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Experimental Quantitative Transport Probe and Control Box Sampling System

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June 1978

EXPERIMENTAL QUANTITATIVE TRANSPORT PROBE AND CONTROL BOX SAMPLING SYSTEM

by

Madhav B. Ranade
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

Contract No. 68-02-2434

Project Officer

Thomas E. Ward
Emissions Measurement and Characterization Division
Environmental Sciences Research Laboratory
Research Triangle Park, North Carolina 27711

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

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ABSTRACT

Three quantitative sampling transport probe and control box sampling systems were designed and fabricated. The systems are designed to permit transport of samples of aerosols from a source to a sensor without significant modification of mass rate and size distribution of the sample aerosols. Descriptions of the systems are given. An operating manual is included. Results of functional tests demonstrated that the systems operate as designed with the exception of pumping rates.

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ACKNOWLEDGMENT

The author wishes to acknowledge support from the Environmental Sciences Research Laboratory, U.S. Environmental Protection Agency (EPA). Special appreciation is expressed to the EPA project officer, Mr. Thomas E. Ward, and to Mr. John D. Stockham of IITRI. Messrs. Robert Purcell, Donald Hrdina, and Joseph Puretz of IITRI assisted in fabrication and testing.

SECTION 1

INTRODUCTION

In extractive sampling of particulate emissions, the aerosol must be transported from the source through a sampling interface to the sensor with a minimum of deposition, agglomeration, and reentrainment. A conventional sampling interface consists of a long probe open to the stack gases on one end and to the sensor on the other. Particle losses to and reentrainment from conventional probe walls can be excessive. A probe which minimizes these types of losses has been developed in a program sponsored by the United States Environmental Protection Agency (EPA). The Fine Particles Research Section of IIT Research Institute performed the work.

In the first of three phases of this program, a probe was developed which consists of a porous metal tube encased in a manifold through which transpiration air is passed inward to provide a moving clean air sheath that minimizes particle deposition on the walls. The efficiency of the probe to transport an aerosol ranging in size from 0.05 to 50 μm was demonstrated in a statistically designed test program. The results of this phase of the program are available in Reference 1.

In the second phase of the program, a field-operable sampling interface was developed. In order to sample in a stack, a probe must include a 90° bend. The standard gooseneck nozzle commonly used suffers from significant deposition just as conventional probes do. Extending the porous tube and transpiration air concept to the bend was considered to be the most effective approach to reduce deposition. Under this phase of the program, a 90° bend using the porous internal tube was designed and fabricated. It was then tested to determine its efficiency in transporting particles of 0.05 to 10 μm diameter. The bend was tested separately, as well as when attached to the experimental probe. A final design of the prototype sampling interface containing the probe, a transpiration air supply system, and a control box, was developed to meet the specifications listed in Table 1. The bend was fabricated and the experimental probe was modified to withstand temperatures up to 700°F in addition to the other specifications in Table 1. The probe was tested in both laboratory and field situations. The sampling probe could be used for several hours without significant particle deposition in the probe. The results of this second phase are available in Reference 2.

This report covers the current third phase of the program in which three additional sampling interface systems consisting of the porous tube probes and the control boxes were fabricated. Two probes are 2 meters and one is 3 meters long. The working specifications for dimensions and nominal capacities are as shown in Table 1. After approval of the designs by the EPA, shop quality

TABLE 1. PERFORMANCE SPECIFICATIONS FOR SAMPLING INTERFACE

Aerosol concentration range	10^2-10^8 particles/cm^3
Aerosol size range	0.05-10 μm
Sampling rate	7.1-28.3 lpm (0.25-1.0 cfm)
Sampling temperature	Ambient to 300°C (572°F)
Sampling probe	1.29 cm ID (1/2 in. ID) x ∿180 cm (6 ft) long (length ∿280 cm for one unit)
Sampling nozzles	0.63, 0.95, and 1.29 cm ID (1/4, 3/8, and 1/2 in. ID)
Sampling requirements	Isokinetic sampling
	90° bend
	Minimum diameter of sampling port compatible with the probe -- 10 cm (4 in.)
	Probe to be heated to at least 150°C (300°F) to prevent water condensation
Transpiration rate	Up to 71 lpm (2.5 cfm)

drawings were generated for the probes and submitted to the EPA. Upon EPA approval, fabrication was completed. The systems were operated in the laboratory to verify the functioning status of all the mechanical, electrical, and pneumatic components.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

Three control boxes and quantitative transport probe systems were designed and fabricated. Two probes are 2 meters long and one is 3 meters long. Design changes from prior prototypes included construction of a unitized probe with air supply tubes enclosed between the porous liner and stainless steel jacket. Transpiration air heating elements were placed closer to the probe. An aerosol test with 1 to 5 μm uranine particles indicated that the transport efficiency was 78%. This is comparable to the field prototype sampling probe(2) operated under similar conditions. Test conditions were at room temperature and included a sampling rate of 14 lpm (0.5 CFM) with front transpiration air at the rate of 43 lpm (1.5 CFM). Pumps were purchased to the same specifications as previous pumps for the field prototype systems; however, the new ones will pump approximately 71 lpm (2.5 CFM) compared to 142 lpm (5 CFM) for the field prototype.

A recommended improvement to the present system would be a better flow measuring and control subsystem with direct digital indicators. This modification will improve field performance by allowing quicker flow adjustment and calculations.

SECTION 3

DESIGN OF THE SAMPLING INTERFACE

The basic design of the sampling interface system was similar to the prototype interface system delivered to EPA and described in a final report from a previous program (2). The significant design changes are described in this report.

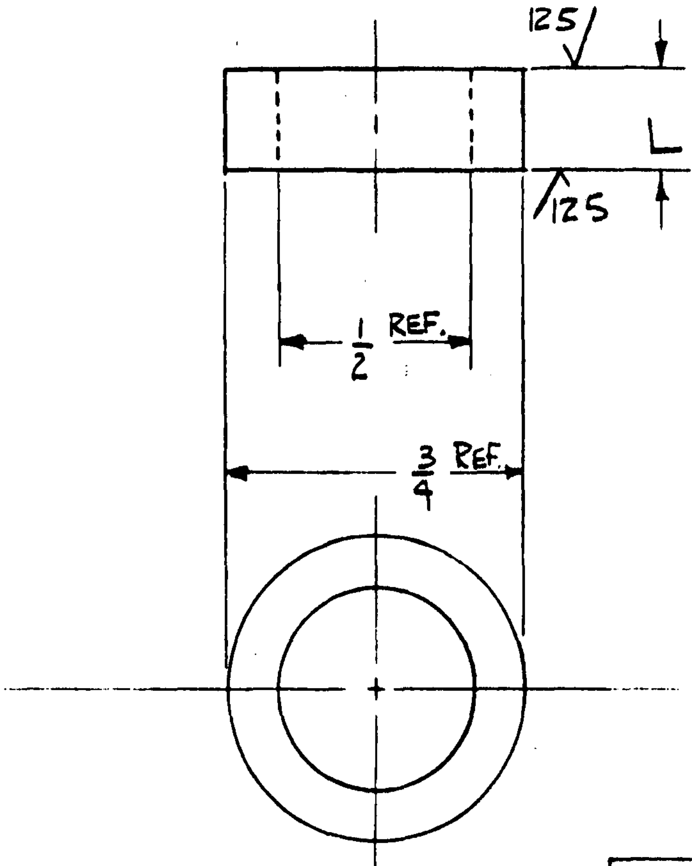
TRANSPIRATION SAMPLING PROBE

In conventional sampling situations, the sampling probe is inserted into the stack through sampling ports. The ports are usually 10 cm (4 in.) diameter circular openings. The sample flow must be in the direction of the stack flow. The sample stream, therefore, must be turned 90° in the sampling probe. Many conventional probes use a gooseneck nozzle. Considerable loss of the particulate sample occurs in this type of nozzle. Minimized particulate losses in the nozzle resulted from extending the internal porous tube to the 90° bend.

Fabrication of the 90° bend with a porous inner tube, such that the entire front end of the probe would pass through a 10 cm (4 in.) port, was a challenging problem. Attempts at bending the porous tube were unsuccessful even for large radius bends. Our successful approach for obtaining the bend was based on joining tube pieces cut on an angle to form an arc. The 90° bend was formed by welding the pieces together. Several 10° cut segments were joined to form the 90° bend. The 90° bend section was designed to have an independent transpiration air supply. In the previous field prototype(2), the 90° bend was attached to the rest of the probe by a threaded joint and the transpiration air was fed through an external 1/4" O.D. tube. To eliminate the external tubes in these probes the front section was welded to the rear section of the transpiration probe, and the transpiration air was supplied through a 1/4" O.D. tube enclosed in the outer sheath of the probe rear section. Figures 1 through 10 show the complete probe component parts and assembly.

The straight section of the probe is fabricated from a 1.9 cm (3/4 in.) diameter, and 173 cm (68-1/8 in.) long 316 stainless steel porous tube. The air distribution manifold used in the field prototype was eliminated to keep the outer diameter of the probe uniform. The transpiration air was supplied through a 1/4" O.D. tube provided with holes for air distribution.

Two of the probes were 2 meters long and one probe was 3 meters long.



DETAIL NO.	"L"
1	1/4
2	1 3/8

MAT'L: 3/4 O.D. × 1/2 I.D.
316 STAINLESS POROUS TUBE
2 μm POROSITY

Figure 1. 90° Diluter transition pieces.

