BAW-1280-29

MODEL TESTS OF THE SODIUM DISTRIBUTOR FOR THE SODIUM HEATED STEAM GENERATOR

AEC CONTRACT AT(11-1)-1280

ORDER NO. 4028-01 FILE 14K2

RESEARCH REPORT NO. 4475

BY: G. D. LINDSTROM

AUGUST 5, 1965

RESEARCH DEVELOPMENT B&W

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MODEL TESTS OF THE SODIUM DISTRIBUTOR FOR THE SODIUM HEATED STEAM GENERATOR

by: G. D. Lindstrom

ABSTRACT

PURPOSE

The objectives of this program were to develop a sodium distributor that provides uniform flow distribution entering the superheater and a flow pattern that does not result in high velocity fluid impingement on tube surfaces. It was also necessary to determine the general extent of cover gas entrainment and establish a minimum liquid level for acceptable performance.

BRIEF OF TESTS

Performance tests were conducted with water in a 1/3.23 scale plastic model. Because of the requirements for similitude in modeling, subsurface and surface flow conditions had to be studied separately rather than simultaneously. Also, the distributor had to be proof-tested in two slightly different physical environments to match those in the prototype steam generator. Water flow distribution was determined by velocity measurements, visual observation and photographic records. Pressure drop data was obtained where necessary.

RESULTS AND CONCLUSIONS

A distributor arrangement was developed that performed satisfactorily in the water model. This distributor will meet the requirements set forth for the prototype steam generator. This conclusion is justified because of the adherence to model scaling criteria during the program.

RECOMMENDATIONS

It is recommended that:

(1) The distributor arrangement developed in the test program be installed in the prototype steam generator.

(2) The sodium level be kept at least 10 inches above the distributor discharge plane in the prototype steam generator.

(3) Before installation of this distributor in the full-size steam generator, model tests be conducted to establish the proper number and placement in the superheater annulus.

Report No. 4475, File 14K2, ON-4028-01
August 5, 1965
MODEL TESTING - Sodium Distributor

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FIGURES

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INTRODUCTION

The test work described in this report is related to a B&W Contract from the Atomic Energy Commission to develop a large sodium-heated steam generator of improved design. This steam generator is to be available for use in the AEC Sodium Reactor Development Program which has the overall objective of developing reliable, economical, large central station nuclear power plants. The contract calls for designing of a prototype steam generator with associated Research & Development work.

To assure satisfactory performance and trouble-free operation of sodium-heated steam generators, uniform distribution of sodium over the heat transfer surface is considered essential. High local velocities from the distribution system can cause vibration and wear failures of superheater tubes. To prevent such failures, the incoming sodium must be distributed uniformly over the full circumference of the tube bundle while reducing the high velocity of the sodium in the downcomer pipe to the relatively low velocity of the sodium in the tube bundle. In addition to this, the incoming sodium must be distributed into the sodium pool with a minimum of surface disturbance to prevent carrying cover gas down into the steam generator and eventually into the sodium pumps.

In connection with the development of sodium-heated steam generators, the Fluid Mechanics Section of the Alliance Research Center undertook the development of a sodium distributor using water-modeling techniques. This development began in January of 1965.

The objectives of the program were as follows:

a) Develop a sodium distributor arrangement that provides uniform distribution entering the superheater as determined by visual inspection of the model and photographic records.

b) Establish visually and photographically that the distributor does not result in high-velocity impingement on tube surfaces that might lead to vibration problems.

c) Determine visually the general extent of cover gas entrainment and establish a minimum liquid level for acceptable performance from this standpoint.

The prototype steam generator arrangement is shown on Figure 1. Its design is such that the superheater section can be modeled by itself without regard to the remainder of the steam generator. Also, the superheater tube supports are arranged so that they form solid barriers that separate the superheater section into four distinct 90° quadrants for sodium flow, each having its own sodium downcomer pipe and distributor.

In the full-sized steam generator the superheater is also separated by the supports; however, there are eight 45° sectors instead of the four shown in the prototype.

In the tests covered by this report, the model simulated a 90° sector of the prototype superheater section at a prototype-to-model scale ratio of 3.23.

RESULTS

1. The distributor shown in Figure 19 provided relatively uniform water distribution in the model with no high-velocity jets in the region of the tube bundle (Figures 20 and 21).
2. The model distributor did not create surface disturbances to entrain the air cover gas if the water level was maintained at least 1½ inches above the distributor discharge plane (Figure 22).
3. The final distributor with only a minor alteration (Figure 19) operated satisfactorily both in the full and reduced sectors, as shown in Figure 22.

CONCLUSIONS

1. The distributor shown in Figure 24 will provide relatively uniform sodium distribution within the superheater annulus of the prototype steam generator with no high-velocity impingement on the superheater tubes. This conclusion is justified because at $V_m = 1.8\ V_p$*, the Reynolds number ratio (Re_p/Re_m) was sufficiently close to unity to ensure that the subsurface flow conditions of the prototype will be similar to those in the model.
2. The prototype sodium distributor will result in a relatively calm surface and cause no cover gas entrainment if the sodium level is maintained at least 10 inches above the sodium discharge plane. This conclusion is justified because at $V_m = 0.55\ V_p$ the Froude number ratio (Fe_p/Fr_m) was unity. This will ensure that the surface conditions of the prototype will be similar to those in the model.
3. The sodium distributor shown in Figure 19 can be readily extrapolated to larger or smaller sizes according to Figure 24. Because of the different configuration of the superheater section of the full-size steam generator, the number and placement of the sodium distributors may differ from that used in the prototype. The distributor design, however, will remain essentially the same.

RECOMMENDATIONS

It is recommended that:

1. The distributor shown in Figure 24 be installed in the prototype steam generator.

---

*V_p = Sodium Velocity in each Prototype Downcomer - 11.7 ft/sec @ 145,750 lb/hr (full load)

V_m = Water Velocity in the Model Downcomer

2. The sodium level be kept at least 10 inches above the distributor discharge plane.
3. Before installation of this distributor in the full-size steam generator, model tests be conducted to establish the proper number and placement in the superheater annulus.

DESCRIPTION OF TEST EQUIPMENT

Since the operation of any distributor is dependent on the configuration of its surroundings, a model of the superheater annulus had to be constructed. As stated in the Introduction, it was permissible to limit investigations to a 90° sector with a single downcomer rather than to model the full annulus and its flow distributors. It was necessary, however, to obtain satisfactory results of the distributor operation both in a full 90° sector and a 90° sector with 30° at one end of the sector occupied by riser tubes (Figure 3).

A water model of a 90° sector and a distributor with its downcomer pipe was built to a scale ratio $(\frac{\text{prototype}}{\text{model}})$ of 3.23. A removable bundle of tubes was used to simulate either the full-open sector or the reduced sector as required.

The dimensions used to locate the distributor with respect to the water level and the tube bundle were chosen as the minimum that would be found in the prototype (Figure 3).

The test apparatus shown in Figure 2 was an open loop with water being pumped through the model to a drain. The water flow was controlled by a hand valve and measured by a rotometer. The model outlet was throttled to hold the simulated sodium level as required.

To match the gas-liquid density ratios of the prototype steam generator, the model was constructed so that it could be pressurized to 5 psig. This pressure was measured with a Bourdon-tube pressure gage.

Velocity measurements within the model were made with a miniature turbine meter as shown in Figure 4.

TEST PROCEDURE

In the development of the sodium distributor, several factors had to be investigated. Because of the requirements for similitude in modeling, subsurface flow conditions and surface flow conditions of the distributor had to be studied individually rather than simultaneously. More specifically, viscosity and gravity effects had to be studied at different flows. The calculations and explanation for this requirement are given in the Appendix.

To test a given arrangement after it was installed in the model, three conditions had to be set simultaneously. These were flow rate, cover gas pressure, and liquid level. The flow rate and liquid level were controlled by inlet and outlet valves, respectively, while a pressure regulator was set to maintain the cover gas pressure.

The objectives set forth in the Introduction were the controlling criteria in judging distributor performance. The performance characteristics of a distributor design were determined visually, with photographic records being made where appropriate. With air bubbles or plastic tracer, it could be determined if there were any high-velocity jets that might cause erosion and/or vibration of the tube bank. The amount of surface disturbance at maximum and minimum levels was observed along with the presence or absence of cover gas carry-under.

For the more promising arrangements, pressure-drop data were recorded at various flows. For these measurements, static pressure was recorded at a set location in the inlet pipe. The difference between this static pressure and that obtained for an open-end pipe at the same flow conditions gave the distributor pressure drop, excluding pipe friction.

A velocity profile for final arrangements was obtained at the tube bank level with the meter described under Test Equipment.

