The second layer (Eagle Picher Chem-Elast 5500 coating), which serves as the main impermeable membrane of this vapor barrier system, is a two component butyl rubber which has very low water vapor transmission rates but is soft and has low toughness. The third, and outermost layer (Eagle Picher Chem-Elast 5011 coating) is chloro-sulfonated polyethylene which serves mainly as a protective coating for the Butyl rubber layer.

Purge system. The entire glass fiber thermal insulation system is maintained at a positive pressure of about 1.007 atm (0.1 psig) by a purge system to preclude entry of outside air or moisture. The purge gas is dry nitrogen which, as previously mentioned, is readily available from the normal boil off of the liquid nitrogen storage tanks. The dry nitrogen gas is supplied to a pressure regulator at the purge system supply manifold (fig. 6) through an uninsulated copper pipe approximately 30 m long and 5 cm in diameter. Because of the relatively low mass-flow rate of the nitrogen purge gas, the heat transfer from the atmosphere to the nitrogen gas through the uninsulated copper pipe is sufficient to raise the gas temperature to ambient by the time it reaches the supply manifold at the tunnel. From the supply manifold, the dry nitrogen purge gas is delivered to each section of the tunnel insulation through a small (9.5 mm outside diameter) flexible plastic tubing.

The purge gas flows through a perforated copper tube (9.5 mm outside diameter), shown in figure 7, buried in the insulation and running the full length of each of the tunnel sections. In this way, the purge gas is introduced relatively evenly into the glass fiber insulation. The purge gas is collected in a similar perforated tube located 180° around the tunnel section. The flow area provided by the perforations is larger in the outlet tube than the inlet tube in order to guard against any malfunction of the purge gas supply system applying an overpressure to the vapor barrier system. In a manner similar to the inlet flow, the outlet flow is collected from each of the tunnel sections through flexible tubes which are connected to an exhaust manifold vented to the atmosphere.

When operating at the lowest temperatures, portions of the tunnel pressure shell can approach within a degree or so of the temperature of boiling liquid nitrogen at 1 atmosphere, 77.35 K. For this reason, the purge gas pressure must be selected with some care. For example, should a purge gas pressure of 1.07 atm (1 psig) be used, the purge gas will start to condense when the pressure shell wall temperature reaches 78.00 K. By reducing the purge gas pressure to the design pressure of 1.007 atm (0.1 psig), the wall temperature must be below 77.47 K for the purge gas to condense. This is only slightly higher than the boiling temperature of liquid nitrogen at 1 atmosphere, 77.35 K; thus, the likelihood of collecting liquid nitrogen due to condensation of the purge gas within the insulation layer is greatly reduced.

Insulation of Flanges

A typical flange insulation scheme is shown in figure 8. The glass fiber insulating mats have been terminated in a staggered fashion to minimize heat leakage at the joints and the remaining distance to the flange has been fitted with smaller pieces of insulation for the first three layers. Although termination in the same fashion as the first three layers, the fourth layer of the insulation is carried across the flange. An additional fifth layer of insulation is bridged across the flange and is long enough to overlap the vapor barriers of each of the tunnel sections. Finally, the three layer vapor barrier system is applied over the fifth layer of insulation and carefully joined to the vapor barrier on either side of the flange. Thus, the volume of the insulation in the region of the flange is unified with the purge system on both sides of the flange.

Flanges or other breaks in the tunnel pressure shell, which are likely to be opened for jobs such as maintenance, alternate equipment placement, and instrumentation installation, are insulated as shown in figure 9. In these locations, the vapor barrier has been brought down through the insulation on one side of the flange and adhesively bonded to the tunnel pressure shell. Purge gas is supplied by pipes from the purge gas manifold to both sides of this type of joint. This deviation from the flange insulation scheme described previously allows the insulation system to be opened without disturbing the insulation on at least one side of the joint.

Insulation of Special Areas

There are many small areas of the 0.3-m TCT, which are not insulated as previously described, but rather given special insulation treatment as requirements dictate. Three examples of such areas are provided in the following sections.

Test section. Typically, an airfoil model mounted in a special turntable module is installed in the two-dimensional test section by using an overhead crane after removing the plenum cover and the ceiling of the test section. Figure 10 is a photograph of a model module as it is being inserted into the test section. To accommodate this type of activity, the thermal insulation system used in the region of the test section must be more rugged than that employed for the bulk of the tunnel.

Ruggedness is achieved by bonding 5.8-cm-thick rigid urethane foam insulation directly to the aluminum pressure shell and sealing it with a mastic coating adhesive, Crest 391 A & B. The various components of the test section are then wrapped with four layers of woven glass fiber cloth which is subsequently sealed with Crest adhesive. Because of the relatively thin thermal insulation, the test-section area eventually becomes covered with frost after long periods of cryogenic operation. Thus, thermal efficiency and low installation cost have been traded for durability in the region of the test section.

Tunnel supports. A typical tunnel support is shown in figure 11. The combination of temperature extremes and the high thermal expansion coefficient of aluminum leads to substantial horizontal movement of the tunnel pressure shell on its supports, typically 4 cm or so in going from temperatures of ambient to 100 K. The aluminum support surfaces of the 0.3-m TCT are welded directly to the pressure shell. These support surfaces rest on 2.5-cm-thick Du Pont Teflon pads, which, in turn, rest on a buffer support of stainless steel. The stainless-steel buffer is bolted directly to A-frame supports made from ordinary structural steel.

The aluminum part of the tunnel support is insulated by a thin elastomeric covering except where it rests on the Teflon pad, and even this part becomes reasonably well insulated when frost forms. The Teflon pad provides high thermal resistance between the aluminum tunnel support and the stainless steel. In addition, the pad provides a relatively slippery surface to allow easy sliding of the aluminum support surface with respect to the fixed support structure.

There is sufficient heat transfer from the tunnel through the pad to form frost on the upper portion of the stainless-steel support after extended operation at low temperatures. If structural steel were used here instead of stainless steel, the frost and subsequent moisture on warming would possibly result in excessive corrosion, and, more importantly, the low temperature could place the ordinary structural steel in a dangerously low fracture toughness condition. In addition to resisting corrosion and providing fracture toughness, the uninsulated stainless-steel section gains heat rapidly from the surroundings, thus avoiding placing the adjoining structural steel support at an unfavorably low temperature. Some additional thermal resistance is also introduced by the contact resistance at each joint between the various components of the support system. Thus, the tunnel supports represent a carefully planned part of the overall thermal insulation system.

Momentum rake and angle-of-attack actuators. The actuators which drive the momentum (wake survey) rake and the angle-of-attack mechanism are located outside the tunnel pressure shell in an ambient temperature and pressure environment. Consequently, the actuator drive rods must pass through the tunnel pressure shell. The rake is shown in figure 12 and the externally mounted actuator in a heated sheet metal enclosure is shown to the right in figure 13. The actuator which drives the angle-of-attack mechanism is in the heated sheet metal enclosure to the left in figure 13.

Because of the relatively high heat transfer through the actuator drive rods, the heat available inside the heated sheet metal enclosure was not sufficient to prevent moisture in the air from forming ice on the rake actuator drive rod. The ice would cause the rod to bind in the drive-rod pressure seal rendering it inoperable. Rather than attempt to solve the problem by increasing the size of the heater, a purge-gas line was attached to the sheet metal enclosure to keep it filled with dry nitrogen. This eliminated all moisture from the enclosure which, in turn, eliminated the problem with icing. Although not shown in figure 13, a small duct is provided to allow recirculation of the dry nitrogen through the heater inlet.

Discussion

Operation of the insulation system described in this paper over the past 5.5 years has proven it to be a practical system. It has been possible to pursue vigorous operational schedules as well as frequent tunnel modification, inspection, and repair with no significant delays or problems traceable to the insulation system.

Since only two types of thermal insulation systems have been used with the 0.3-m TCT, it is difficult to judge how near the present system might be to an optimum insulation system. Compared with the previous insulation system, the present system was almost an order of magnitude lower in initial installation costs. However, the major advantage of the present system is related to improvements in productivity. The time required to reactivate the insulation system after it has been opened for some tunnel function typically has been reduced from a few days for the previous system to a few hours for the present system.

If faced with the task of replacing the insulation system for the 0.3-m TCT at the present time, the design would remain essentially unchanged. Although insulation system requirements are highly dependent on the type, size, and operational cycles for a particular cryogenic wind tunnel, the information provided herein may serve as a helpful guide to the tunnel designer facing for the first time the problem of providing a cryogenic tunnel with a suitable thermal insulation system.