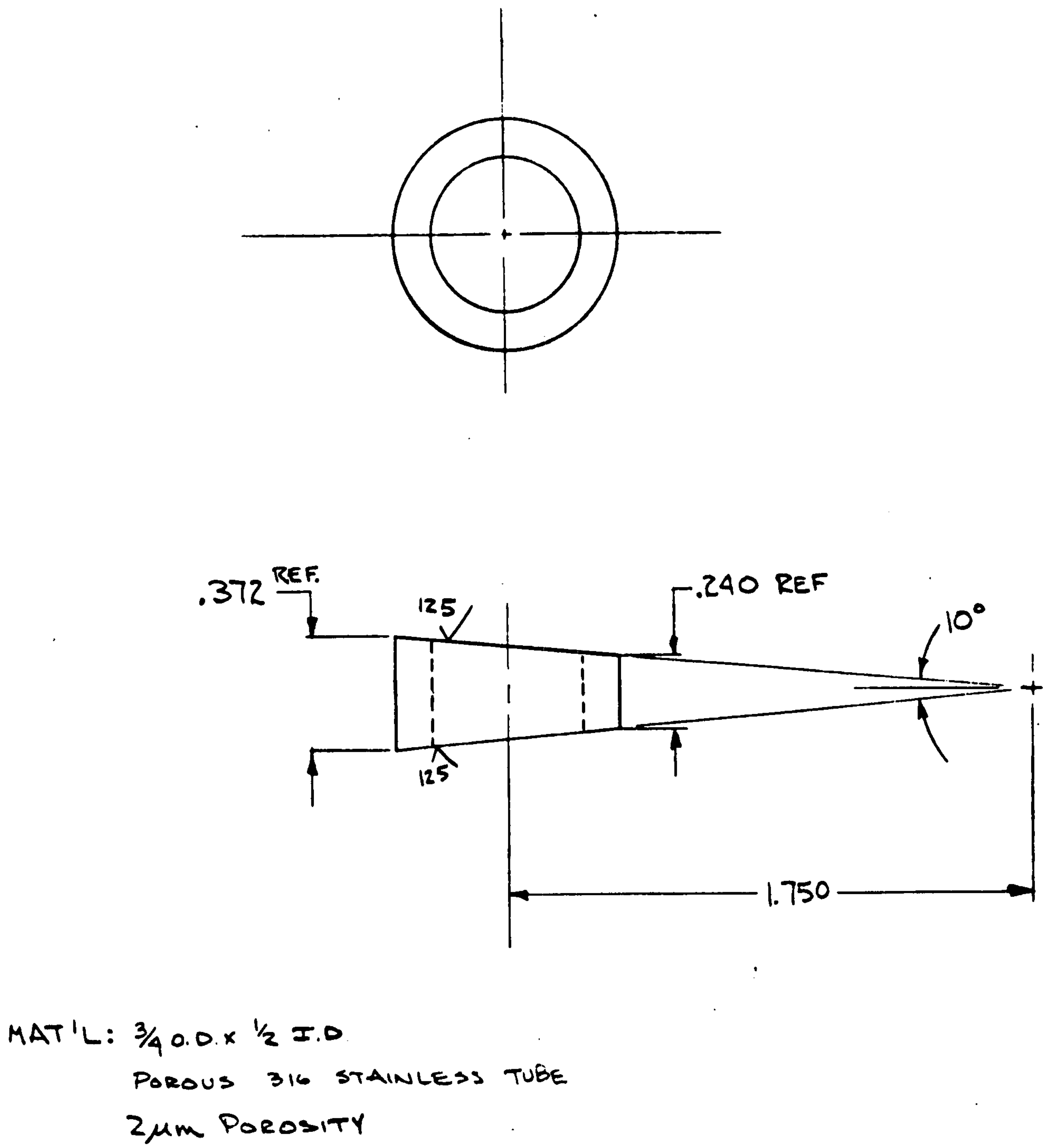


Figure 2. 90° Angle diluter pieces.

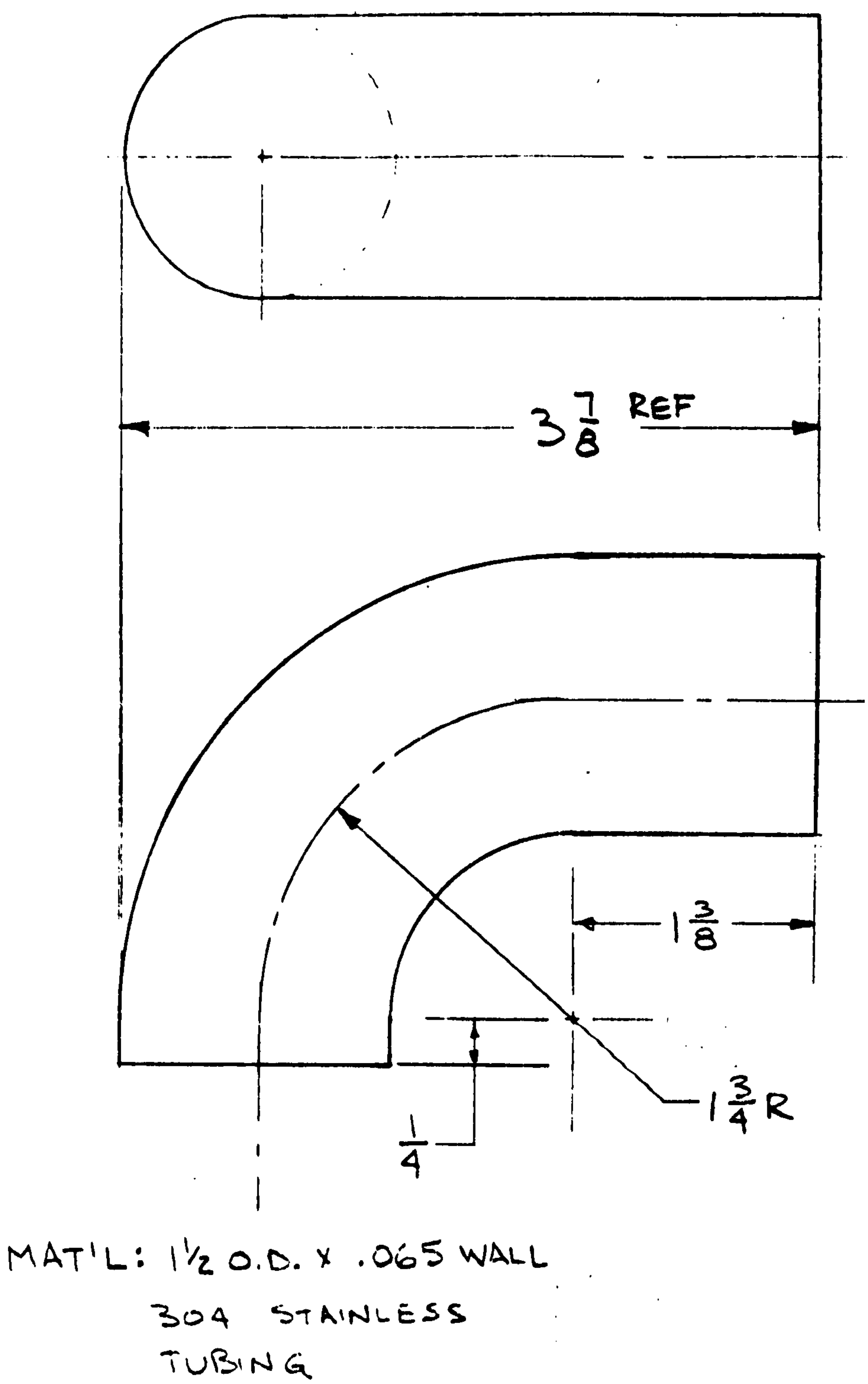


Figure 3. Front ell, outer tube.

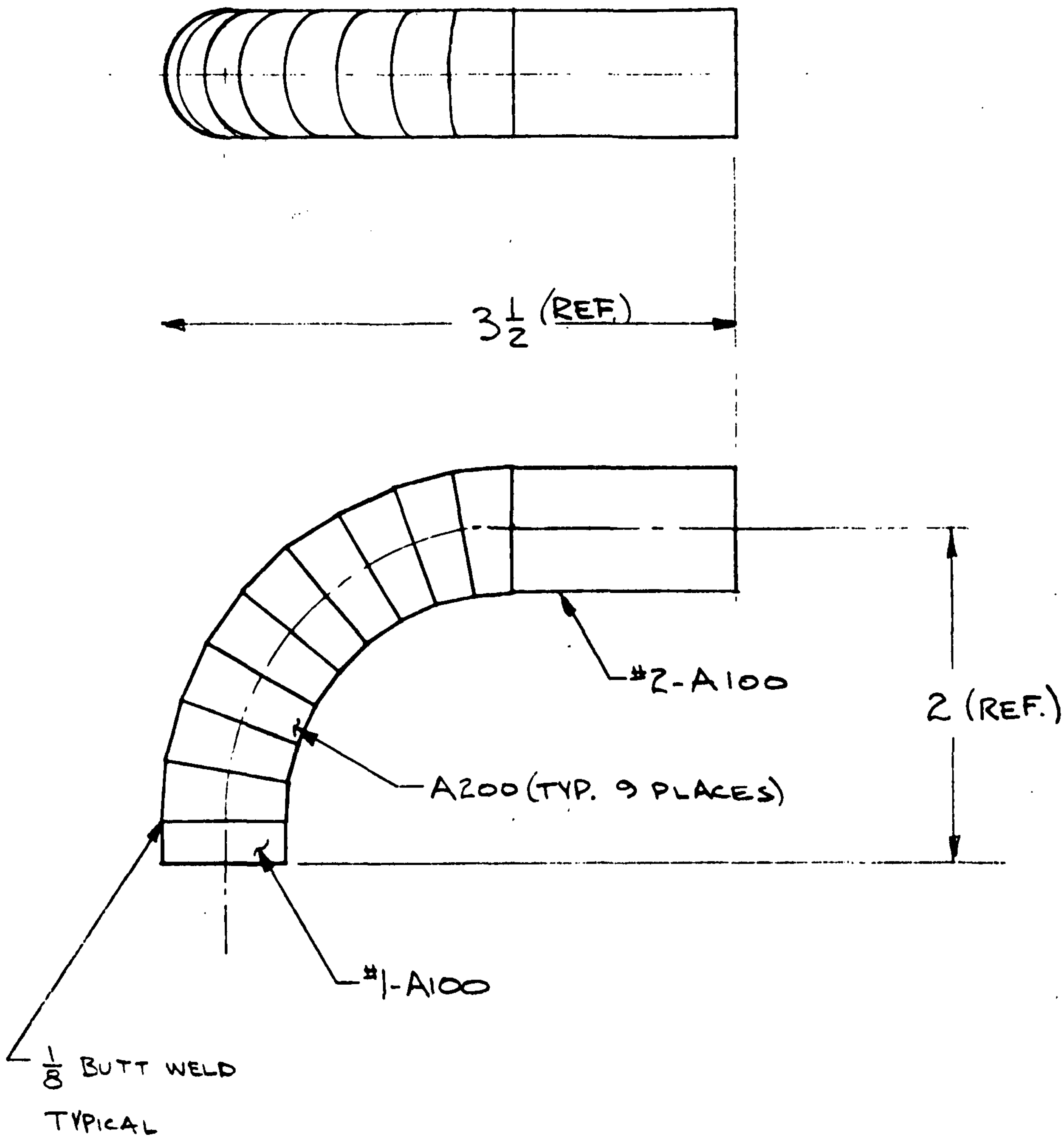


Figure 4. Dilution element, 90° ell section.