DISCUSSION

As in all modeling work, the test program and flow conditions were established on the basis of similarity ratios. The variables were examined with the test objectives in mind in order to specify the parameters to be investigated. A detailed discussion of these parameters and an evaluation of each is given in the Appendix.

To match the similarity ratios, it was necessary to study the conditions controlled by the surface parameters and the subsurface parameters separately. To investigate subsurface flow patterns, the model was operated at the maximum flow rate possible with the existing facilities. This resulted in a downcomer velocity equal to 1.8 times the full-load prototype velocity. The model Reynolds number at these conditions was 1.82×10^5 which is 14.5% of that for full-load flow in the prototype. Despite the lower Reynolds number in the model, the flow conditions in the prototype will be similar, since both the model and the prototype flows are well into the turbulent zone (see Appendix, page iv - "Viscosity Control" for substantiating statements and data).

The similarity criterion relating inertial and gravity effects with the behavior of the liquid surface is the Froude group. For the model Froude group to match that of the prototype, it was necessary to establish the flow such that $V_m = .55\ V_p$. Tests were conducted to satisfy this requirement.

One other condition required simulation. In the prototype, argon cover gas is pressurized to 20 psig. To simulate this, the model was pressurized to 5 psig to establish the same gas-to-liquid density ratios as the prototype.

For these criteria, the development of a satisfactory distributor was accomplished in the steps discussed below.

The first step in the development was a test of the very simple cylindrical distributor shown in Figure 5 to determine the magnitude of the problem. Results of these tests showed high-velocity subsurface jets with disturbed surface conditions and excessive air entrainment at reduced liquid levels as shown on Figure 5.

Following this, an arrangement utilizing a horizontal distributor pipe was designed and tested. As deficiencies in this design became apparent, modifications were made to correct them. This resulted in arrangement 6H, which performed satisfactorily in the full sector (Figure 13). The individual steps involved are shown in Figures 6 through 12, and detailed remarks concerning the performance of each arrangement are given in Tables 1 and 2.

While arrangement 6H performed satisfactorily in the full sector, when reduced in size to fit into the reduced sector the resulting velocities became proportionately higher. These higher velocities confined in a smaller space resulted in excessive surface disturbances and subsurface jets.

Preliminary investigations were made of several alternative types of distributors. These are shown in Figures 15, 16, and 17, and the performance of each is described in Tables 3 and 4. The most promising of these, the diffuser-type shown in Figure 17, was thoroughly analyzed. Minor modifications were needed to correct some of its deficiencies, and these are shown in Figures 17 and 18 with comments on performance in Tables 4 and 5. The modifications included breaking the diffuser about its vertical centerline and assembling with an included angle of 160^{o} between the two halves to provide a better fit in the curved sector. This was necessary to provide flow patterns that did not induce eddy currents beneath the distributor. Another modification that was necessary was the use of perforated end plates, when the distributor was operating in the full sector, and solid end plates, when operating in the reduced sector (Figure 19). The solid end plates prevented tube impingement, and the perforated end plates allowed the fluid to fill the full sectors. The final diffuser with modifications as shown in Figure 19 meets the design criteria specified at the onset of the program.

The subsurface flow patterns of the model at the maximum flow obtainable ($V_m = 1.8\ V_p$) are shown in Figure 20. The velocity data shown in Figure 21 verify the visual results shown in Figure 20.

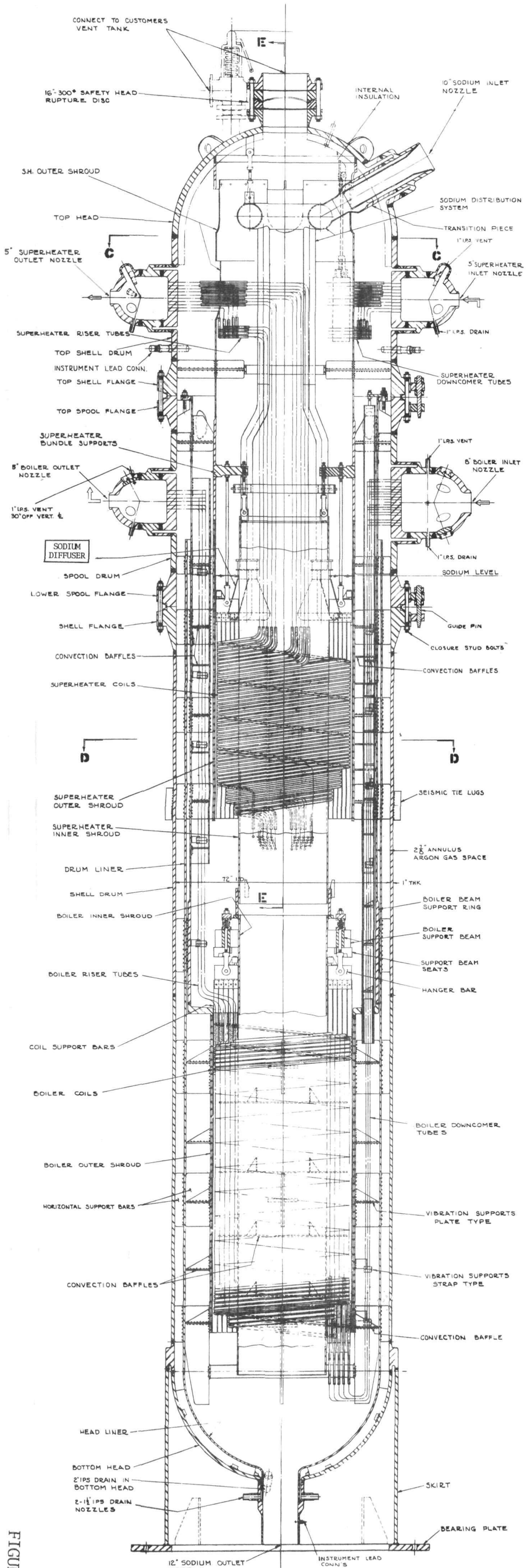
The surface conditions are shown to be calm in Figure 22. The conditions for these photographs are those that were used to simulate the Froude number criteria ($V_m = .55\ V_p$). As can be seen, the lowest level of the fluid is 1½ inches above the distributor discharge plane. To provide some safety margin, however, it is recommended that in the prototype the liquid level be kept at least 10 inches above the discharge plane.

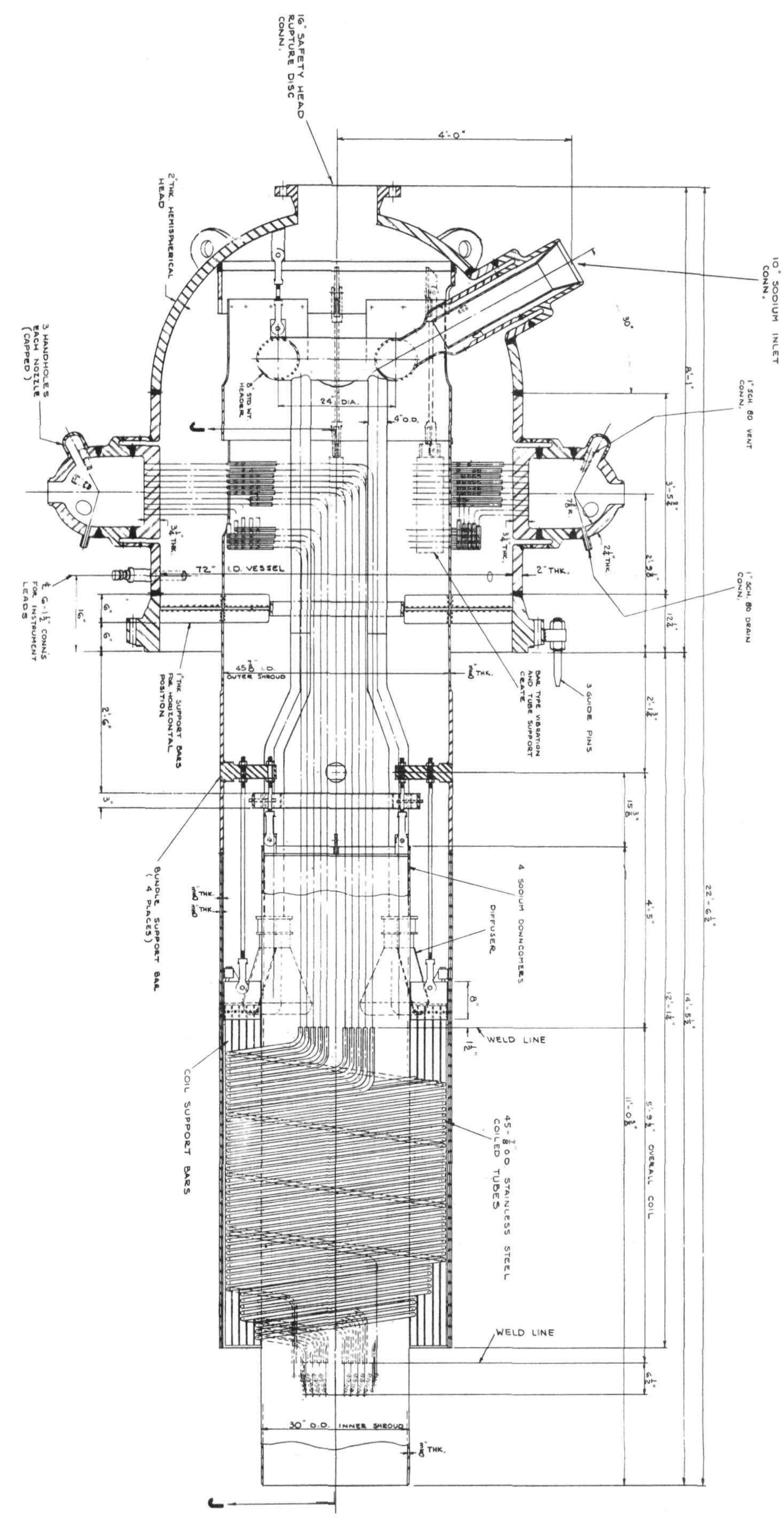
Pressure drop results for the model are shown in Figure 23 along with an extrapolated curve for the pressure drop through the prototype sodium distributor. It can be seen that at the nominal full-load flow there will be a pressure drop through the prototype distributor of 1.86 psi.