Concluding Remarks

The thermal insulation system of the Langley 0.3-Meter Transonic Cryogenic Tunnel (0.3-m TCT) described in this report has been operational for about 5.5 years and has proven to be a safe, economical, and practical system. Since the 0.3-m TCT is the first of its type, this description should serve as a primer on thermal insulation systems for designers of similar cryogenic-wind-tunnel systems yet to come.

The present system represents a considerable savings in cost with respect to the original insulation system used on the 0.3-m TCT. Typically, the associated delay in system closing has been reduced from a few days for the original thermal insulating system to a few hours for the present system.

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Appendix

Description of the Original Insulation System for the 0.3-m TCT

Since the 0.3-m TCT was the first wind tunnel designed and built specifically for cryogenic operation, there was a tendency toward a very conservative design. This conservatism led to a rather complex and expensive thermal insulating system. Basically, the insulation system consisted of two separate layers of polyurethane foam, separated by two layers of glass fiber cloth. The combined thickness of the foam and the glass cloth was approximately 13 cm. The outer layer of foam was covered with a hard shell vapor barrier of glass fiber reinforced polyester.

A photograph of a sample of the original insulation system is shown in figure 14. Operational experience with the original insulation system soon demonstrated that in order to temporarily remove and reinstall even a small portion of the insulation for inspection, tunnel modification, or repair, the services of skilled technicians had to be procured at considerable expense and tunnel downtime.

Upon removal of the original insulation system during a major modification to the tunnel, large areas of corrosion were discovered on the exterior walls of the aluminum pressure shell. This evidence of moisture condensation was taken as proof of leaks in the vapor barrier and demonstrated the possibility of condensing oxygen on the external tunnel walls at the lower tunnel operating temperatures. Since polyurethane foam is not an oxygen compatible material, the evidence of moisture condensation was regarded as a serious safety hazard which should be corrected.

As a result of this operational experience, the new thermal insulation system discussed in the main body of this paper was designed, tested on an unused section of the original 0.3-m TCT, and shown to perform well under conditions typical of those that would be encountered during the operation of the 0.3-m TCT.

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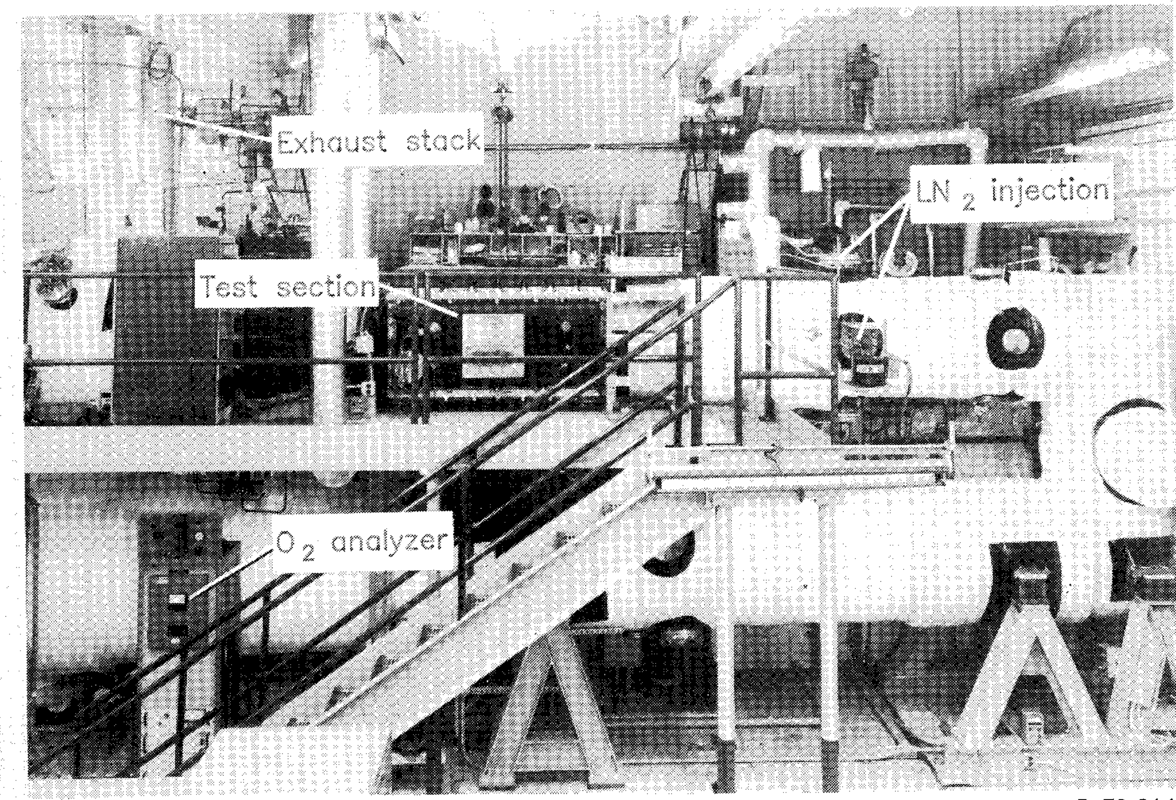

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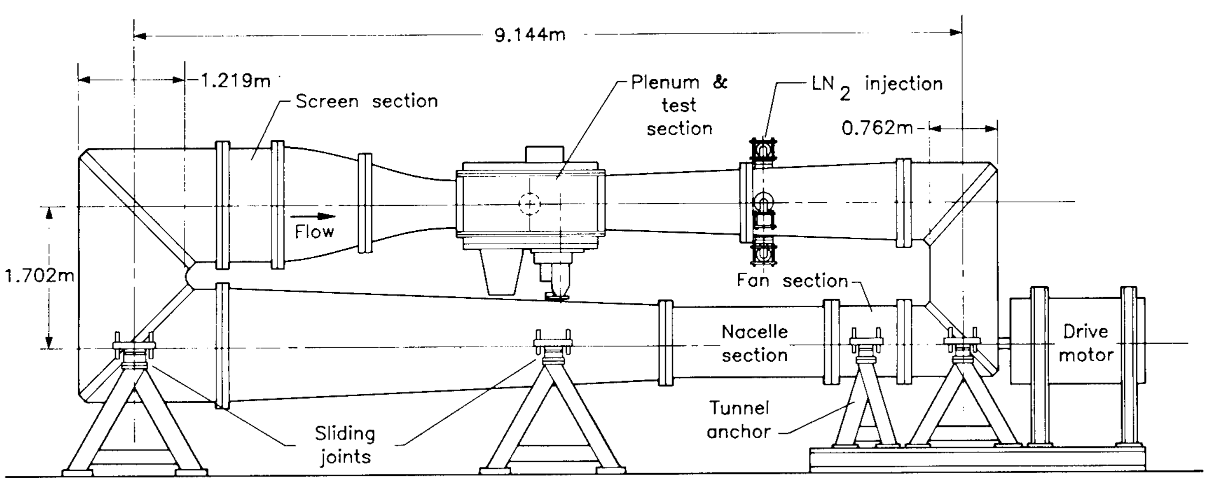

Figure 1.— Elevation view of 0.3-m TCT with two-dimensional test section installed.