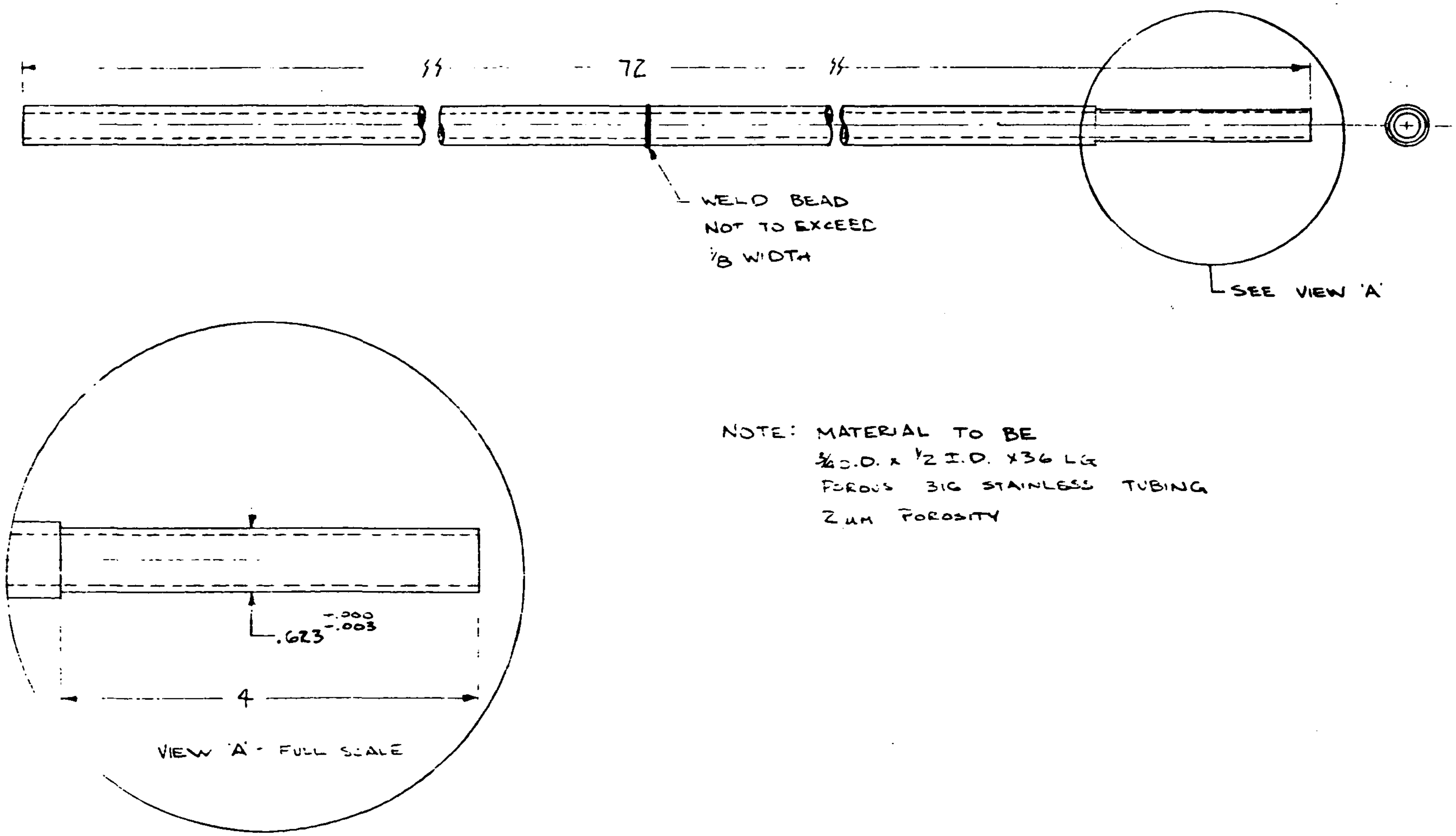


Figure 5. Main dilution tube.

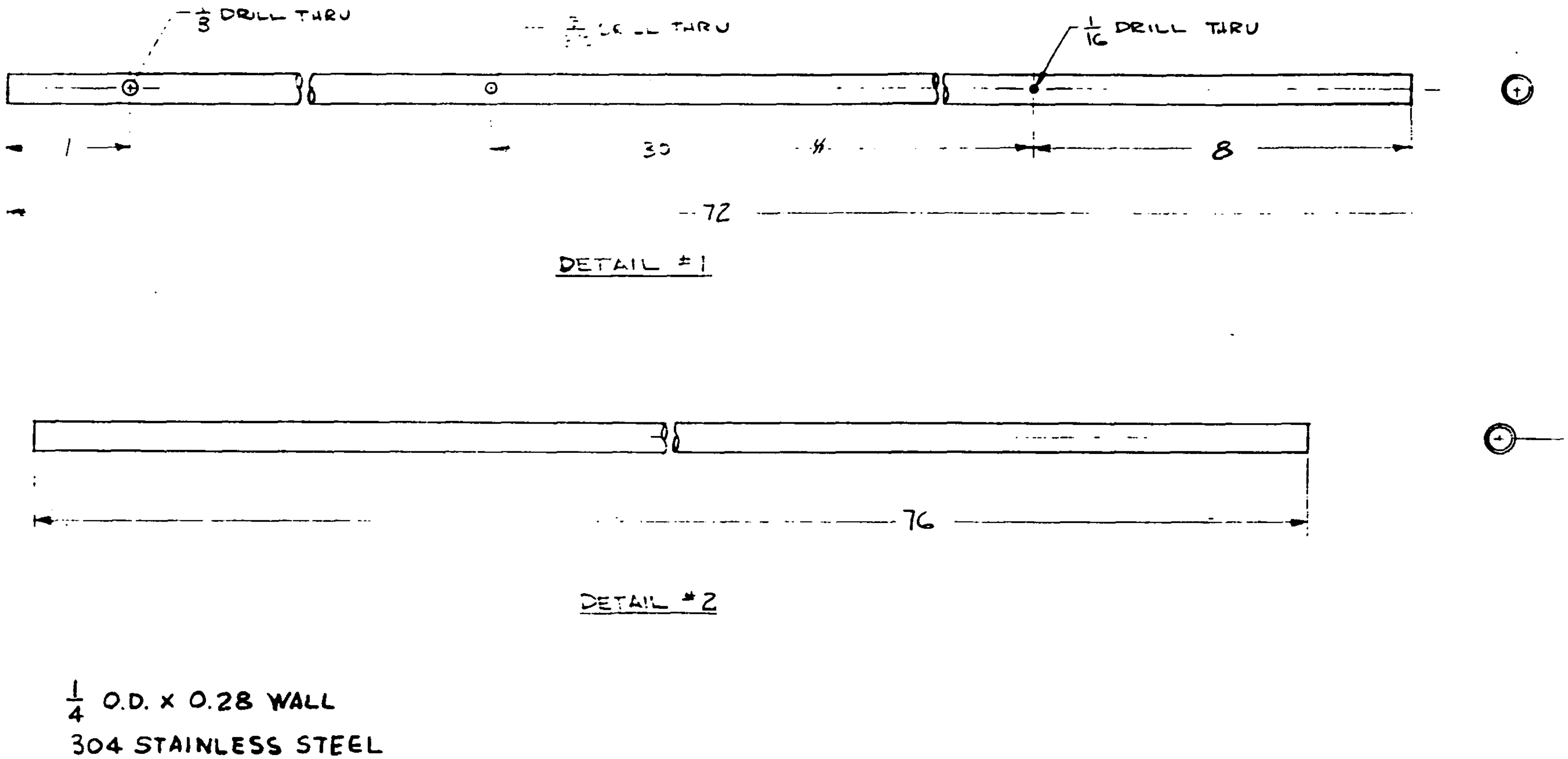


Figure 6. Dilution air supply tubes.

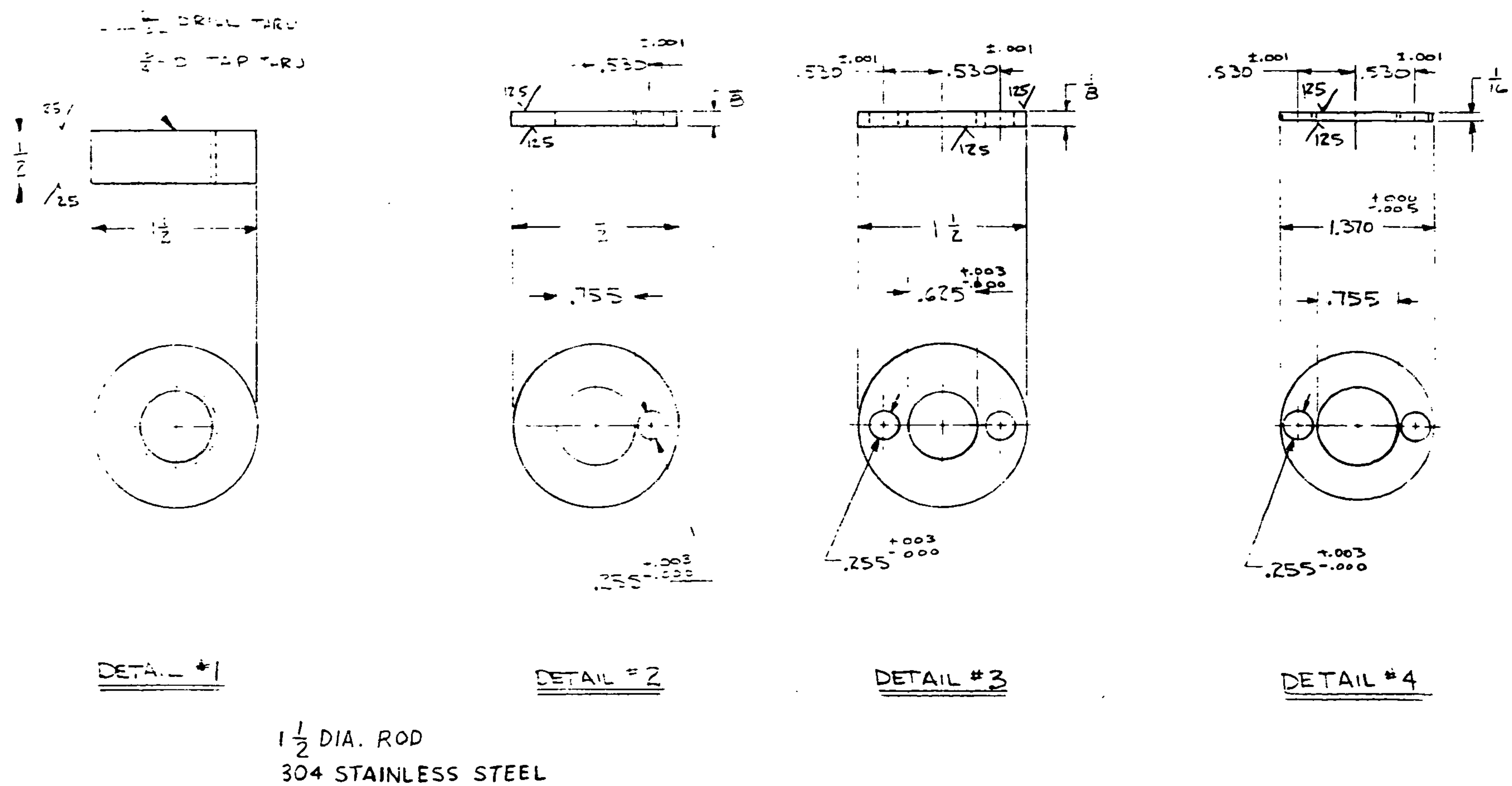


Figure 7. Dilution tube dividers.