This distributor design is such that it can be readily extrapolated to larger and smaller sizes if needed. A detailed drawing of the prototype distributor to be used is shown in Figure 24. This same design can be used in the full-size steam generator; however, it will be necessary to investigate the number and placement of the distributors since the sectors in the full-size superheater annulus are different from those in the prototype.

Submitted by: G. D. Lindstrom (signature)
G. D. Lindstrom

Approved by: J. H. Kidwell (signature)
J. H. Kidwell

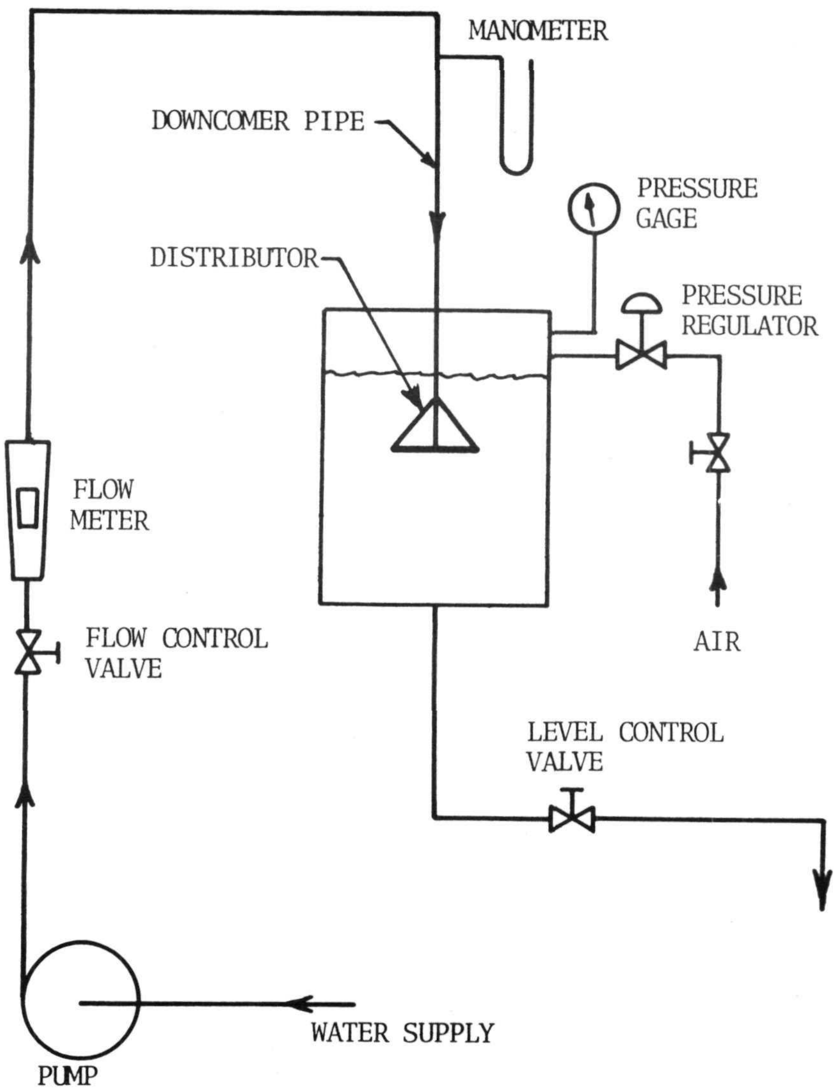




SUPERHEATER SECTION

FIGURE 1

PROTOTYPE SODIUM HEATED STEAM GENERATOR



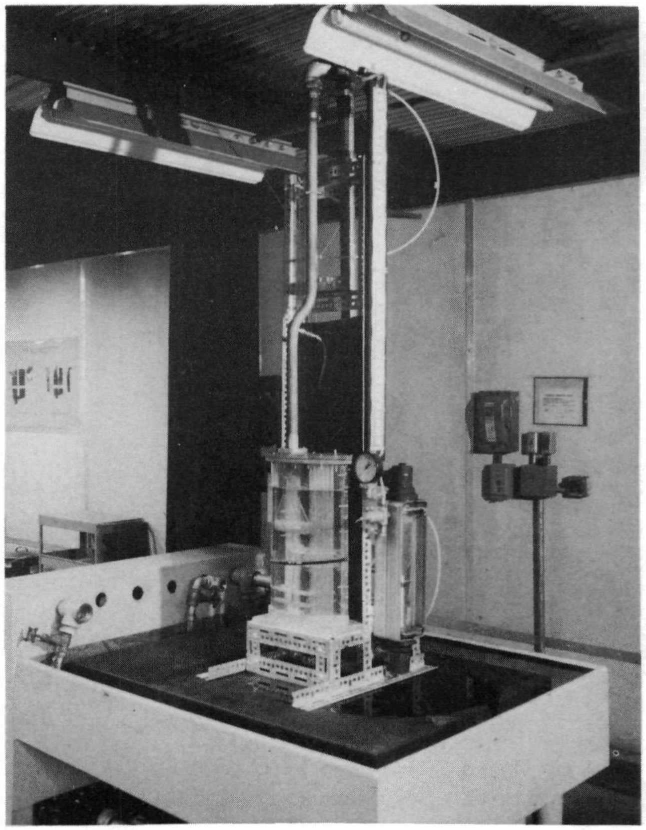


FIGURE 2

SCHEMATIC DIAGRAM OF TEST APPARATUS
FOR SODIUM DISTRIBUTOR FLOW TESTS

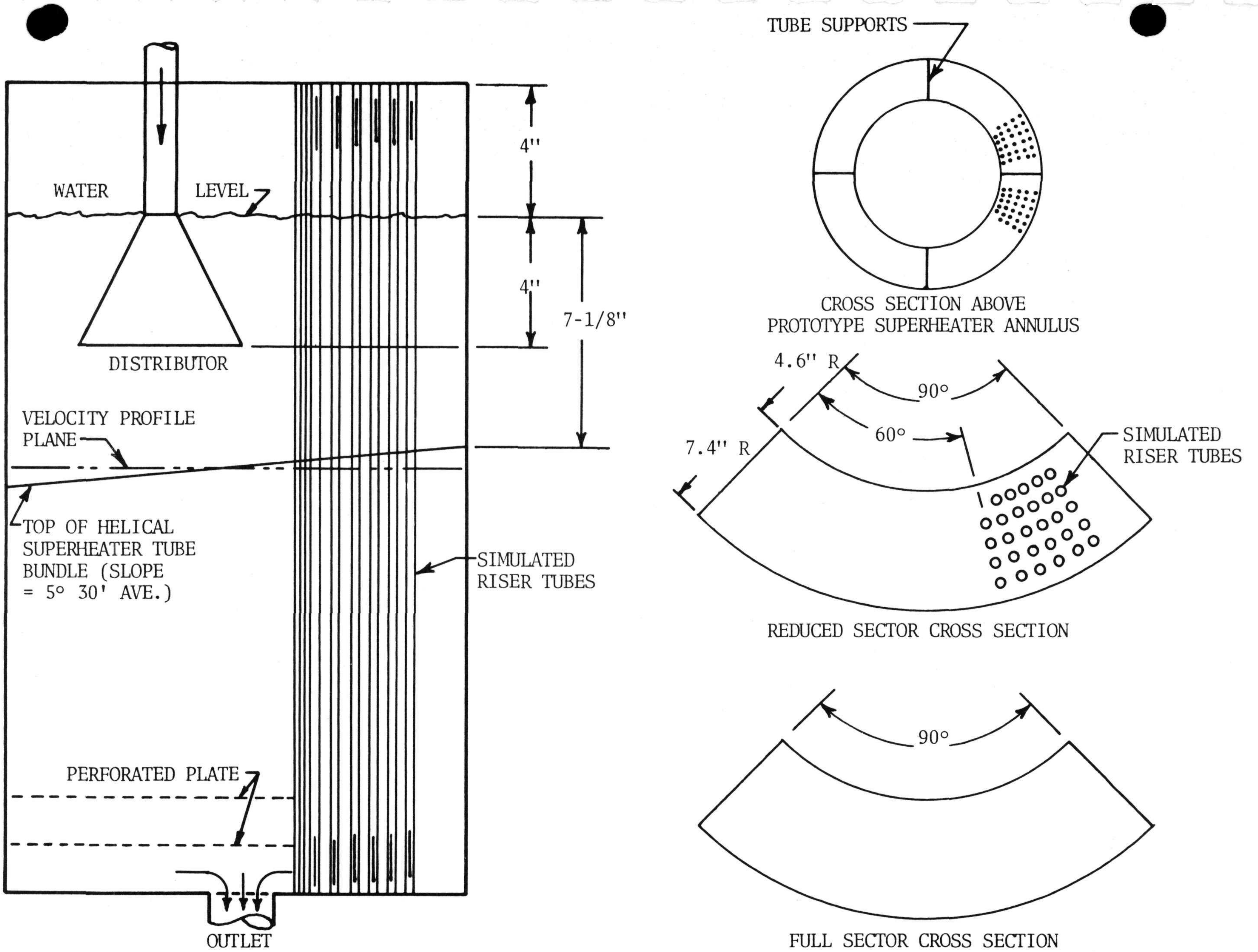
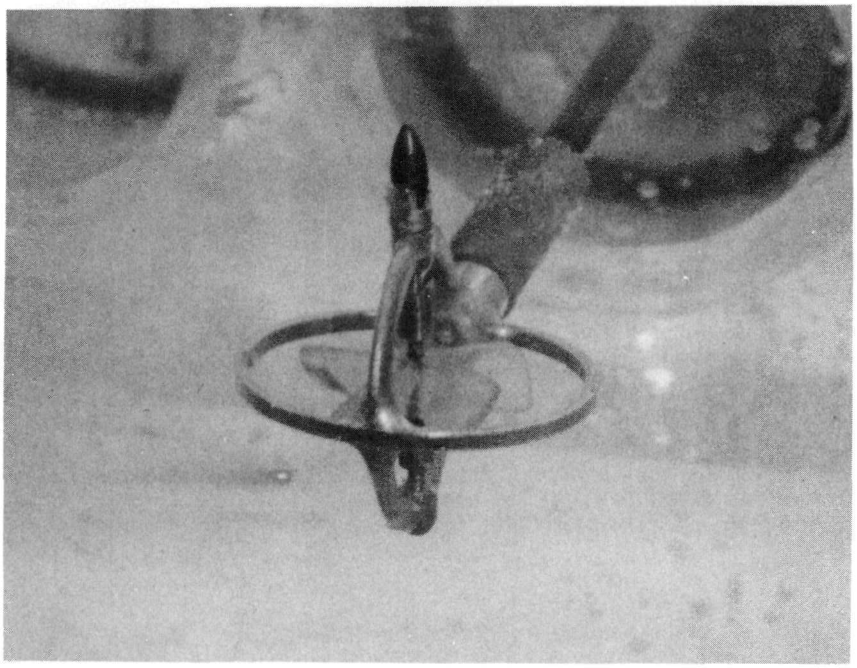


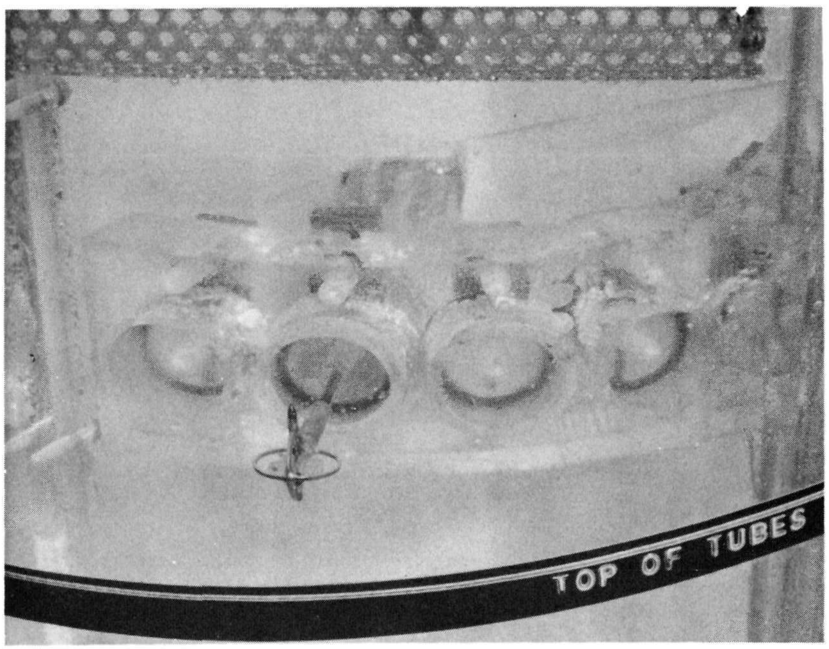
FIGURE 3

DRAWING OF MODEL 90° SECTOR OF SUPERHEATER ANNULUS



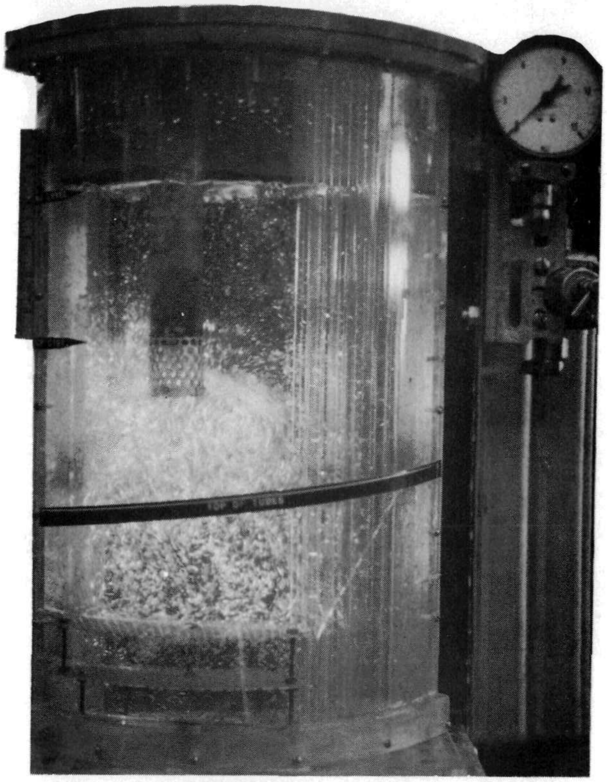
ENLARGED VIEW OF PROBE TIP
(DIAMETER ACROSS TURBINE BLADES = 0.4")