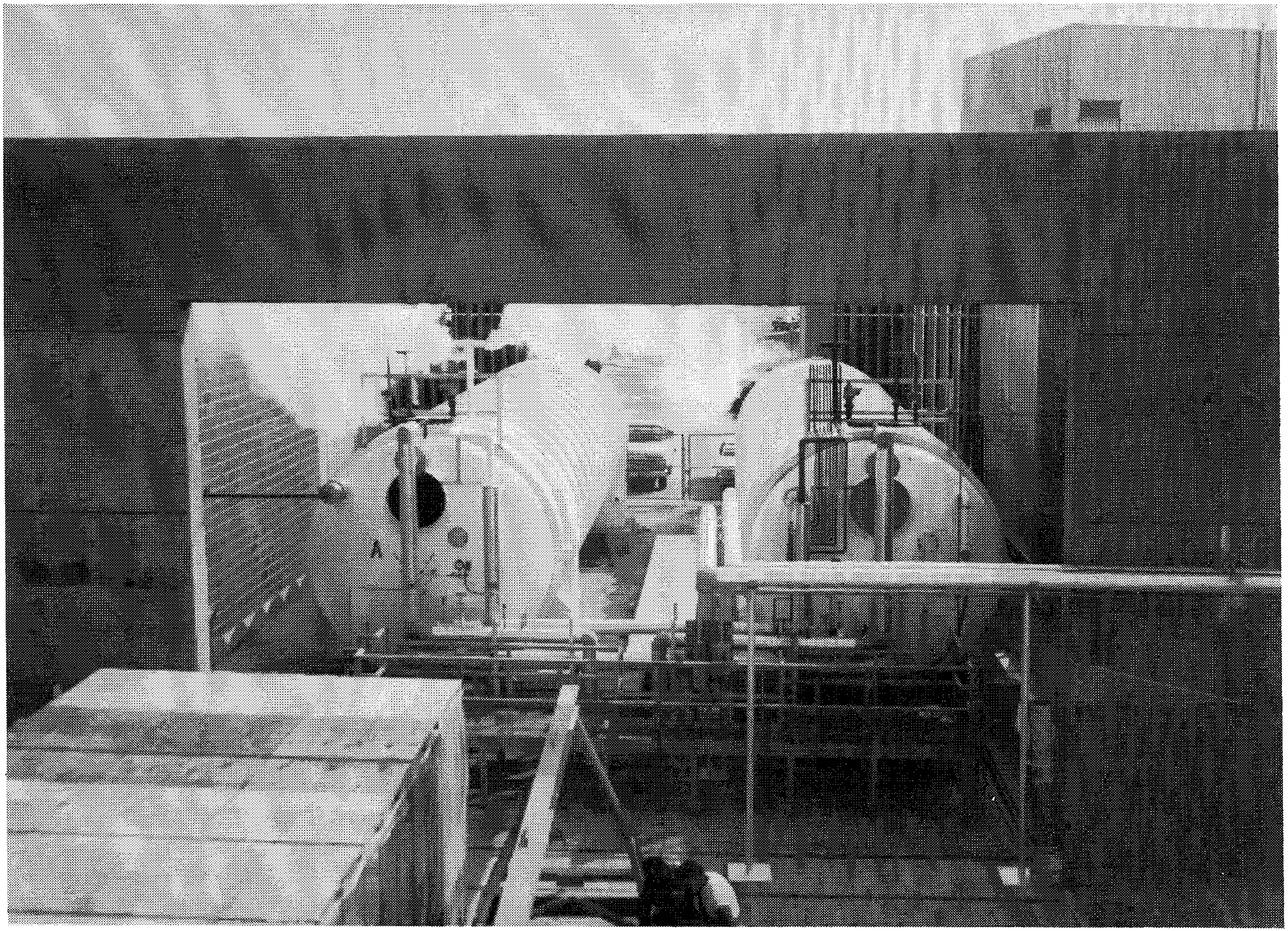

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Figure 2.— Liquid nitrogen storage tanks for the 0.3-m TCT.

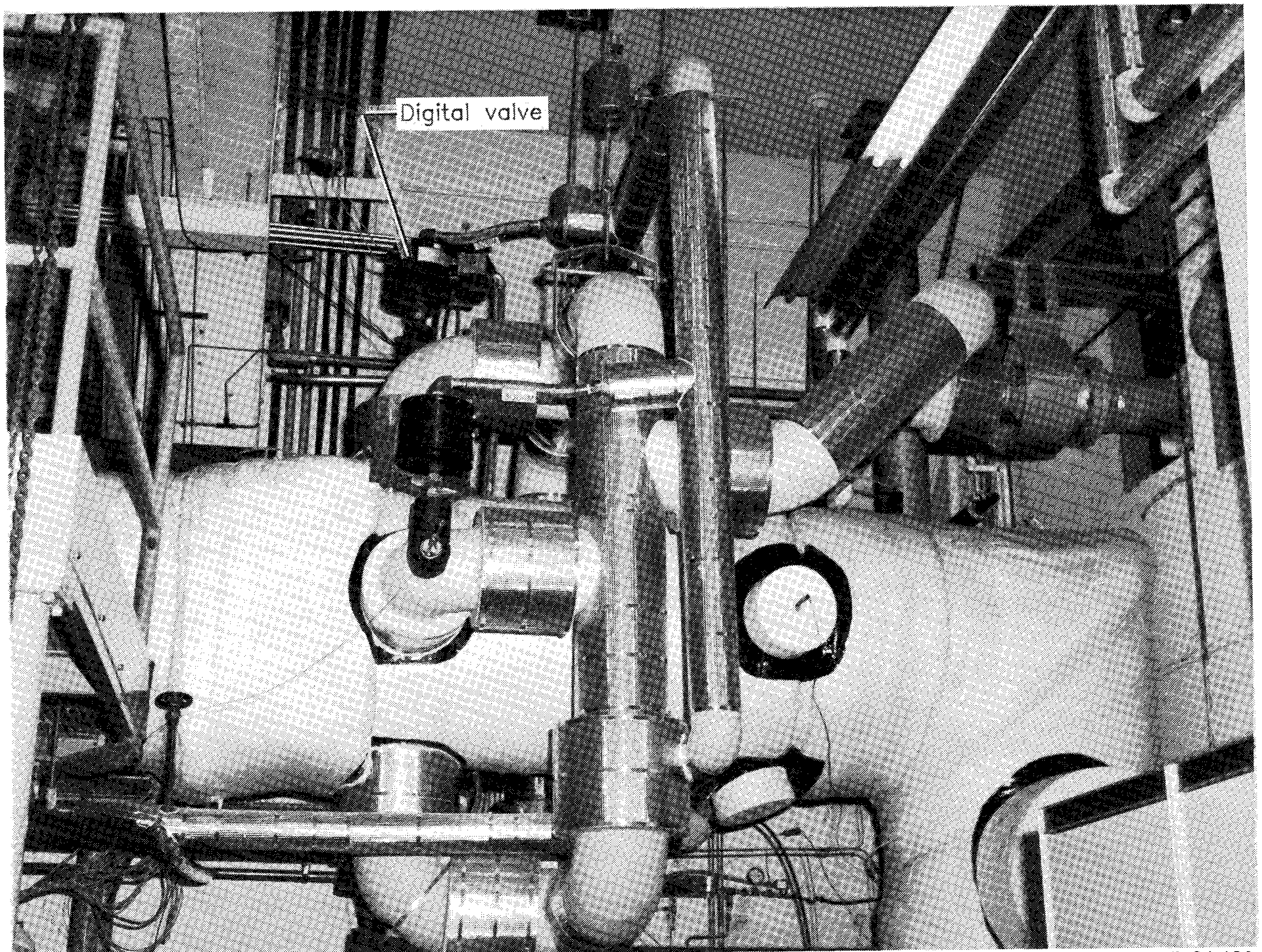

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Figure 3.— Plumbing for liquid nitrogen injection showing two of the four control valves.