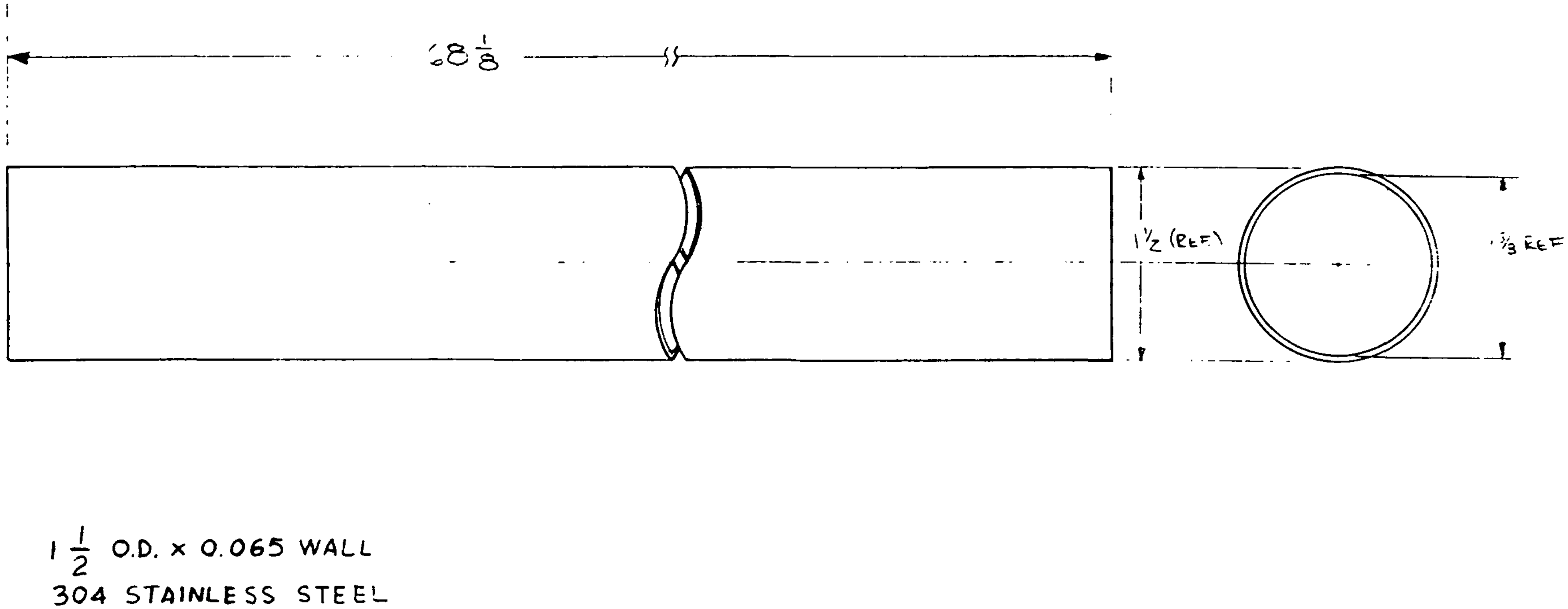


Figure 8. Dilution air manifold.

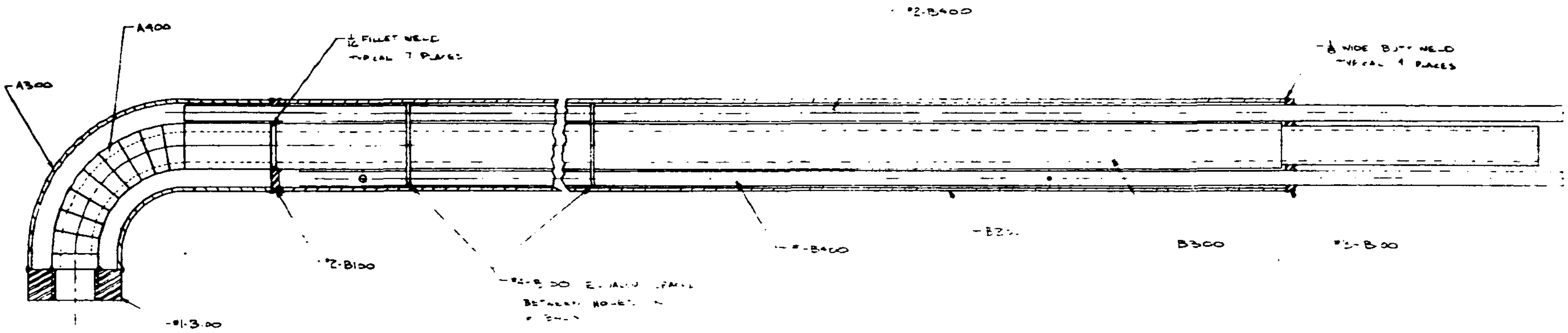


Figure 9. Assembly, sample probe.

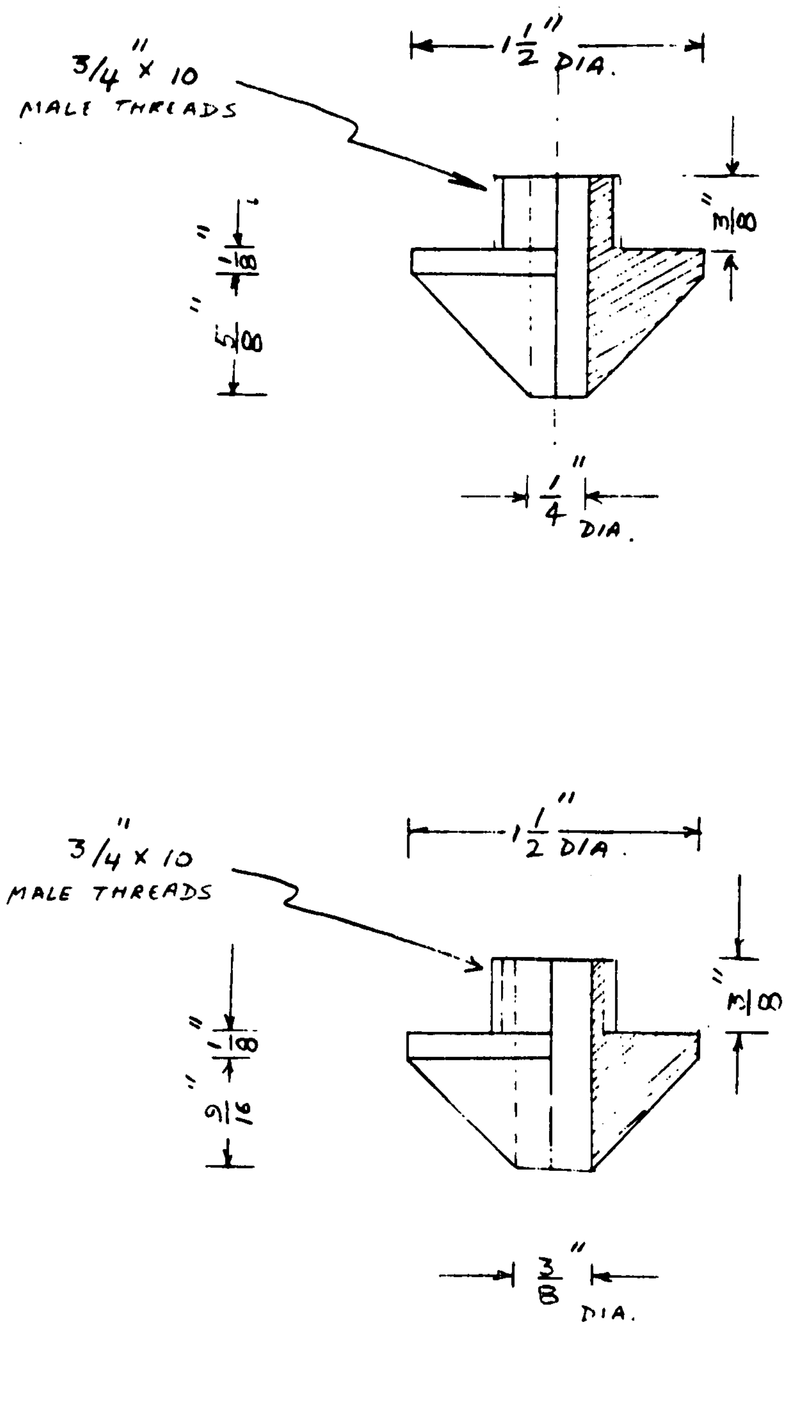


Figure 10. Sampling nozzle set.

CONTROL BOX

The control box housing the auxiliary components and controls was modified to streamline its operation. The details of the box case are shown in Figures 11 through 13.

The flow diagrams of the transpiration air supply and the sample suction system are shown in Appendix A. The main change in these diagrams and the field prototype is that the single heater in the original control box was replaced by two heaters attachable to the probe's transpiration air inlet. The heaters were fabricated using band heaters (Chromalox #MB1J1J1A3) which were mounted on a 1-1/2" O.D. sampling cylinders (Whitey Model #304-HD4-75) packed with #3 coarse stainless steel wool. This change will reduce the heat loss in the supply hoses and allow use of rubber hoses rather than the Teflon hoses previously specified since the air temperature through the box and hoses is near ambient. Other changes include the use of thermocouples in place of dial thermometers and modified arrangement of the controls.

LABORATORY TESTING

All of the control boxes were operated according to the operating manual and found fully functional prior to shipping. One of the probes was checked by sampling a 5 μm uranine aerosol. Tests were also performed to evaluate the new heater design.

Functional Check

A functional check of the control box showed all components except the pump to be operating as designed. Since the pump used in the prototype is no longer manufactured, a new model was purchased. The air output of the new pumps was 71 lpm (2.5 CFM) which is only one-half of the specification even though the manufacturer stated that the new model was similar or better in performance to the pump model used in the prototype. If needed higher flow rates can be attained if the outputs of all four pump heads are used. This requires modification of the plumbing by addition of tubing as described in Appendix A.

Test with Uranine Aerosol

A 1-5 μm uranine aerosol was generated by nebulizing a 1% uranine solution. The aerosol was introduced into a chamber and was sampled through a probe with a 1/4" diameter nozzle and a glass fiber filter. Collection time was approximately one-half hour. The uranine deposited on the filter was analyzed by dissolving it in distilled water. Uranine deposited in the probe was analyzed after repeated washing with distilled water. The amount of uranine recovered from the probe was 2.46 gms, while 9.06 gms were recovered from the filter. The front transpiration flow rate was approximately 42.5 lpm (1-1/2 cfm) and the sampling rate was adjusted to 14.1 lpm (1/2 cfm). The transport efficiency was calculated as:

$$\text{Transport Efficiency} = \frac{\text{Uranine on Filter}}{\text{Total Uranine into Probe}} = \frac{9.06}{9.06 + 2.46} \approx 78\%$$