DISTRIBUTOR
DISCHARGE →

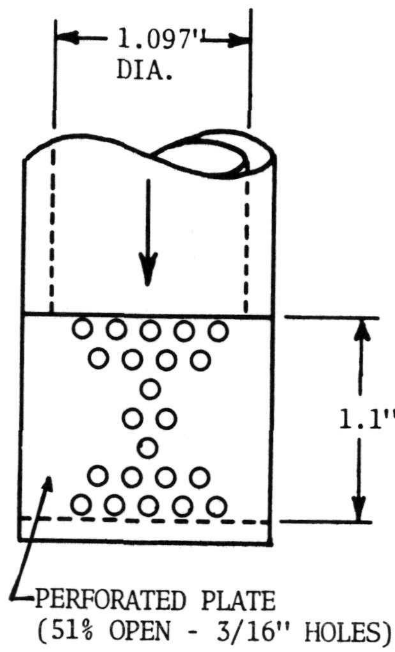


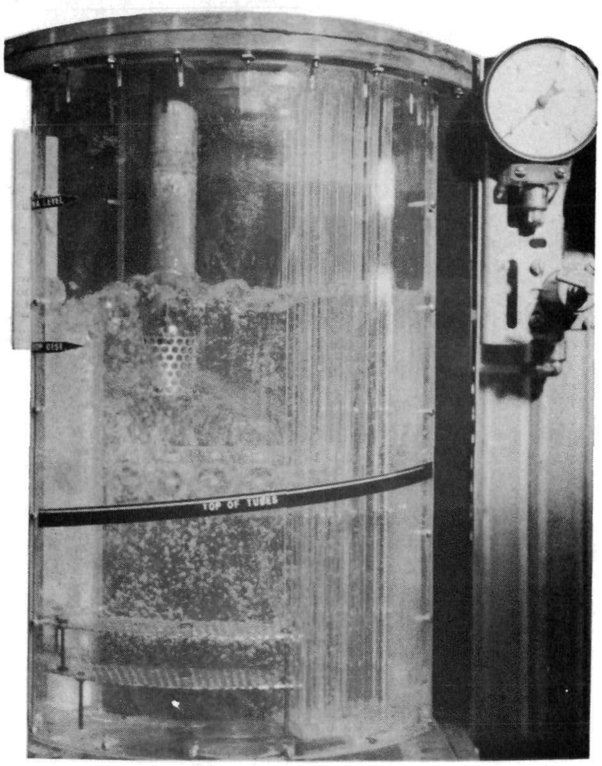
MINIATURE TURBINE METER VELOCITY PROBE USED
IN SUBSURFACE VELOCITY MEASUREMENTS

FIGURE 4

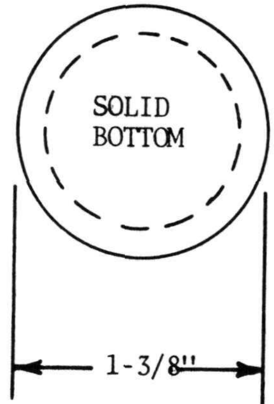


HIGH WATER LEVEL





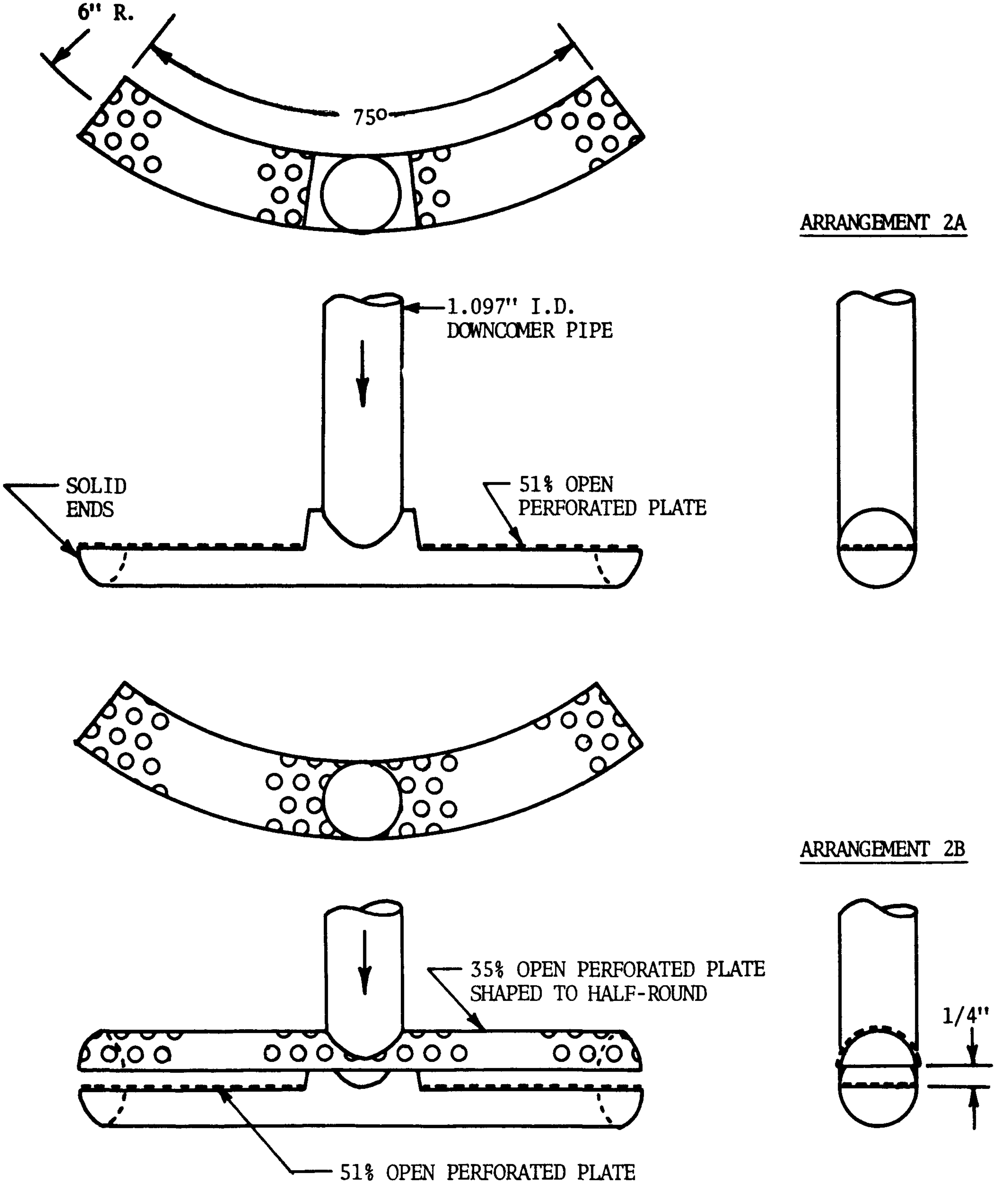
LOW WATER LEVEL



SURFACE AND SUBSURFACE CONDITIONS - ARRANGEMENT #1

$$V_m = V_p$$

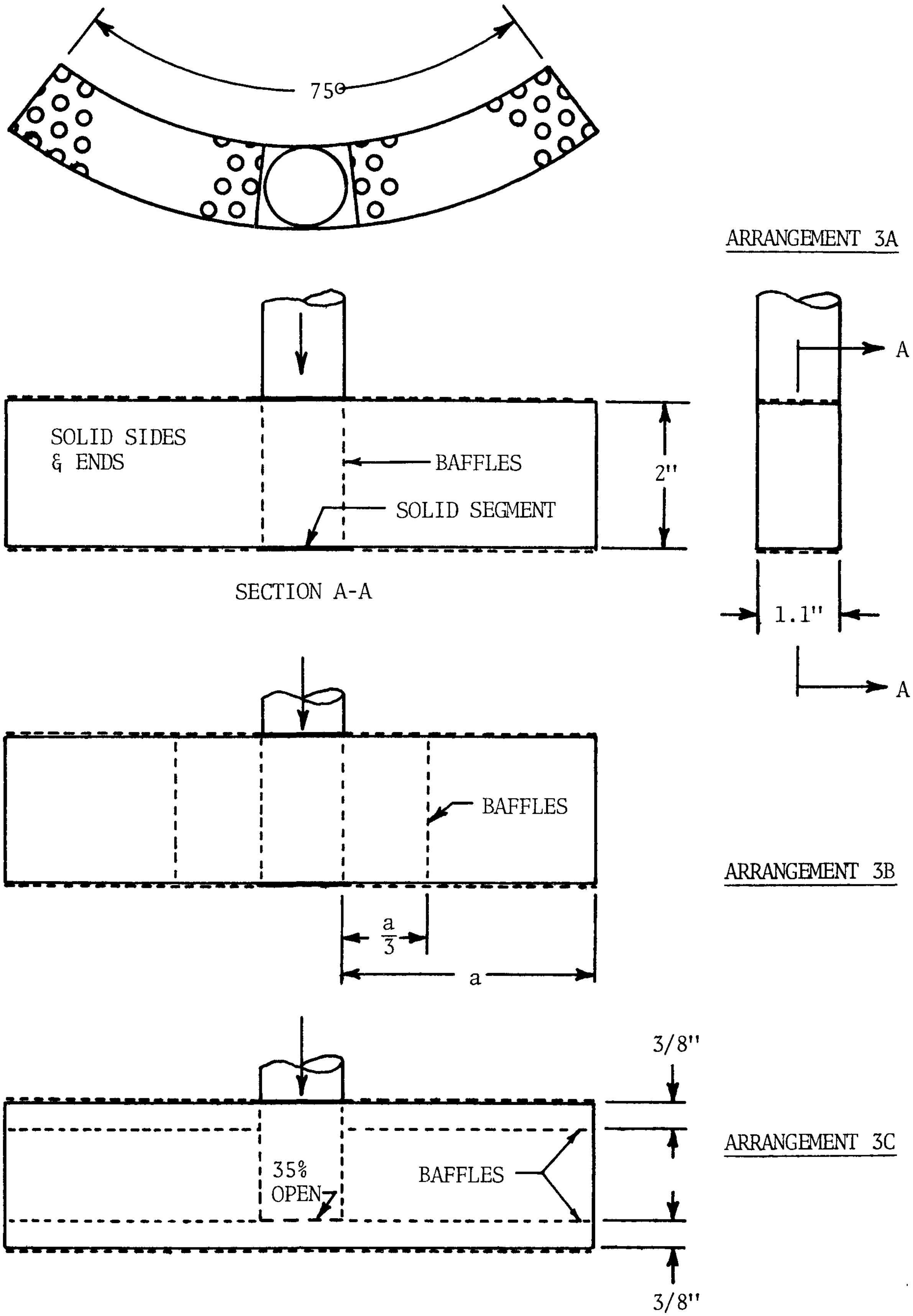
FIGURE 5



NOTE: EDGE VIEW OF PERFORATED PLATE IS DENOTED BY DASHED LINE.