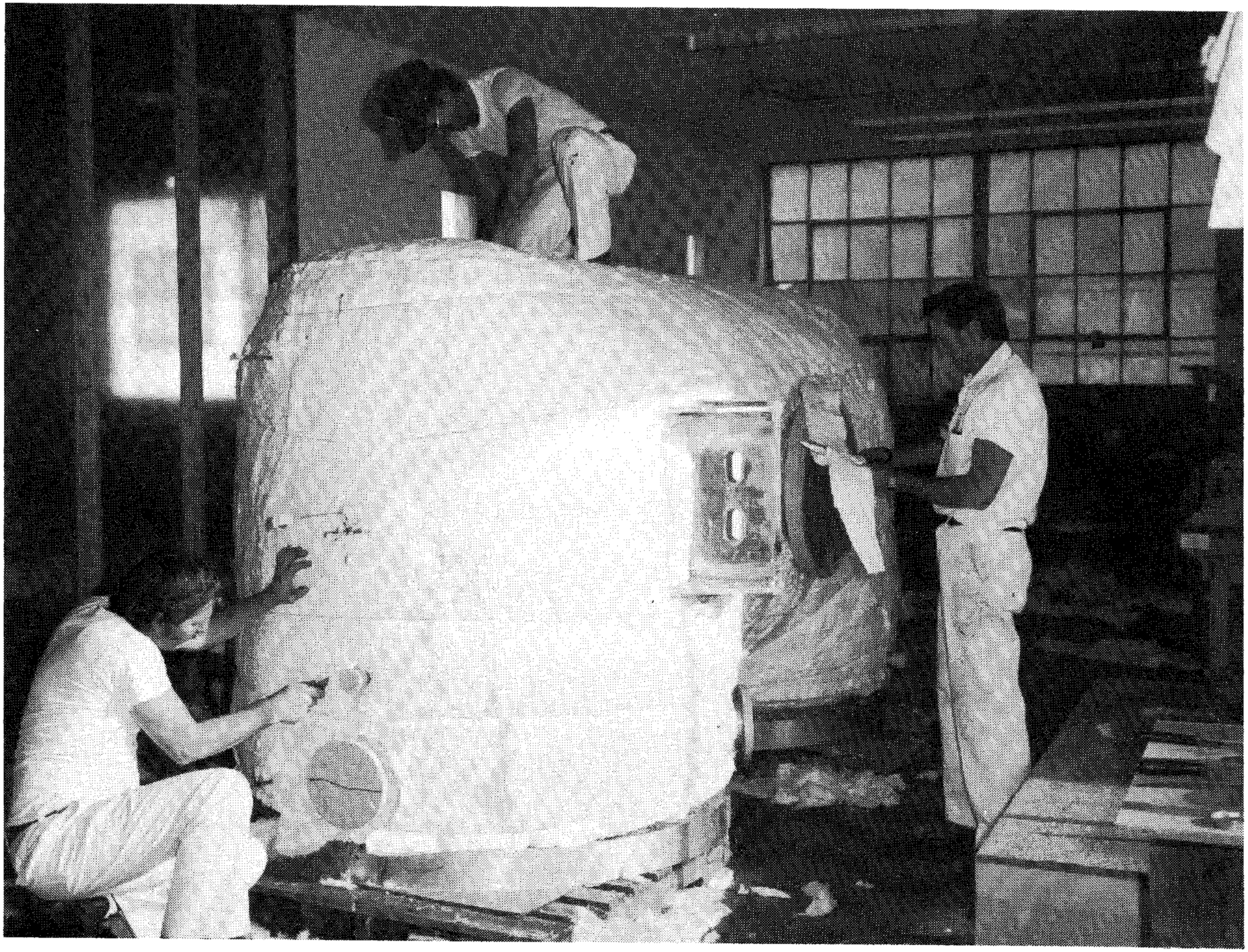

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Figure 4.— Installation of glass fiber insulation on the third and fourth turns of the 0.3-m TCT.

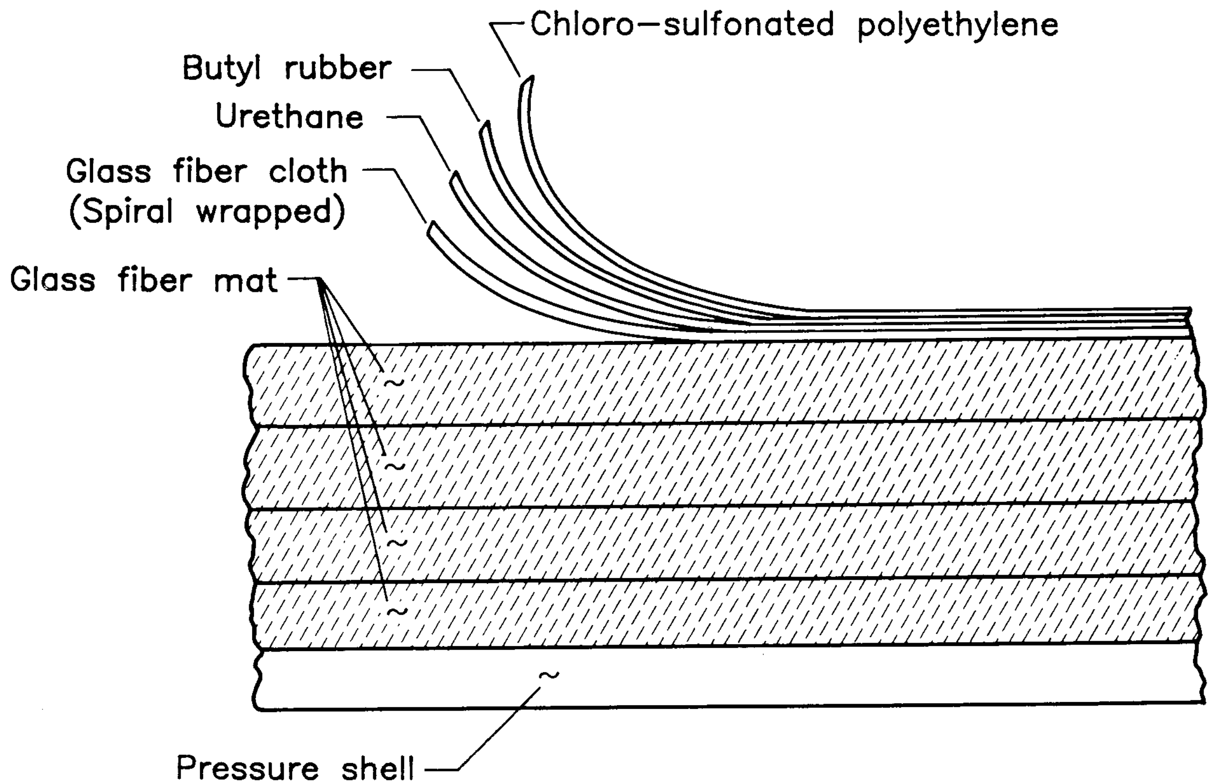

Figure 5.— Details of the vapor barrier system.