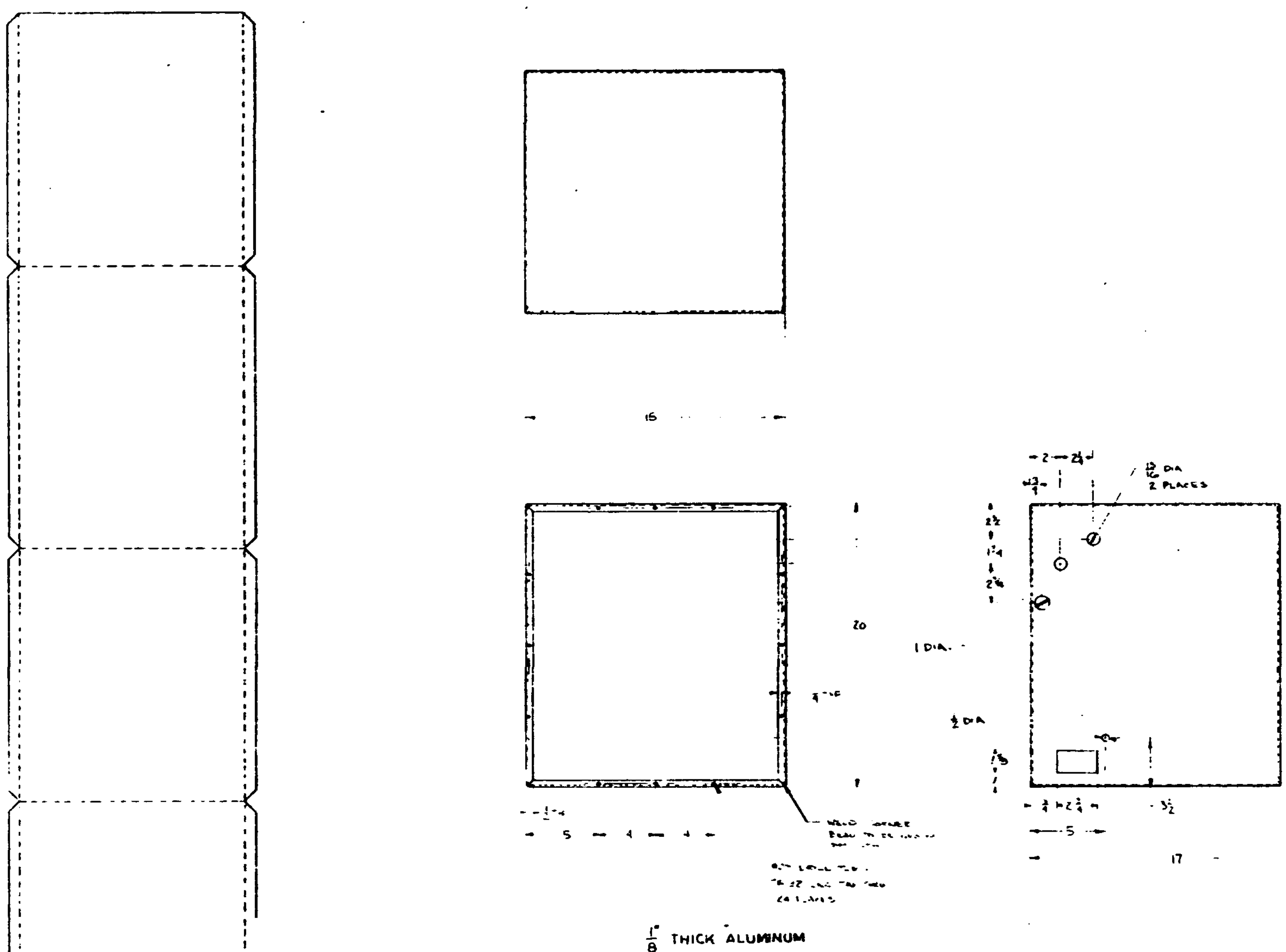


Figure 11. Control box frame.

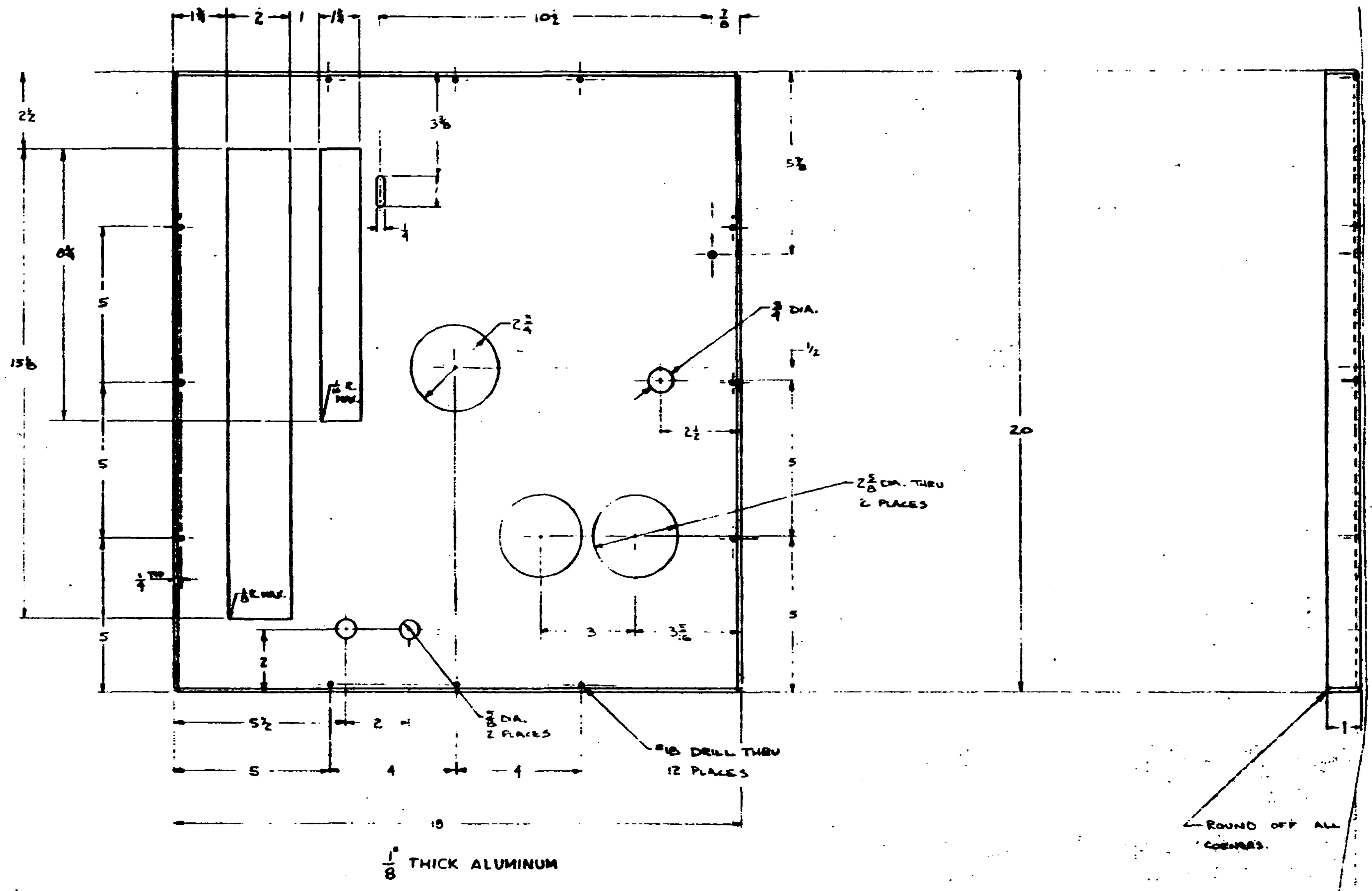


Figure 12. Front panel.

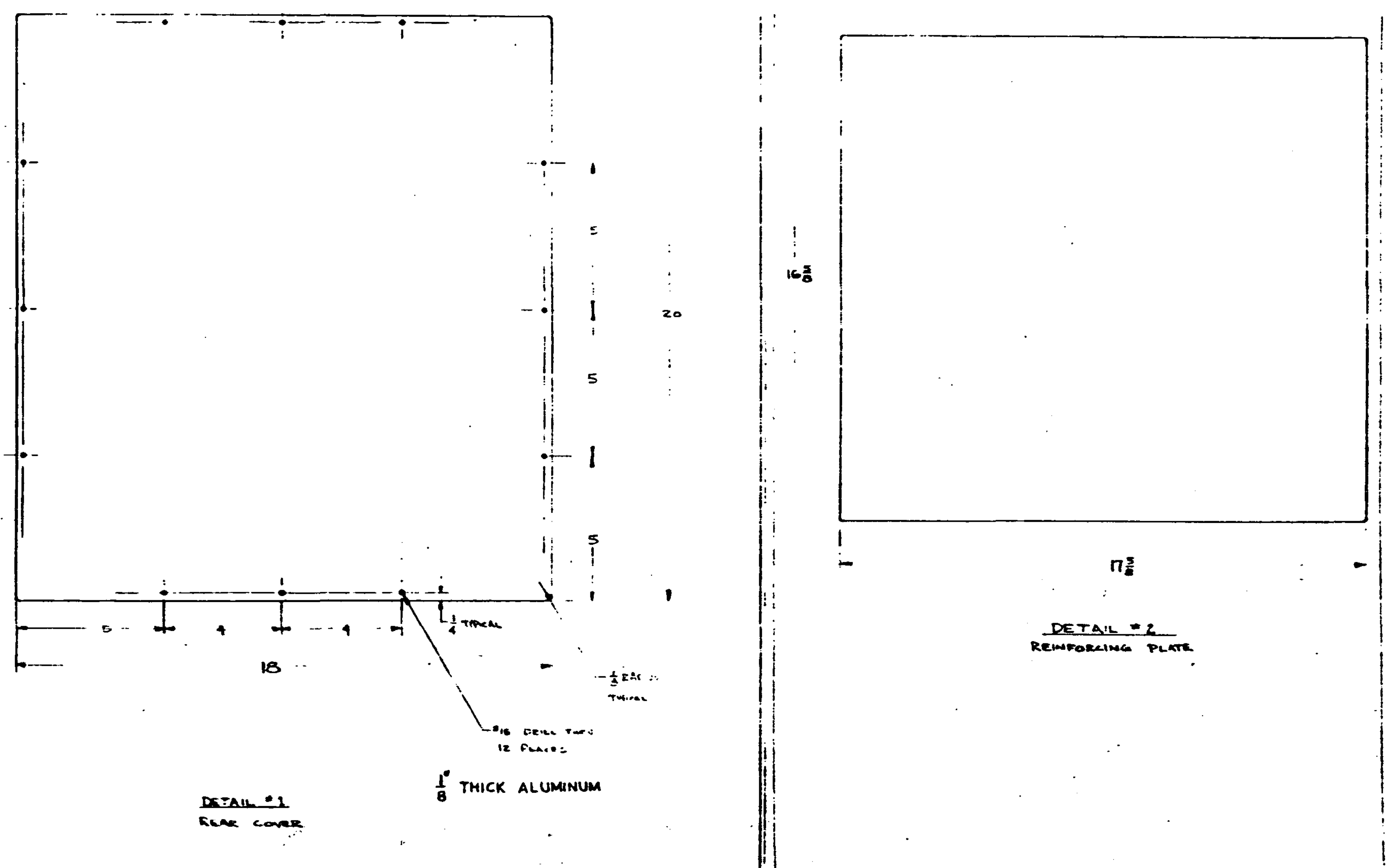


Figure 13. Miscellaneous control box parts.

The filter deposit showed a symmetric distribution of particles.

No attempt to optimize the test conditions was made. The transport efficiency of 78% is in line with results obtained under similar conditions with the field prototype. It may be necessary to increase the transpiration flow rate by combining the outputs of all of the pump heads to get optimum results.

Heater Test

The heater's performance was tested by measuring the outlet temperature using the thermocouples. The results are presented in Table 2. The temperature at the outlet of the probe was also checked.

The results show that the operation of the heater at full voltage heats the transpiration air up to 260°C (500°F) at 70% of rated capacity. The probe, however, due to its large mass, may need auxiliary heaters similar to the band type (Chromalox #MB1J1J1A3) used on the air heaters on the 1-1/2 in. diameter probe body.

TABLE 2. RESULTS OF HEATER PERFORMANCE TEST, PROBE TEMPERATURES

Elapsed Time (min)	Transpiration Air				Inlet Heater Temperature		Front Section			Rear Section		
	Front Section		Rear Section					Temperature			Temperature	
	SLPH	SCFH	SLPH	SCFH	°C	°F	Voltage	°C	°F	Voltage	°C	°F
0	1700	60	4250	150	38	100	40	38	100	40	38	100
20	1700	60	4250	150	49	120	40	63	145	40	71	160
23	1700	60	4250	150	49	120	60	71	160	60	79	175
43	1700	60	4250	150	53	127	60	107	225	60	113	235
46	1700	60	4250	150	54	130	80	110	230	80	117	243
71	1700	60	4250	150	54	130	100	182	360	100	199	390
81	1700	60	4250	150	58	137	120	249	480	120	260	500

REFERENCES

1. Ranade, M. B. Sampling Interface for the Quantitative Transport of Aerosols. EPA-650/2-74-016, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December, 1973. 131 pp.