ARRANGEMENTS 2A and 2B

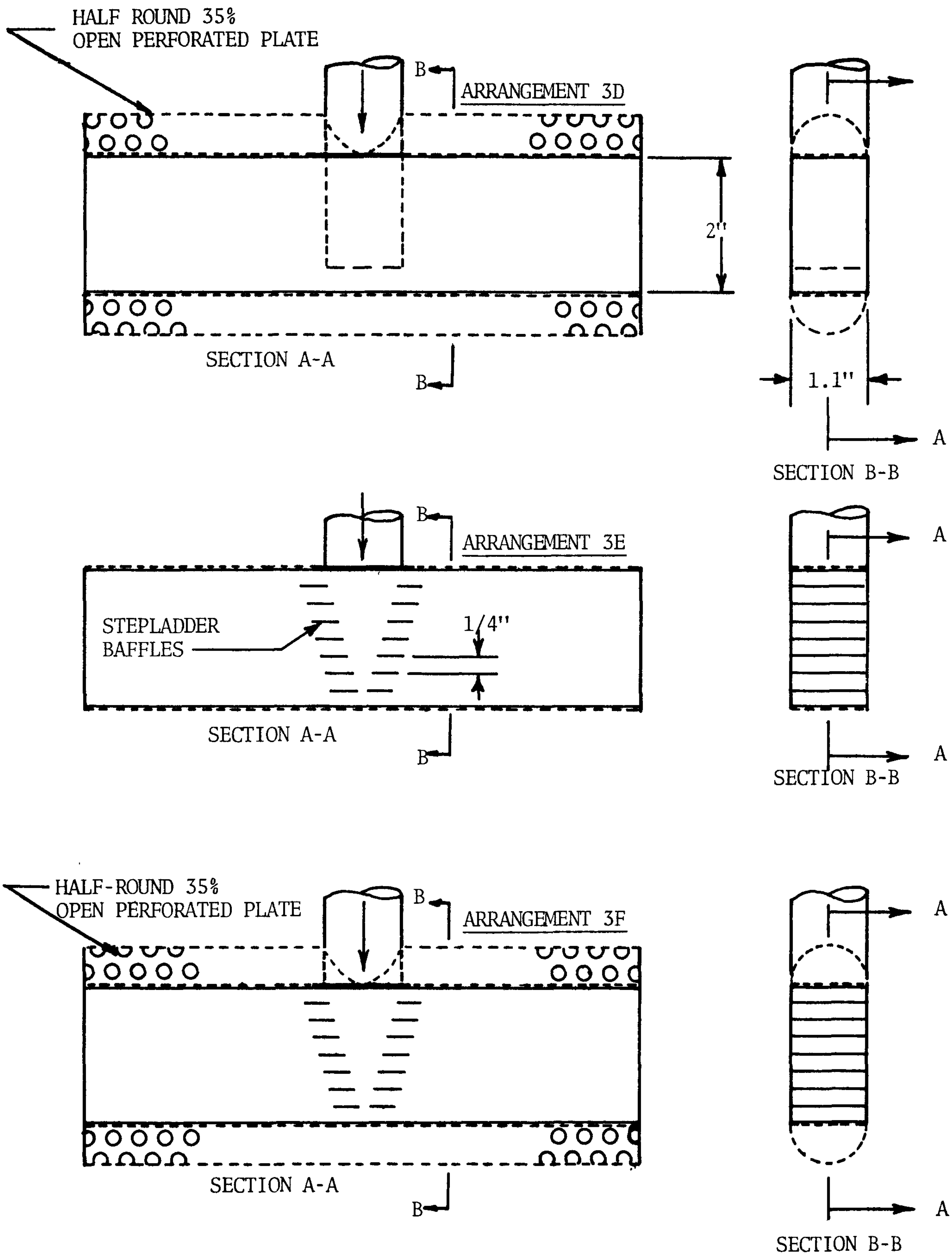
FIGURE 6



NOTE: ALL PERFORATED PLATE WAS 51% OPEN
UNLESS SPECIFIED OTHERWISE

ARRANGEMENTS 3A, 3B, and 3C

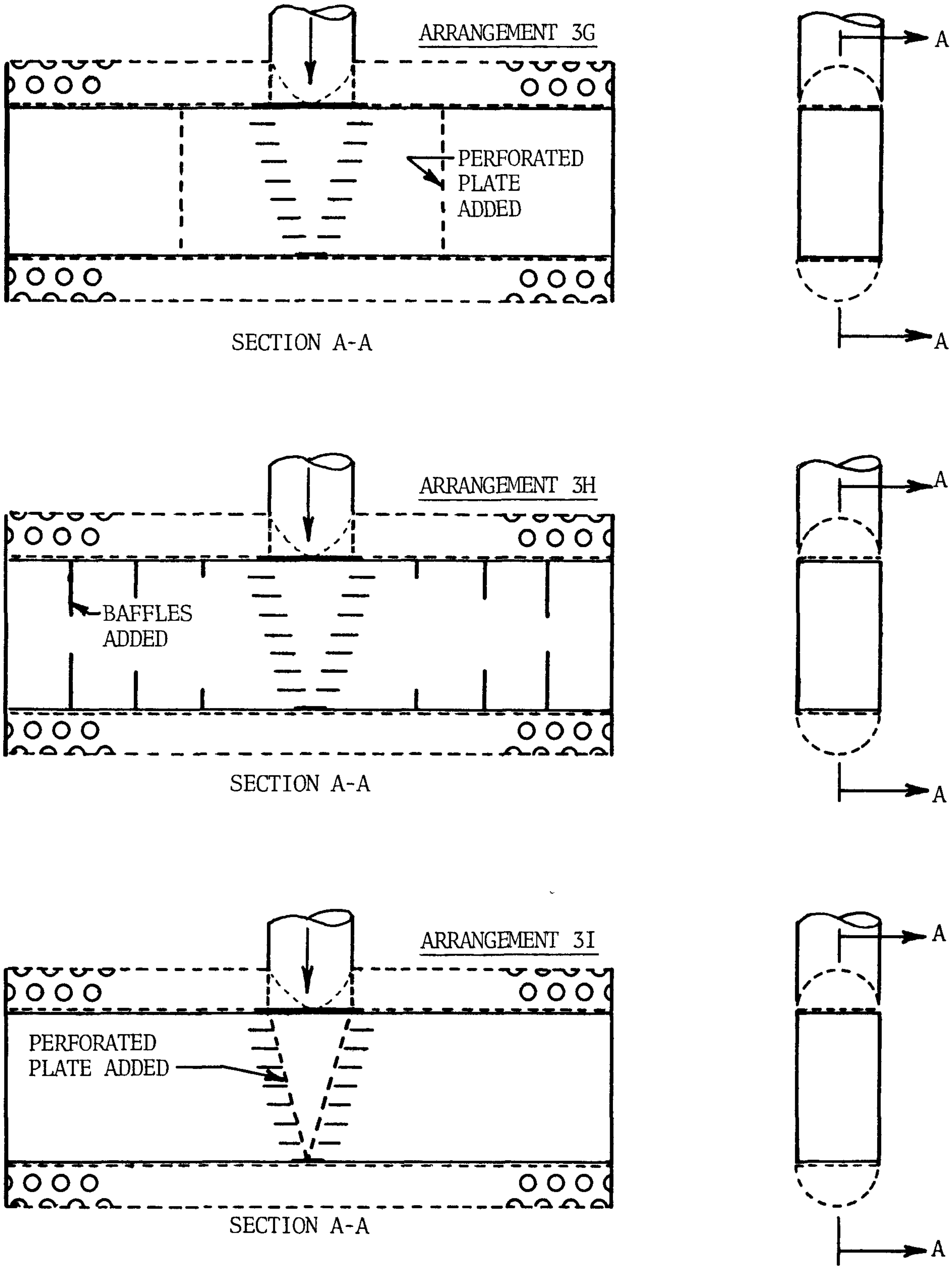
FIGURE 7



NOTE: ALL PERFORATED PLATE WAS 51% OPEN UNLESS SPECIFIED OTHERWISE

ARRANGEMENTS 3D, 3E, and 3F

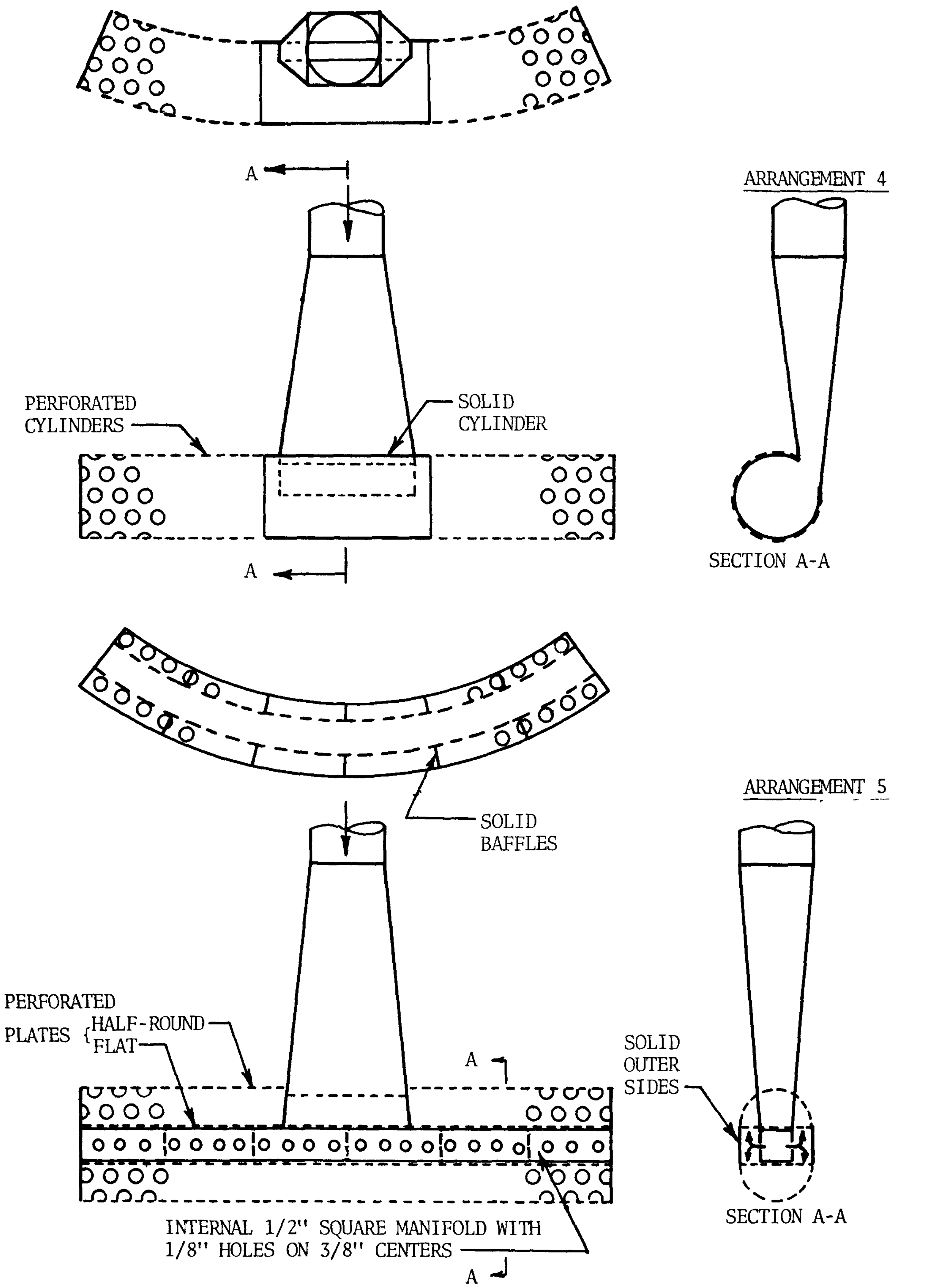
FIGURE 8



NOTE: ALL FLAT PERFORATED PLATE WAS 51% OPEN