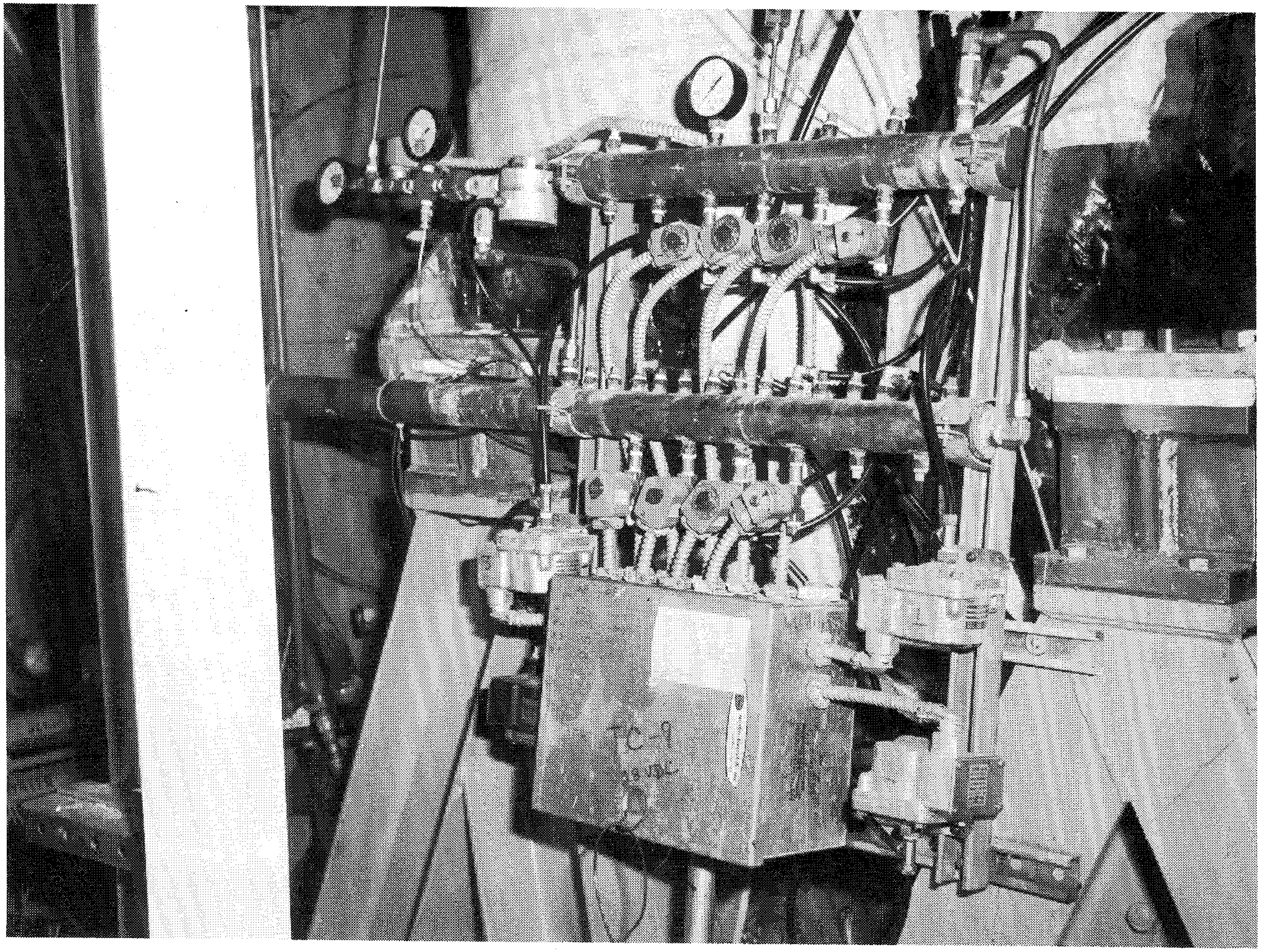

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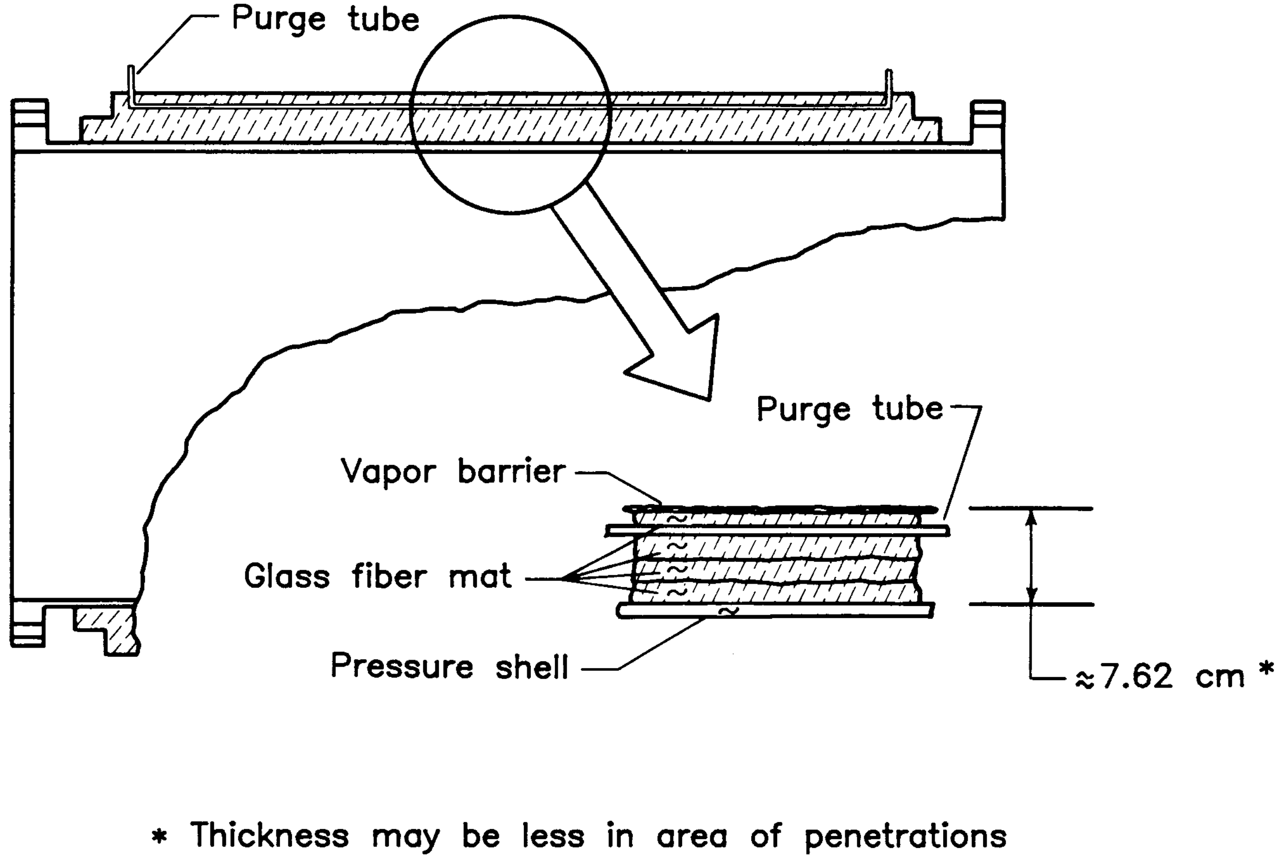
Figure 6.— Purge system supply manifold.

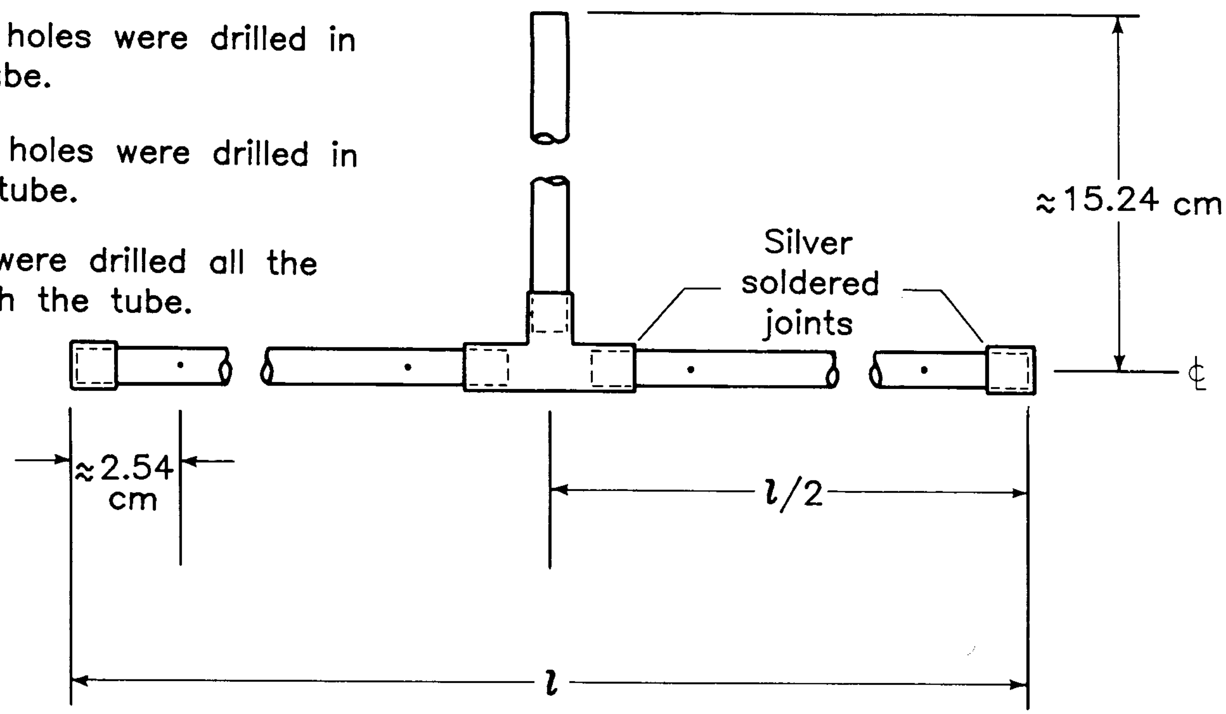


(a) Typical location in insulation.

Figure 7.— Purge tube.

Notes:

* At least one set of holes were drilled every 15.24 cm of tube length.
* 1.524 mm holes were drilled in the inlet tube.
* 3.175 mm holes were drilled in the outlet tube.
* The holes were drilled all the way through the tube.



(b) Details of tube.

Figure 7.— Concluded.