2. Ranade, M. B. Sampling Interface for the Quantitative Transport of Aerosols - Field Prototype. EPA-600/2-76-157, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June, 1976. 62 pp.

Appendix A

OPERATING MANUAL

Transpiration Sampling Interface

1. INTRODUCTION

The transpiration sampling interface is based on the use of a clean air sheath to reduce deposition of particulate matter on the walls of the sampling probe. The interface was developed at the IIT Research Institute on two projects under contracts from the Environmental Protection Agency (EPA). Test results and design principles are reported in the following final reports for these projects:

1. Sampling Interface for the Quantitative Transport of Aerosols. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-650/2-74-016, December, 1973.

2. Sampling Interface for the Quantitative Transport of Aerosols - Field Prototype. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-600/2-76-157, July, 1975.

2. DESCRIPTION

The sampling interface consists of two major components: the sampling probe, and a control box for the sampling operation.

The sampling probe is shown in Figure A-1. It consists of a front section (FS) with a 90° bend and a rear section (RS). Each section has an inner tube of 1.27 cm (1/2 in.) I.D. and a 1.9 cm (3/4 in.) O.D. 316 stainless steel porous tube. The inner tube is encased in an outer stainless steel tube (3.81 cm [1-1/2 in.] O.D.). The two sections are welded together using a transition piece. The front section has provision to screw on either of the sampling nozzles. Air is supplied to the front and the back section through 0.63 cm (1/4 in.) tubes connected by Swagelok® fittings at the rear of the probe. The probe can be joined to a sampling device through a 3/8 in. NPT male connection.

The control box is shown in Figures A-2 and A-3. It contains a combination vacuum and pressure pump rated at 7 cfm air output and 7 cfm intake capacities. Flow diagrams of the air supply and the sample suction are shown in Figures A-4 and A-5. The air from the pump flows through a flowmeter R, and is divided into two streams in order to supply air to the front and rear sections of the probe. On the vacuum side, the flow is monitored by observing

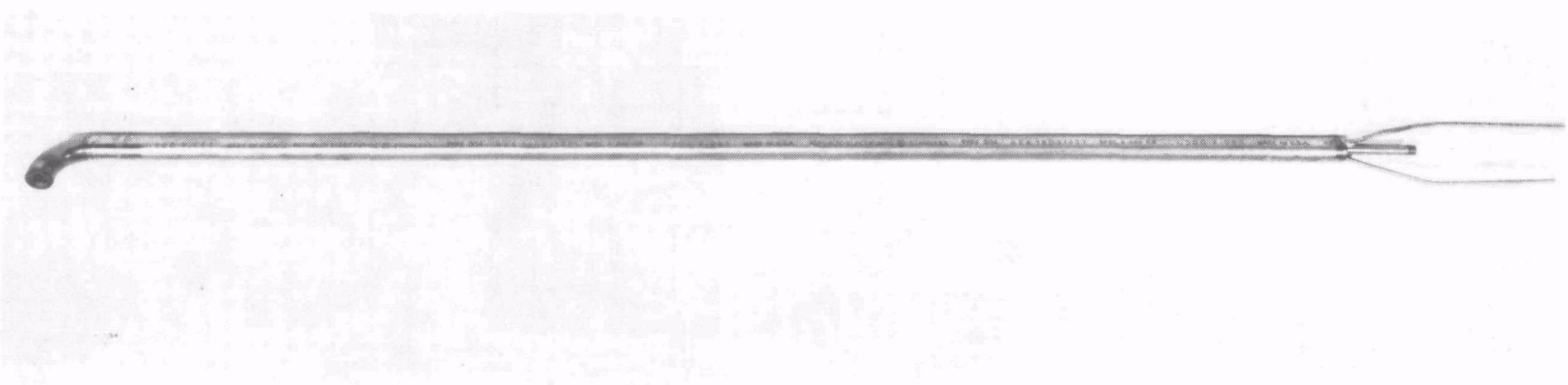


Figure A-1. Transpiration sampling probe.

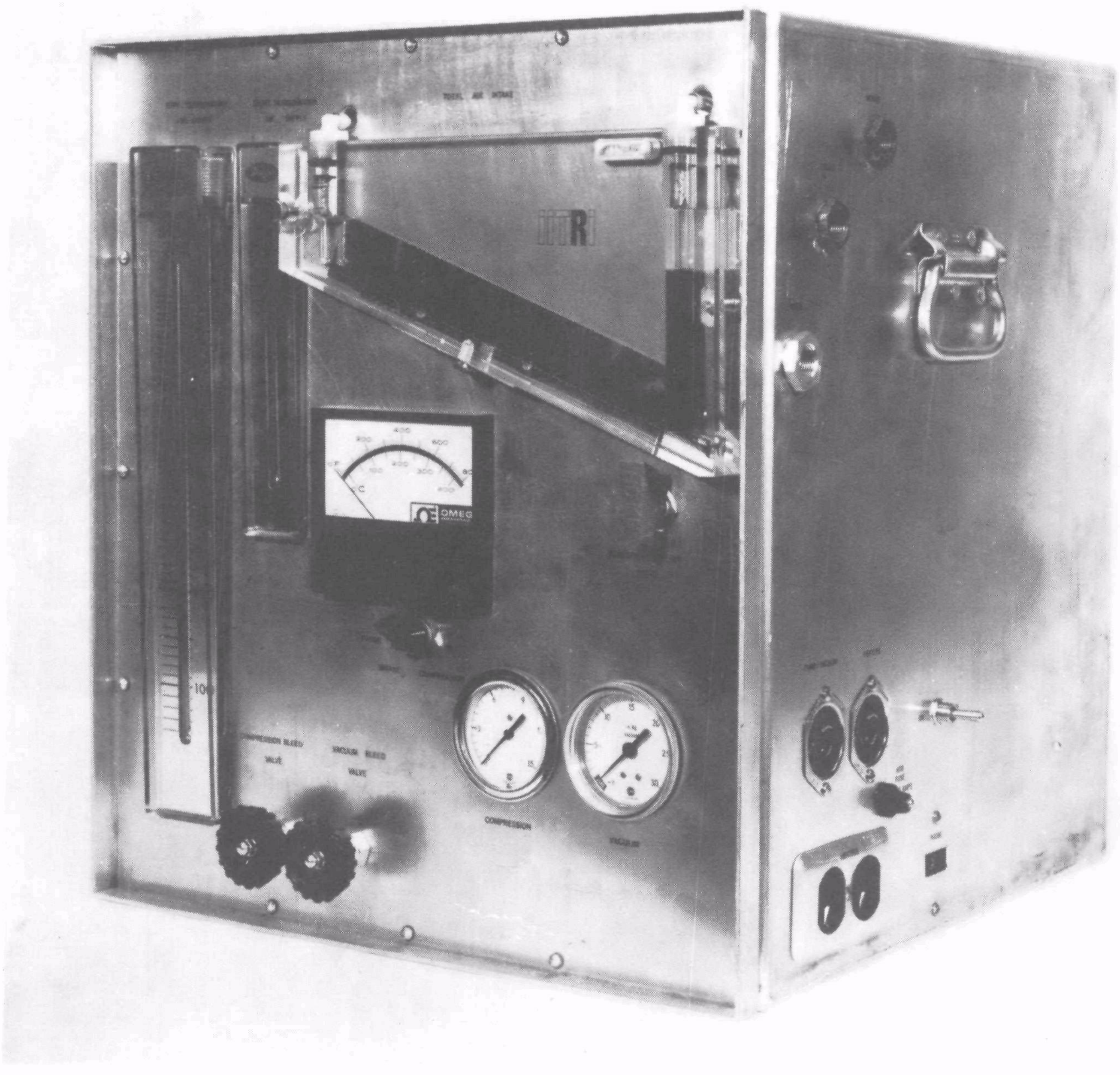


Figure A-2. Front view of control box.

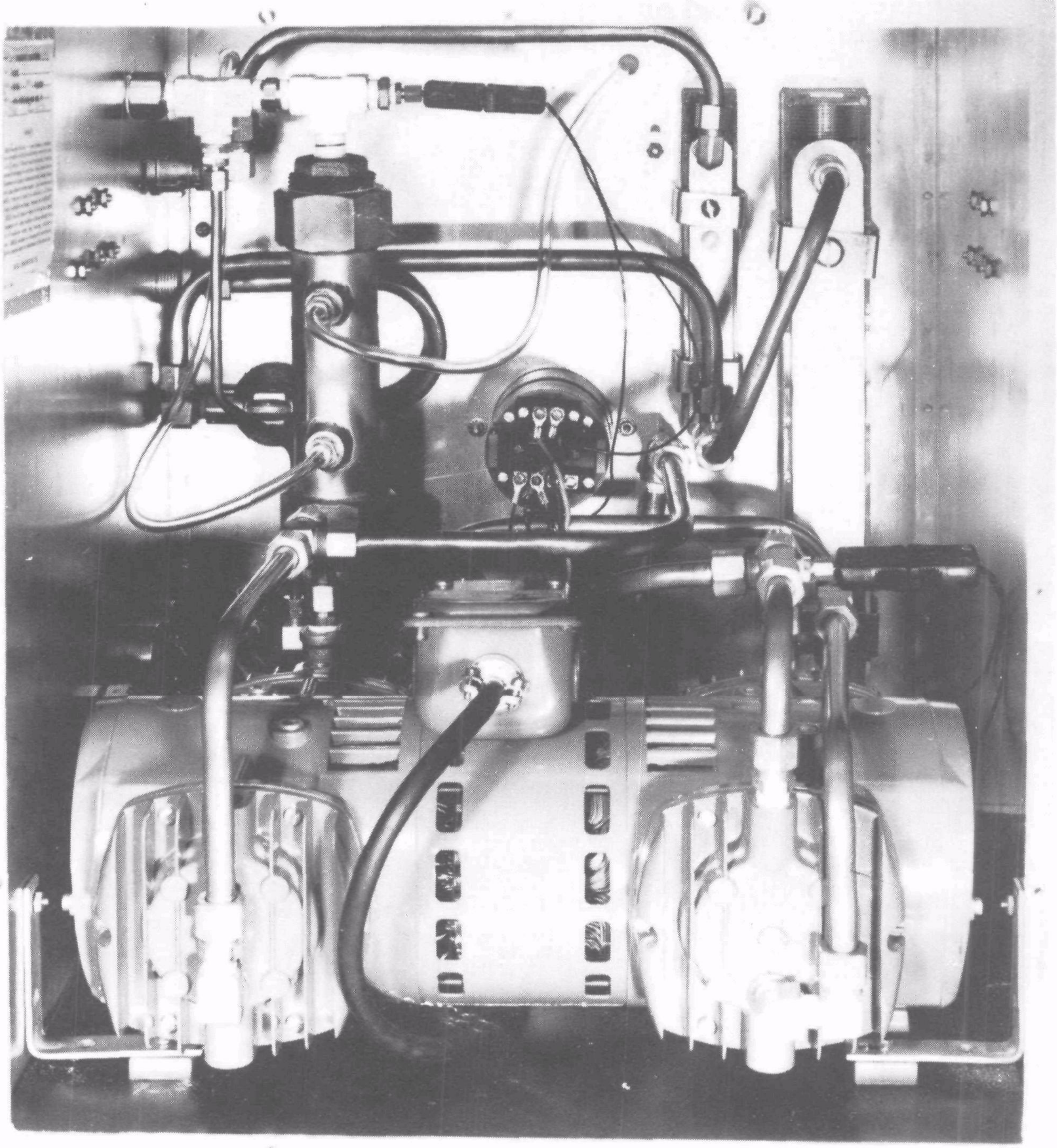


Figure A-3. Rear view of control box.