ALL HALF ROUND PERFORATED PLATE WAS 35% OPEN

ARRANGEMENTS 3G, 3H, and 3I

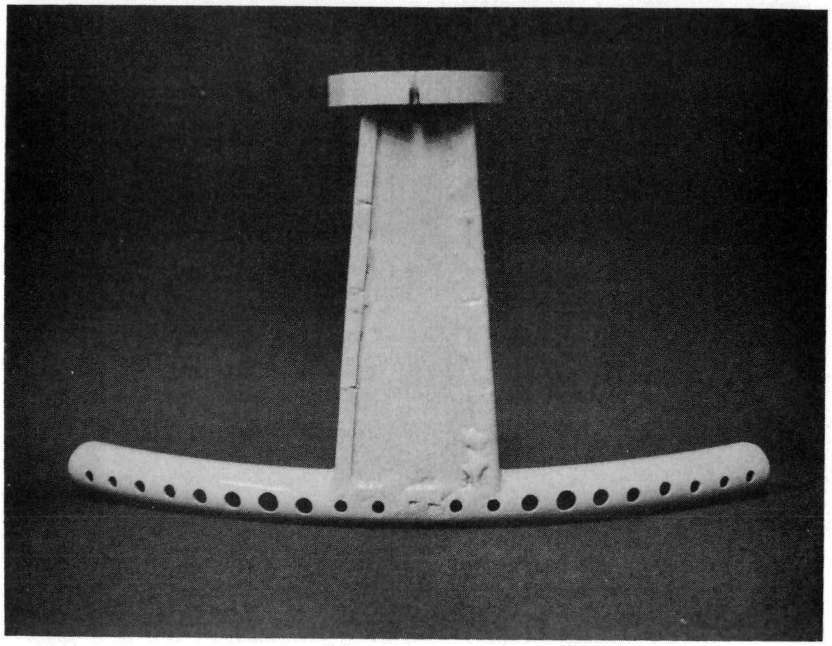
FIGURE 9

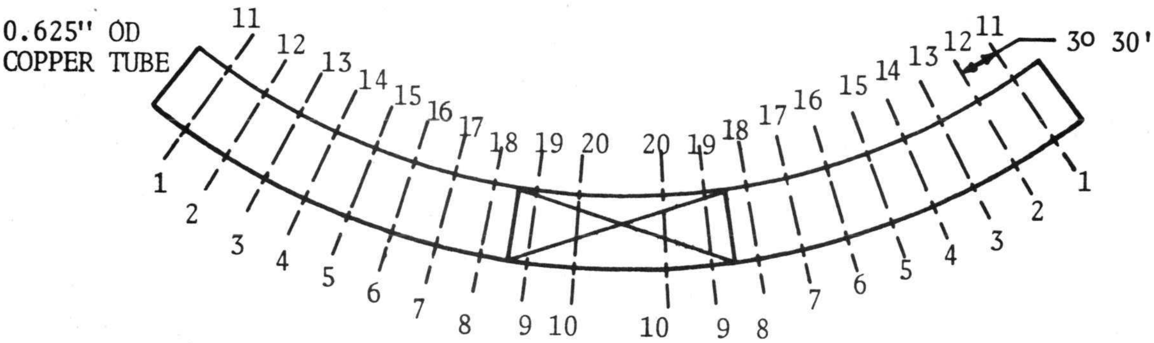


NOTE: ALL PERFORATED PLATE WAS 51% OPEN

ARRANGEMENTS 4 and 5

FIGURE 10



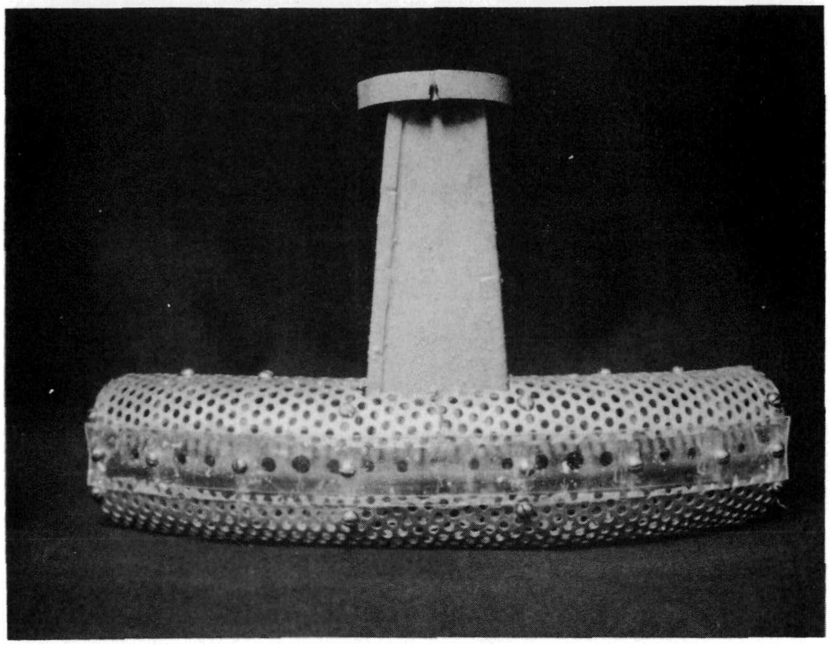


HOLE NUMBER	DIAMETER
7	.228"
18	.209
6,8	.189
17	.177
5	.170
4	.157
16	.152
3	.147
1,9	.141
2,10,15,19	.136
11,14	.125
12,13	.120
20	.104