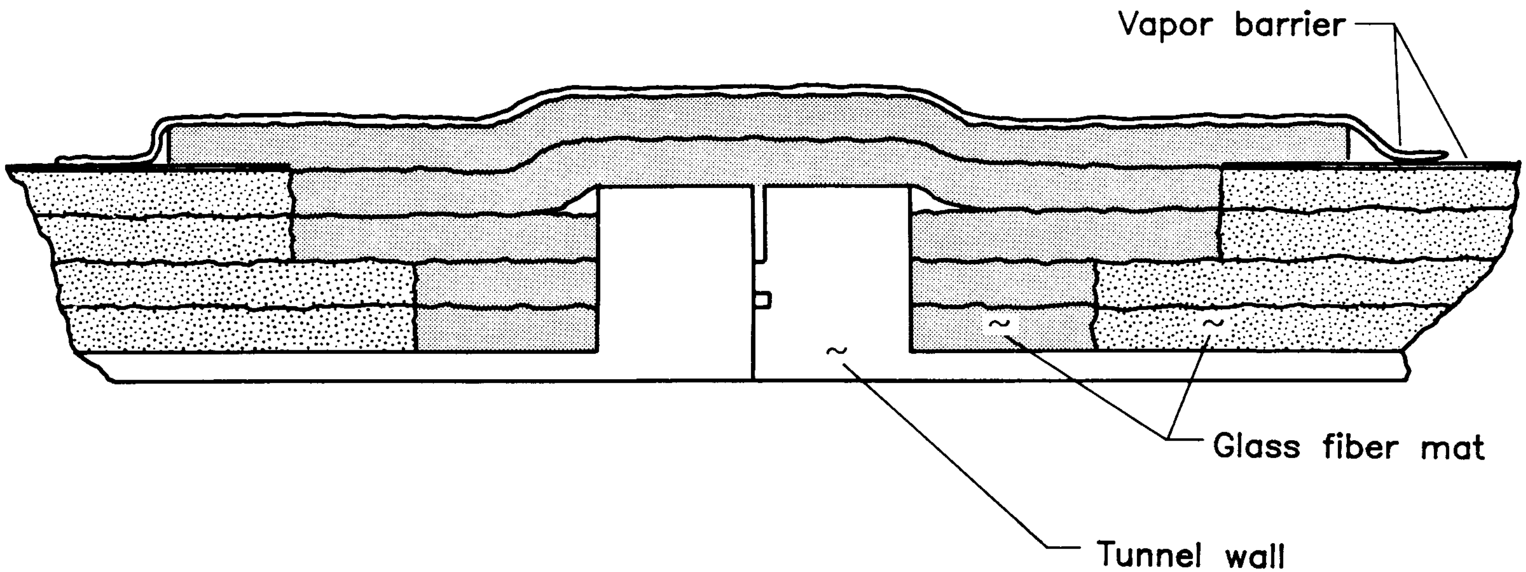
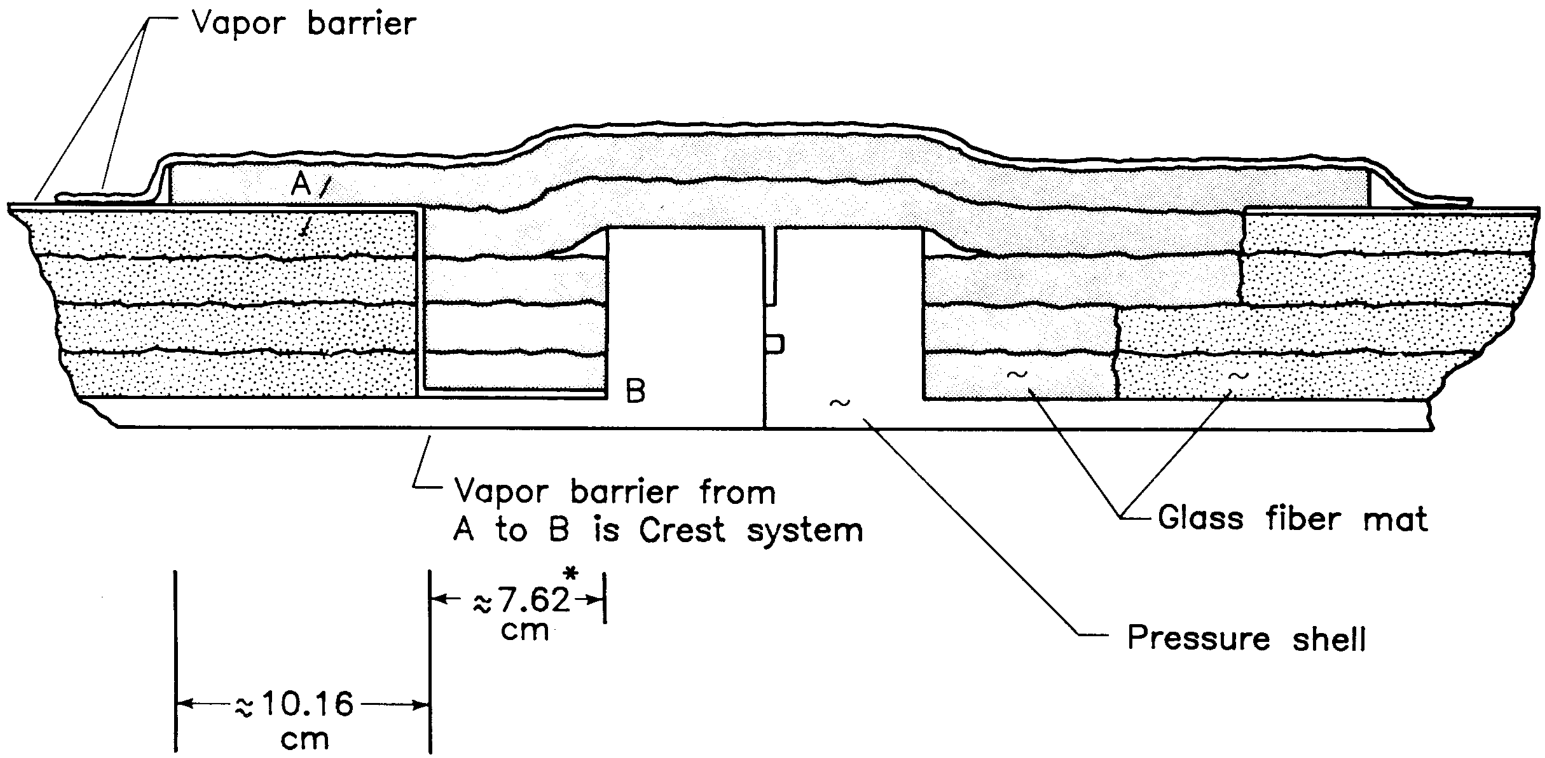


Figure 8.— Typical flange insulation scheme.



* This allows sufficient length for stud insertion.
Studs are inserted in direction of tunnel flow.

Figure 9.— Flange insulation with vapor barrier fixed on one side.

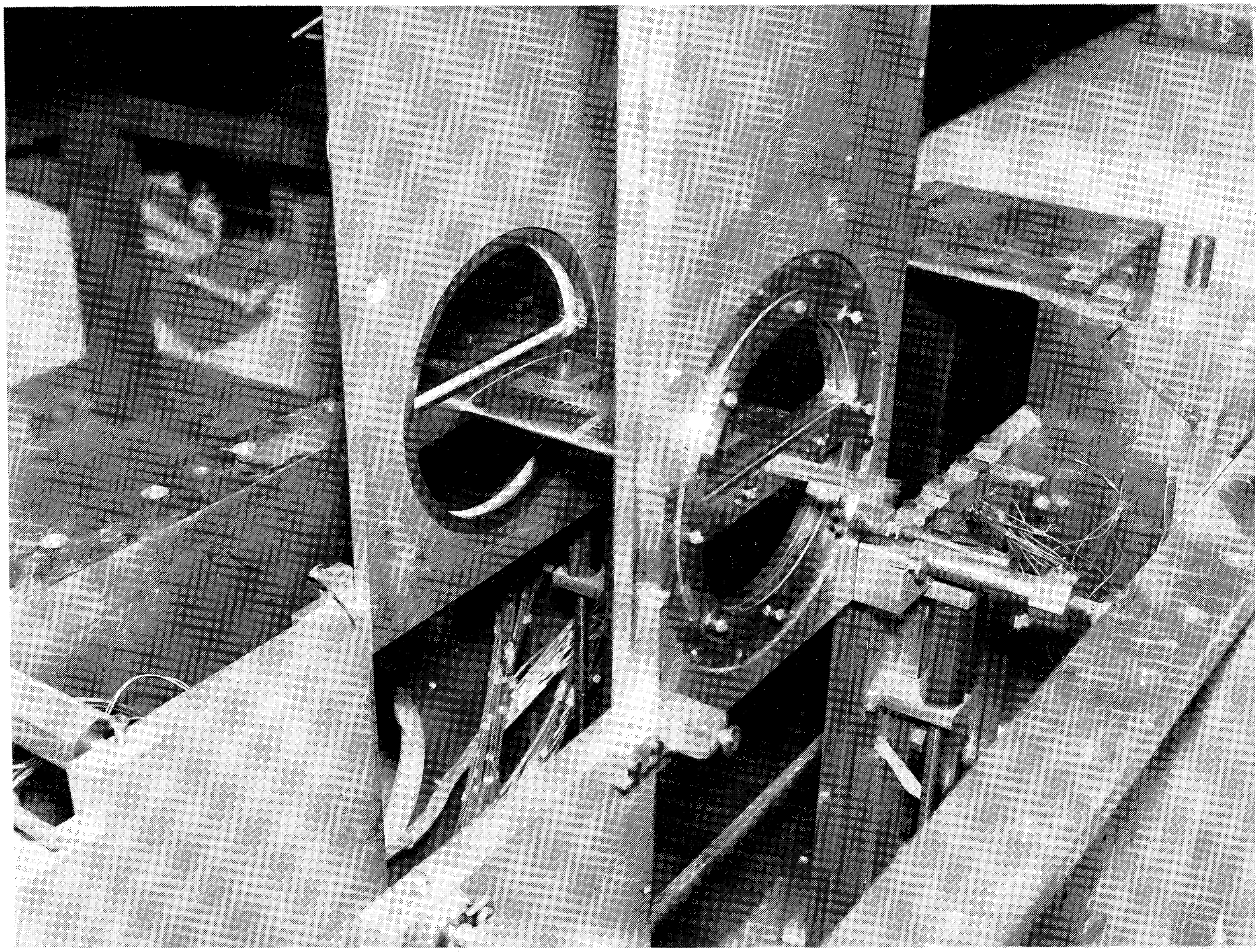


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Figure 10.— Model module being inserted in two-dimensional test section of the 0.3-m TCT.