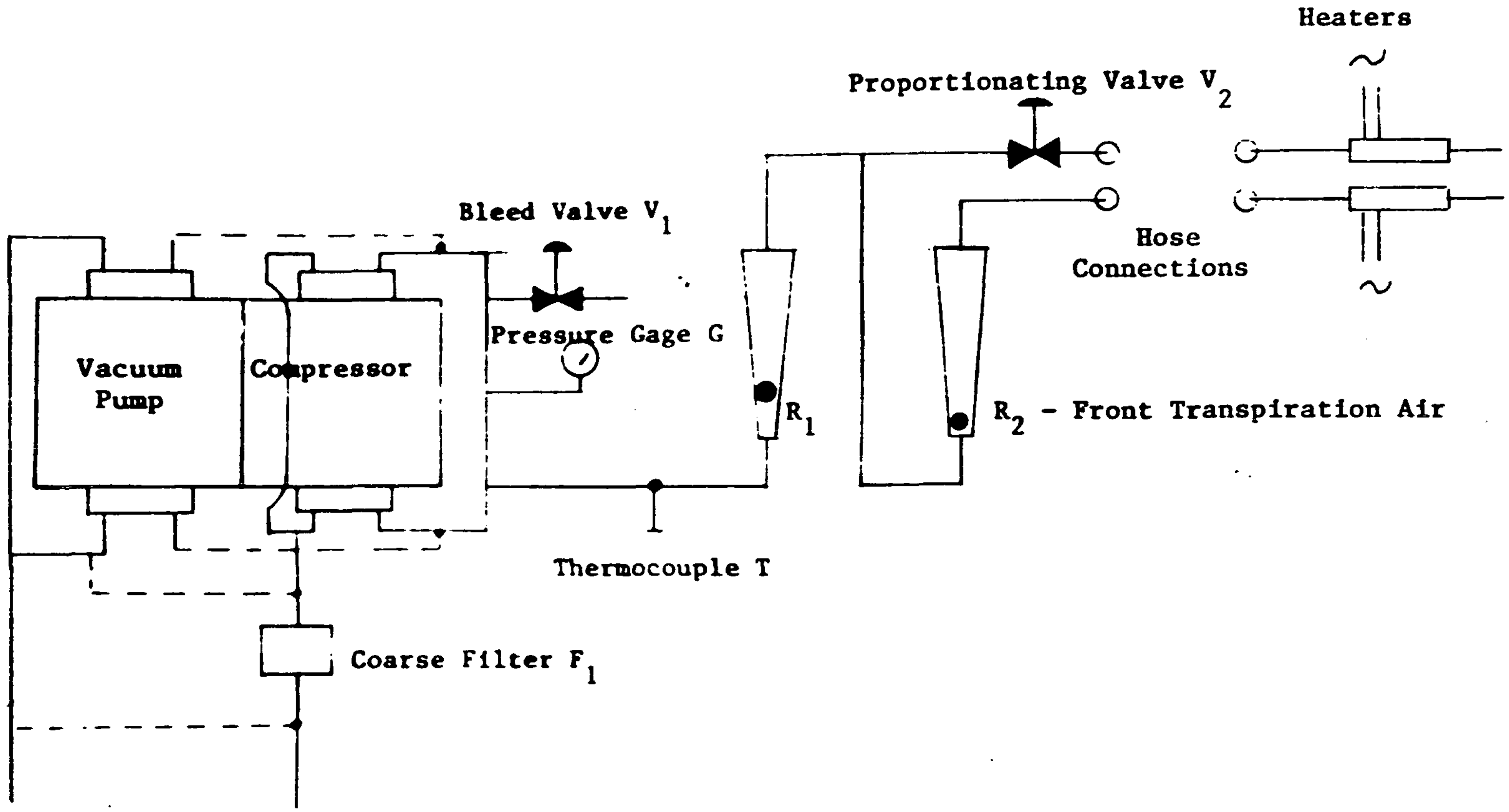


Figure A-4. Compressed air line diagram.

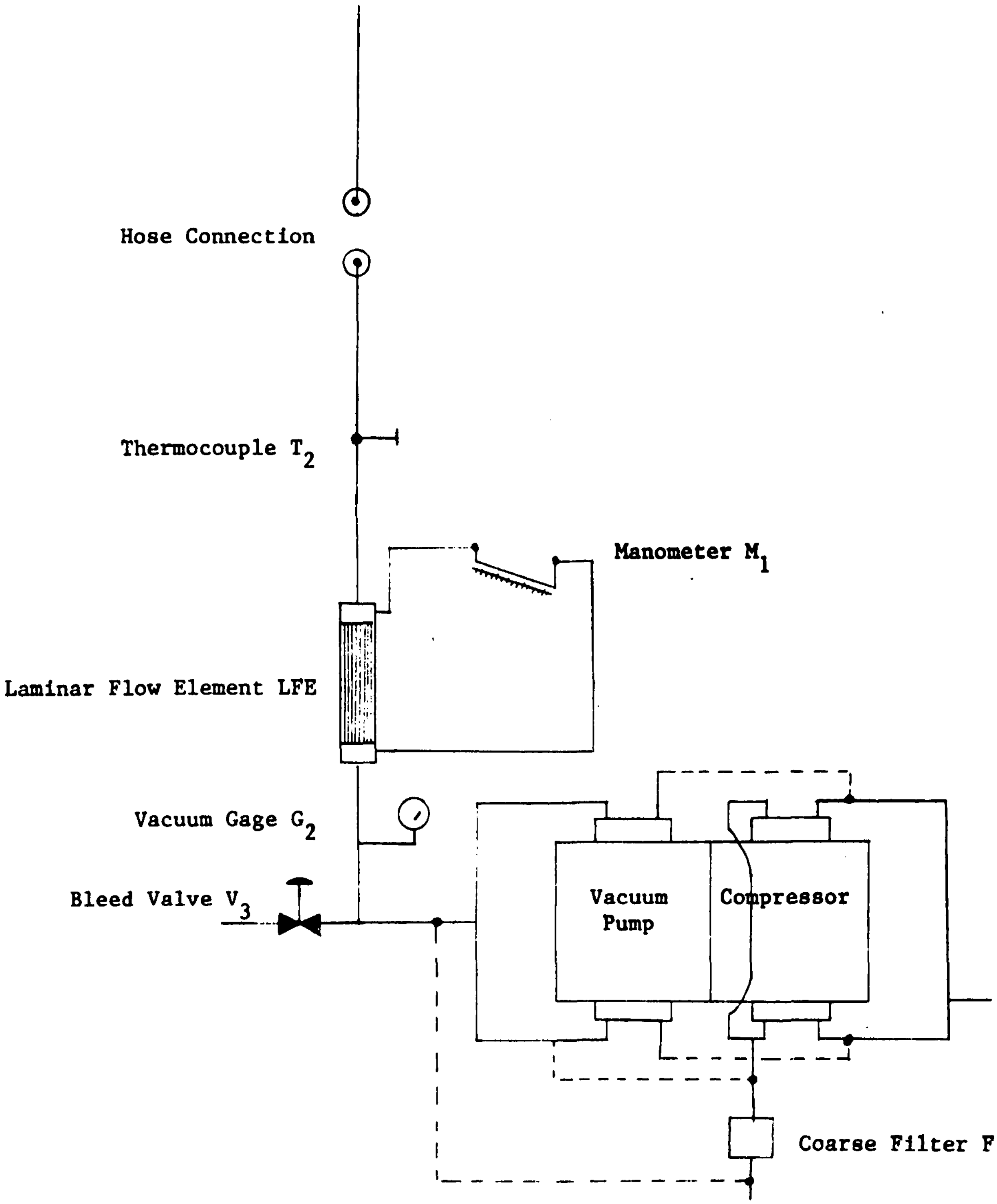


Figure A-5. Suction line diagram.

the pressure drop across a Meriam laminar flow element (LFE) as measured by a 0 to 3 in. water inclined tube manometer (M_1). The output of the pump and the intake are adjusted by the use of two bleed valves (V_1 and V_2, respectively). The relative amounts of the transpiration air to the front and the back sections of the probe are adjusted by manipulation of the bleed valve (V_1) and the proportioning valve (V_3). A pressure gage (G_1), is provided for measuring the pressure at the inlet of the flowmeter (R_1) and a vacuum gage (G_2) is provided for measuring the vacuum at the inlet of the laminar flow element.

Three flexible rubber hoses are provided to connect the sampling probe to the control box. An iron-constantine thermocouple (T_1) is used to measure the temperature at the inlet of the flow meter. Another thermocouple (T_2) is used to measure the temperature at the inlet to the laminar flow element. A jack for connecting thermocouple (T_3) which monitors the stack temperature is provided on the right side panel of the box. The air supplies for the front and rear sections are connected to the probe via hoses which are attached to the outlets on the right side panel of the control box. Provisions for power connections, a switch, power for heaters and fuses are provided on the same panel. A pipe connection is provided to attach the suction line to a collection device such as a glass fiber filter holder, using appropriate fittings. The heaters are shown in Figure A-6. A list of components and specifications is given in Table A-1.

3. PREPARATION OF THE PROBE

1. Select sampling nozzle. Suggested nozzles:

	Velocity (FPM)
N_1 - 1/4" I.D.	> 3,000
N_2 - 3/8" I.D.	1,000 - 3,000

2. Screw the nozzle and washer on the front section, FS.
3. Connect the air hoses to the front and back transpiration air supply (2-1/4" Swagelok® connectors).
4. Connect the hoses and heaters (if used) to the Swagelok® fittings for front and rear transpiration sections.
5. Connect the power cord to a standard 3 prong, 115 volt outlet, and to the control box.
6. The transpiration air may be heated by plugging the heaters into the receptacles on the right side panel after the air flow has started. (Note: The heaters should be on only while the air is flowing through them to prevent damage to the heating elements.)
7. Connect the probe to the measuring device or a sampling collector.