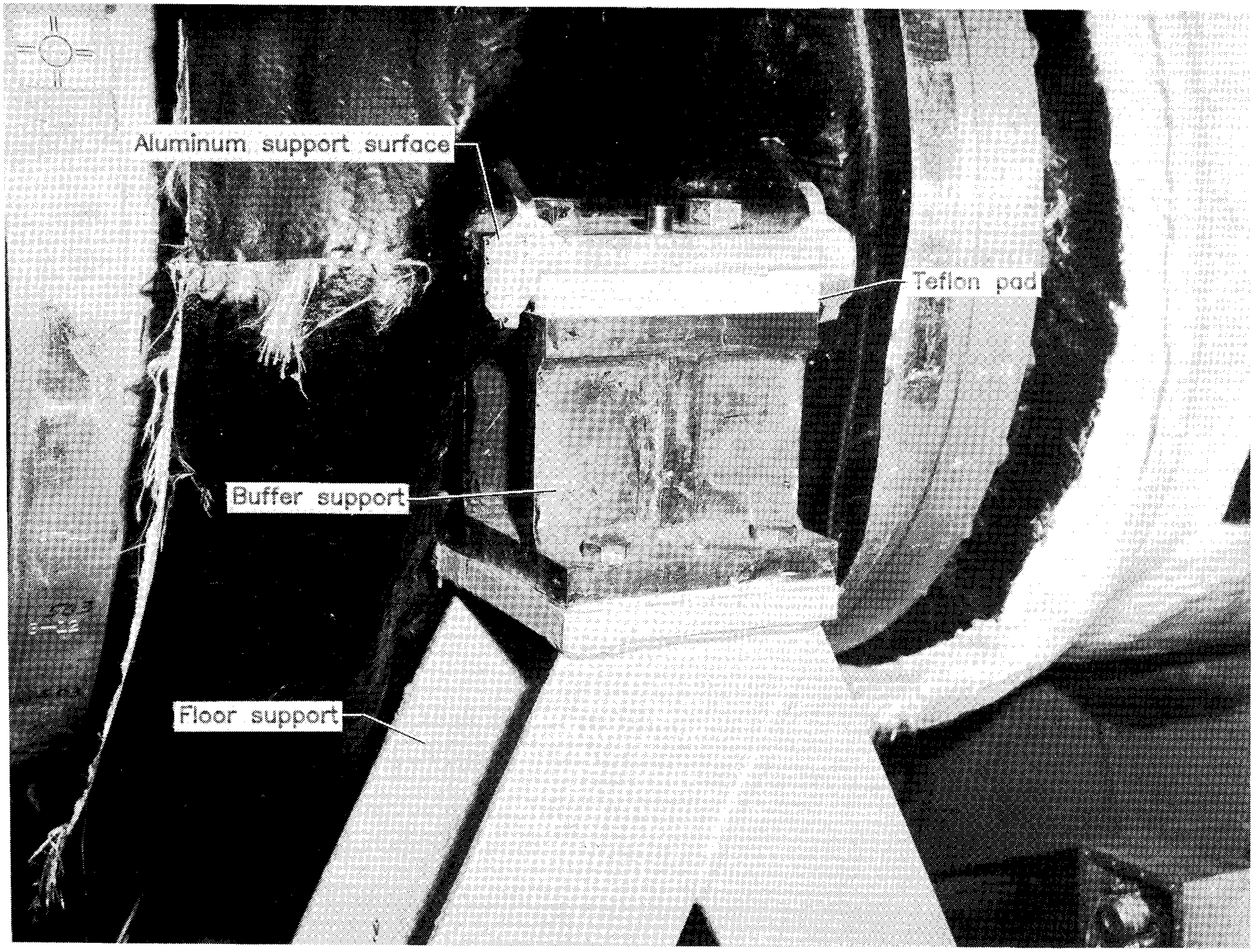

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Figure 11.— Typical tunnel support.

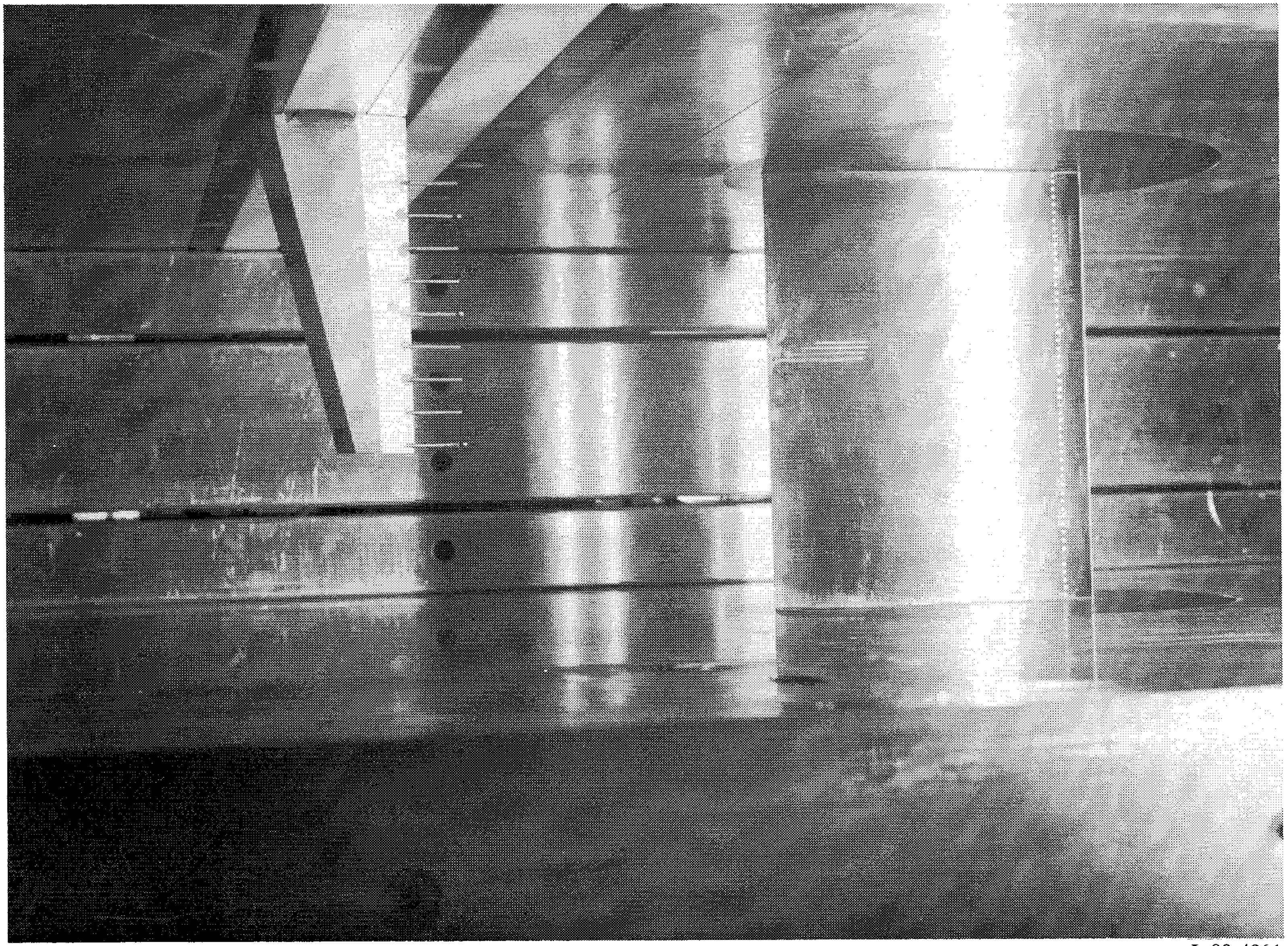

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Figure 12.— Two-dimensional test section showing momentum rake downstream of airfoil.

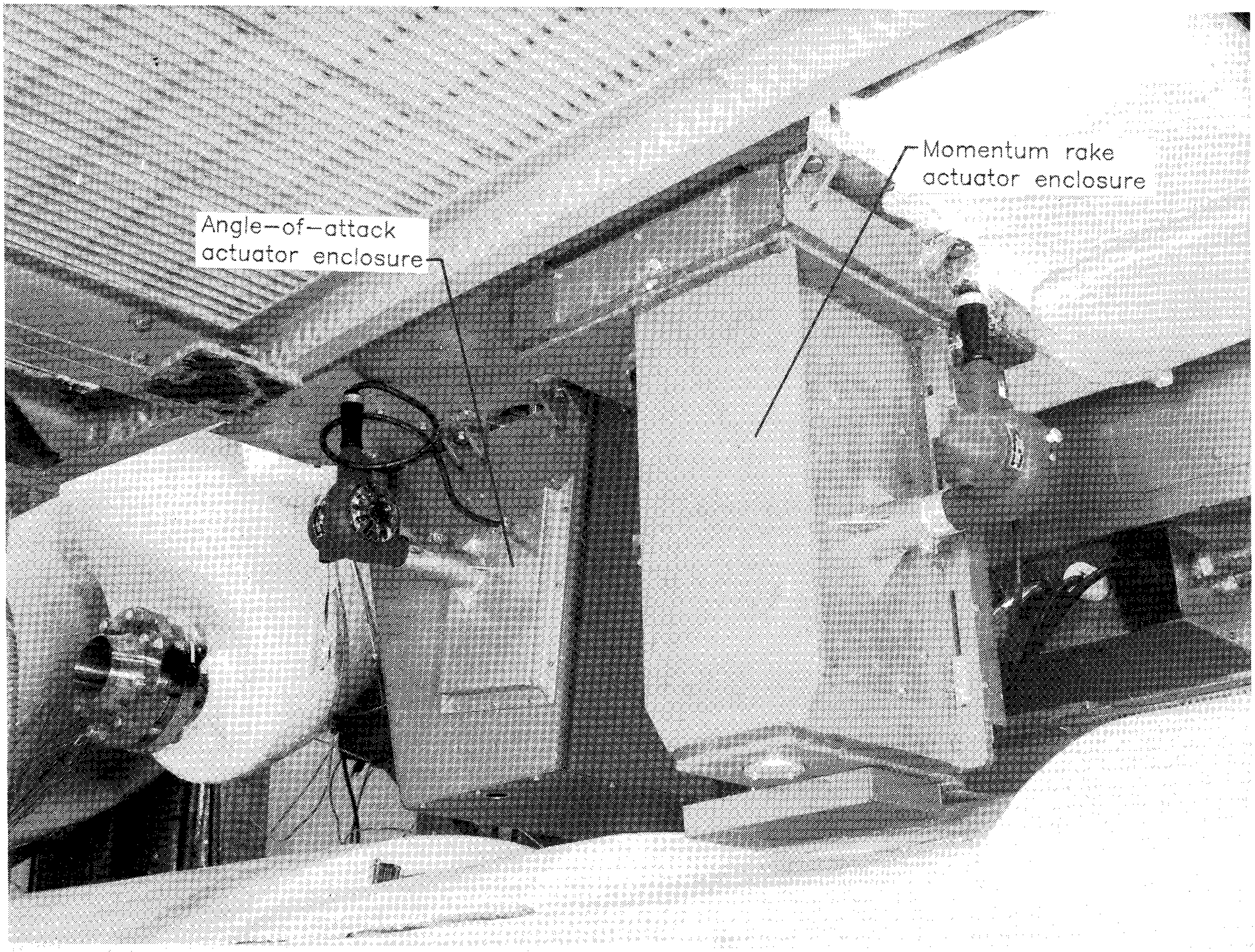

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Figure 13.— Momentum rake and angle-of-attack actuators externally mounted in heated sheet metal enclosures.

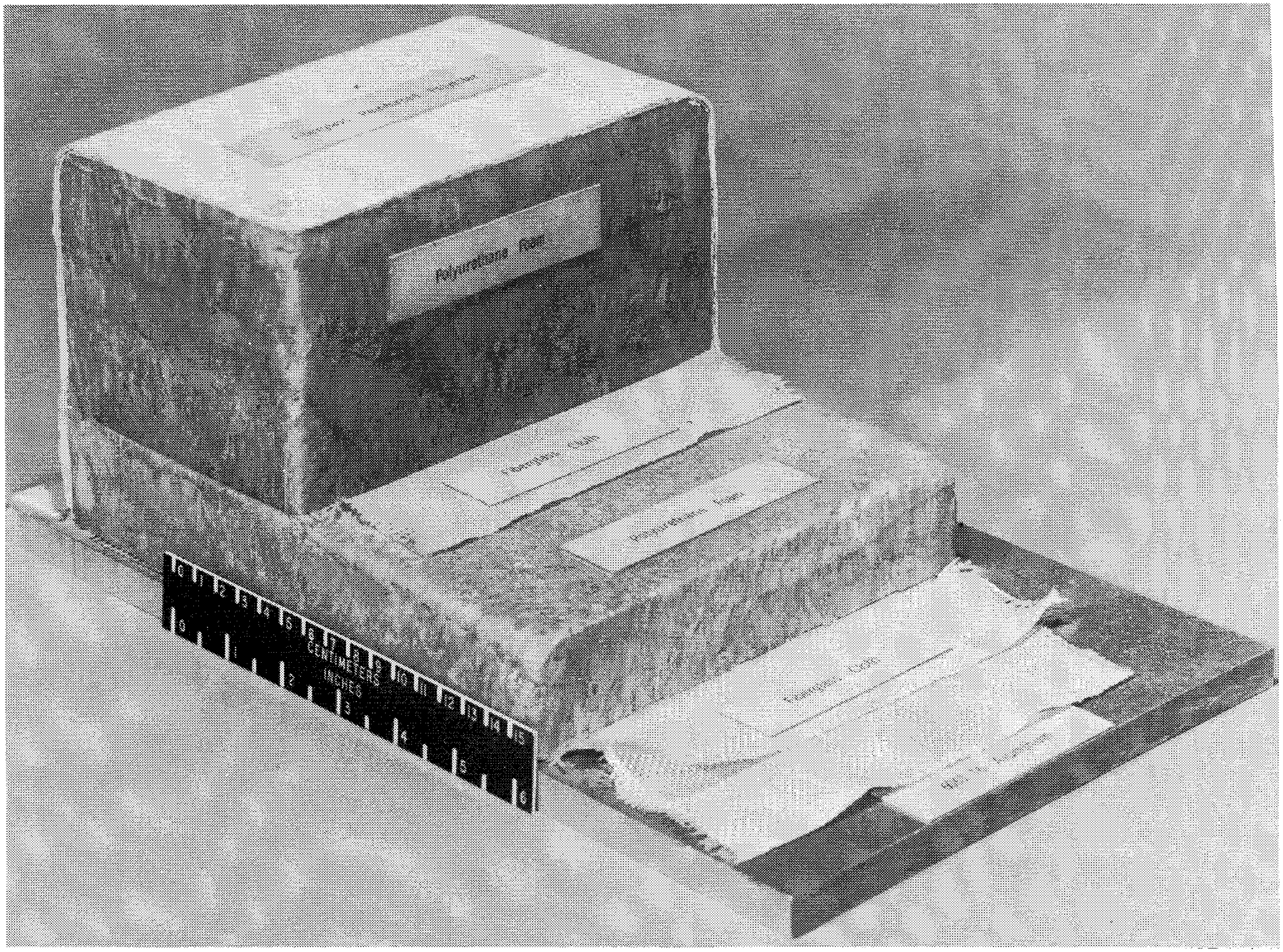

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Figure 14.— Sample of the original insulation system.

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16. Abstract

The thermal insulation system of the Langley 0.3-Meter Transonic Cryogenic Tunnel is described. The insulation system is designed to operate from room temperature down to about 77.4 K, the temperature of liquid nitrogen at 1 atmosphere. A detailed description is given of the primary insulation system which consists of glass fiber mats, a three-part vapor barrier, and a dry nitrogen positive-pressure purge system. Also described are several secondary insulation systems required for the test section, actuators, and tunnel supports. An appendix briefly describes the original insulation system which is considered inferior to the one presently in place. The time required for opening and closing portions of the insulation system for modification or repair to the tunnel has been reduced, typically, from a few days for the original thermal insulating system to a few hours for the present system.

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