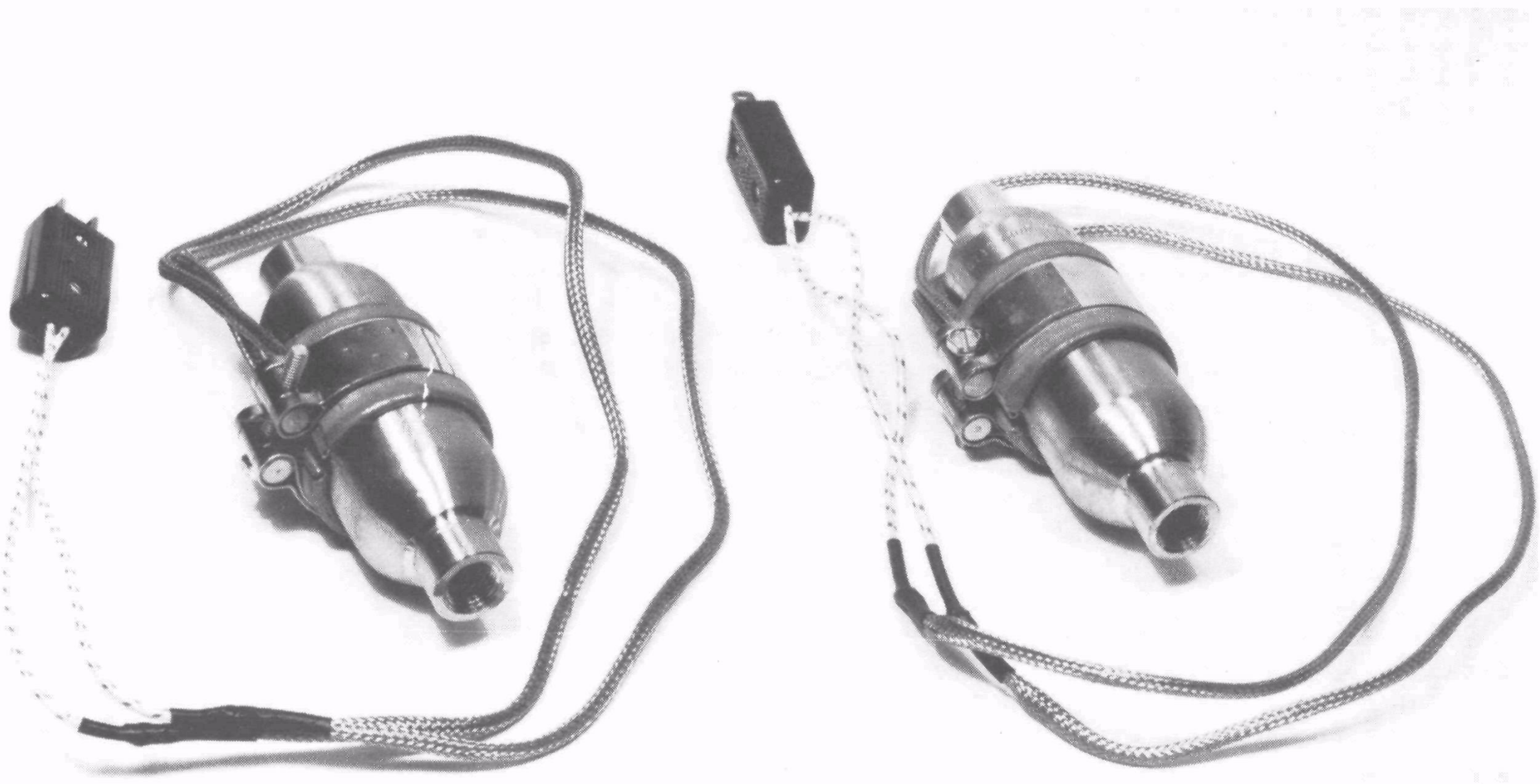


Figure A-6. Heater assemblies.

TABLE A-1. COMPONENTS OF THE SAMPLING INTERFACE

Symbol	Description	Manufacturer and Model	Capacity and Specifications
F_1	Coarse Filter		5 cfm
G_1	Pressure Gage	U.S. Gage Co., P844U	0-15 psi, 2-1/2", Spec. 138010
G_2	Vacuum Gage	U.S. Gage Co., P844U	0-30 in. Hg, 2-1/2", Spec. 138011
H_1	Front Section Heater	Chromalox: MB1J1JA3	250 watts
H_2	Rear Section Heater	Chromalox: MB1J1JA3	250 watts
LFE	Laminar Flow Element	Marion, 50MW 20-1-1/2"	0-24 cfm
M	Inclined Tube Manometer	Dwyer, 209ST	0-3 in. H_2O
N_1,N_2	Sampling Nozzles	Shop Fabricated	1/4 and 1/8 in. I.D.
R_1	Rotameter	Dwyer, Ratemaster, RMB-105	60-600 cfh
R_2	Rotameter	Dwyer, Ratemaster, RMB-54	20-200 cfh
S_1	Power Switch		SPST 10 Amp.
S_2	Thermocouple Switch		
T_1	Air Supply Thermocouple	Omega	I-C type, SS sheathing
T_2	Suction Thermocouple	Omega	I-C type, SS sheathing
T_3	Stack Thermocouple	Omega	I-C type, SS sheathing
V_2	Proportioning Valve	Hoke, Ball Valve 7115F4B	1/4" npt.
V_3	Vacuum Bleed-off	Hoke, Needle Valve 3312F4B	0-7 cfm air pump
P	Combination Vacuum and Compressed Air Pump	Thomas Model 4908 CA18	0-7 cfm vacuum pump

8. If using the vacuum side of the pump, VP, for pulling the flow through a measurement device or a sample collector, it is connected using the third fitting on the right side panel.

9. Level and zero manometer M_1.

4. OPERATION OF THE PROBE

1. Fixed rate sampling:*

A. Convert the desired sample rate to standard conditions.

$$SFR\ (scfm) = SFR\ (acfm) \times \frac{530\ P_s}{T_s \times 29.92}$$

where SFR = sample flow rate, P = stack pressure in (Hg), T_s = stack temperature, °R (460 + F).

B. Choose the transpiration flow rate and convert it to standard conditions.

$$TFR\ (scfm) = TFR\ (acfm) \times \frac{530\ (P_o + 14.7)}{14.7\ T_o} \times f_1 \times f_2$$

where TFR = transpiration flow rate, P_o = operating pressure (psig), and T_o = operating temperature, R = (460 + T_1). f_1 and f_2 are obtained from Tables A-2 and A-3.

C. Calculate total flow.

$$Q_t\ (scfm) = SFR\ (scfm) + TFR\ (scfm)$$

D. Start the transpiration air flow through the probe and place the probe tip in the stack with the nozzle tip pointing in the opposite direction to the flow.

E. Determine the required $\Delta P'$ across the laminar flow element from the calibration curve in the separate manual supplied with each unit corresponding to 1.1 x Q_t.

F. Adjust vacuum bleed valve V_3 until the $\Delta P'$ on manometer M_1 across the laminar flow element is equal to $\Delta P'$ as determined in Step E.

G. Read P_f (in Hg) on vacuum gage, G_2, and T_2.

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* English units are used in this section to be compatible with the output of the control box instrumentation.

TABLE A-2. PRESSURE CORRECTION FACTOR FOR DWYER FLOWMETER

P_o-Operating Pressure, psig	Correction Factor, pcf
0	1.000
1	0.9676
2	0.9382
3	0.9113
4	0.8866
5	0.8638
6	0.8427
7	0.8230
8	0.8047
9	0.7876
10	0.7714
11	0.7563
12	0.7420
13	0.7285
14	0.7157
15	0.7035
16	0.6920
17	0.6810
18	0.6705
19	0.6604
20	0.6509

TABLE A-3. TEMPERATURE CORRECTION FACTOR FOR DWYER FLOWMETER

T_1-Temperature, °F	Correction Factor, f_2
0	0.932
10	0.942
20	0.952
30	0.962
40	0.971
50	0.981
60	0.991
70	1.000
80	1.009
90	1.018
100	1.028
110	1.037
120	1.046
130	1.055
140	1.064
150	1.072

H. Read P_{cf} and T_{cf} from Tables A-4 and A-5.

I. Divide Q_t by P_{cf} and T_{cf}.

J. Read ΔP corresponding to Q_t/P_{cf}, if different from $\Delta P'$ adjust ΔP by means of valve V_2.

K. If the P_f and T_f change significantly, i.e. temperature by more than 10° and pressure by more than 1 in. Hg, readjust the flow by repeating Steps G through J.

NOTE: If sampling near 70°F, the total flow may be set prior to insertion in the sample stream by connecting a wet test meter to the inlet of the sampling nozzle.

2. Isokinetic sampling (single point):

A. Determine the velocity (ft/min) at the sampling point.

B. Calculate the sample flow rate in acfm.

$$SFR\ (acfm) = V_s \times \text{Area of Nozzle}$$

Nozzle	Diameter (in.)	Area (ft^2)
N-1	1/4	0.000341
N-2	3/8	0.000767

C. Follow procedures described for fixed rate sampling.

3. Isokinetic sampling (multipoint):

A. Make a velocity traverse with a pitot tube.

B. Find the stack velocity at the sampling points.

C. Choose appropriate nozzle (see Section 3).

D. Calculate SFR.

E. Choose TFR and keep it constant for the entire sampling operation.

F. Obtain total sample flow rate at each point Q_1, Q_2, . . .

G. Set the ΔP across M_1 to $1.1Q_1$.

H. Adjust for P_{cf} and T_{cf}.

TABLE A-4. CORRECTION FACTOR FOR VACUUM GAGE READING: LAMINAR FLOW ELEMENT

Inlet Vacuum, in. Hg	P_{cf}
0	1.0000
0.5	0.9833
1.0	0.9666
1.5	0.9499
2.0	0.9331
2.5	0.9164
3.0	0.8997
3.5	0.8830
4.0	0.8663
4.5	0.8496
5.0	0.8329
5.5	0.8162
6.0	0.7995
6.5	0.7827
7.0	0.7660
7.5	0.7493

TABLE A-5. AIR TEMPERATURE CORRECTION FACTORS FOR SCFM AIR BASE TEMPERATURE 70°F, VISCOSITY 181.87 MICROPOISE, REFERENCE NBS CIRCULAR 564

$$\text{Tef} = \text{CORRECTION FACTOR} = \frac{529.67}{459.67 + {}^{\circ}\text{F}} \times \frac{181.87}{\mu g^*}$$

μg^* Viscosity of Air at Flowing Temperature

Temp. °F	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
50	1.0707	1.0670	1.0633	1.0596	1.0559	1.0523	1.0487	1.0451	1.0415	1.0379
60	1.0344	1.0308	1.0273	1.0238	1.0204	1.0169	1.0135	1.0101	1.0067	1.0033
70	1.0000	0.9966	0.9933	0.9900	0.9867	0.9834	0.9802	0.9770	0.9737	0.9705
80	0.9674	0.9642	0.9611	0.9579	0.9548	0.9517	0.9486	0.9456	0.9425	0.9395
90	0.9365	0.9335	0.9305	0.9275	0.9246	0.9216	0.9187	0.9158	0.9129	0.9100
100	0.9072	0.9043	0.9015	0.8987	0.8959	0.8931	0.8903	0.8875	0.8848	0.8820
110	0.8793	0.8766	0.8739	0.8712	0.8686	0.8659	0.8633	0.8606	0.8580	0.8554
120	0.8528	0.8503	0.8477	0.8452	0.8426	0.8401	0.8376	0.8351	0.8326	0.8301
130	0.8276	0.8252	0.8227	0.8203	0.8179	0.8155	0.8131	0.8107	0.8083	0.8060
140	0.8036	0.8013	0.7990	0.7966	0.7943	0.7920	0.7898	0.7875	0.7852	0.7830
150	0.7807	0.7785	0.7763	0.7741	0.7719	0.7697	0.7675	0.7653	0.7632	0.7610

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(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

Three quantitative sampling transport probe and control box sampling systems were designed and fabricated. The systems are designed to permit the transport of samples of aerosols from a source to a sensor without significant modification of mass rate and size distribution of the sample aerosols. Descriptions of the systems are given. An operating manual is included. Results of functional tests demonstrated that the systems operate as designed with the exception of pumping rates.

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