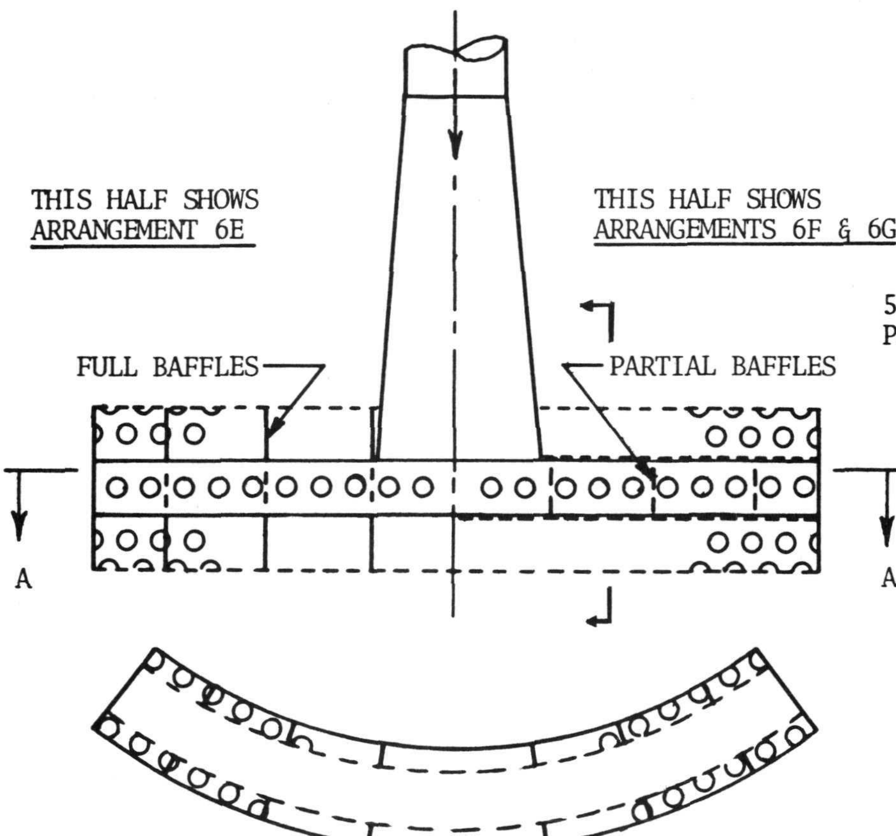
MANIFOLD USED FOR ARRANGEMENTS 6E, F, G, & H

(HOLE SIZES REQUIRED TO OBTAIN UNIFORM DISTRIBUTION IN THE FULL SECTOR OBTAINED FROM FLOW MEASUREMENTS)

FIGURE 11

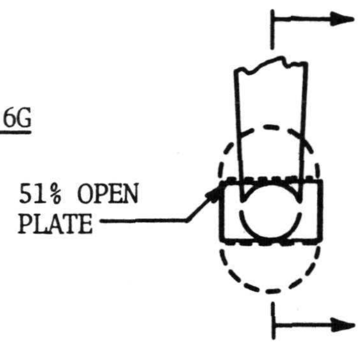


ARRANGEMENT 6E

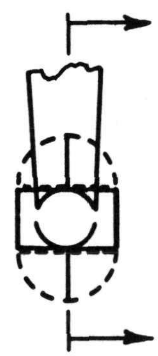


SECTION A-A

ARRANGEMENT 6E



ARRANGEMENT 6F

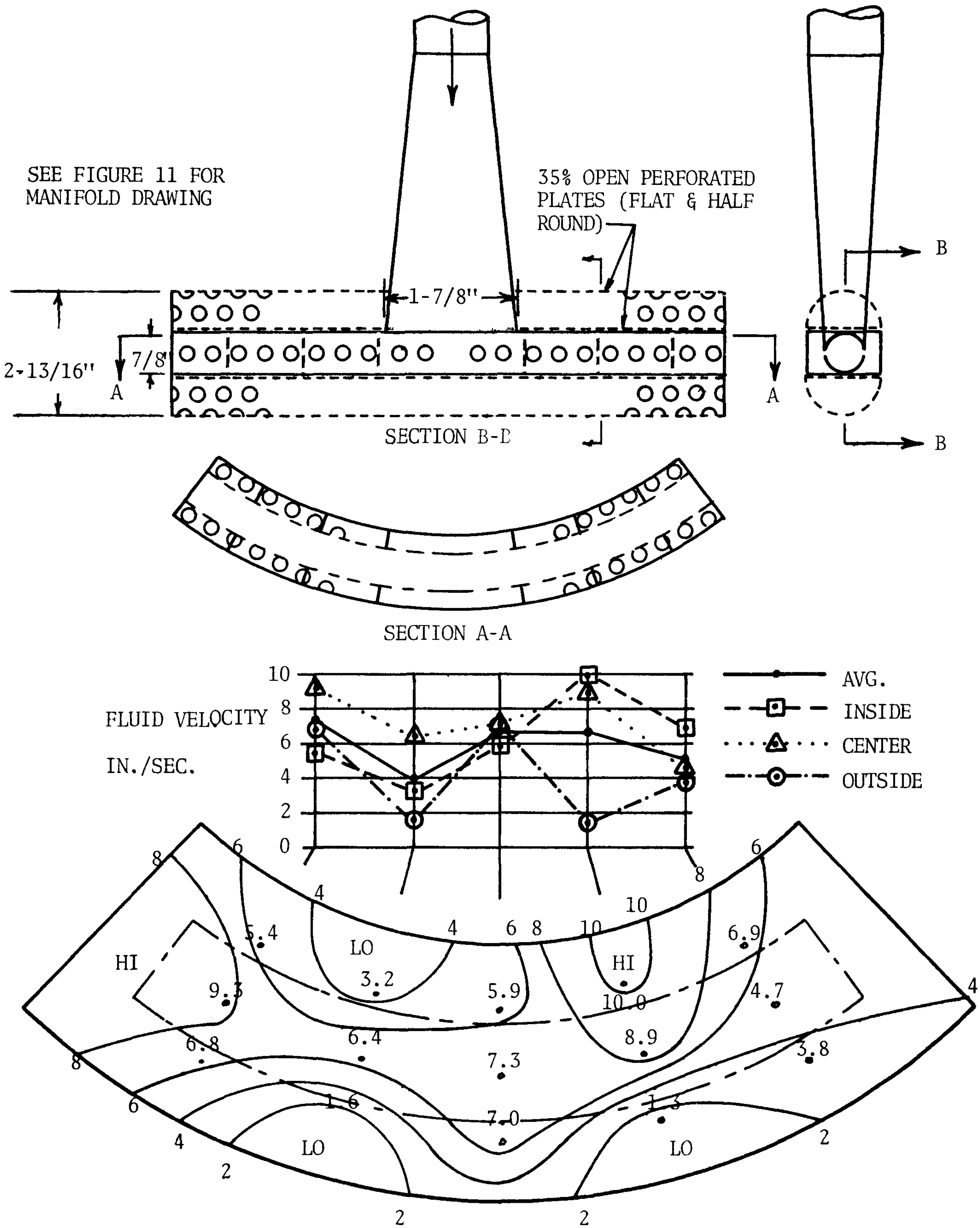


ARRANGEMENT 6G

NOTE: (1) ALL PERFORATED PLATE WAS 35% OPEN EXCEPT WHERE NOTED
(2) SEE FIGURE 11 FOR MANIFOLD

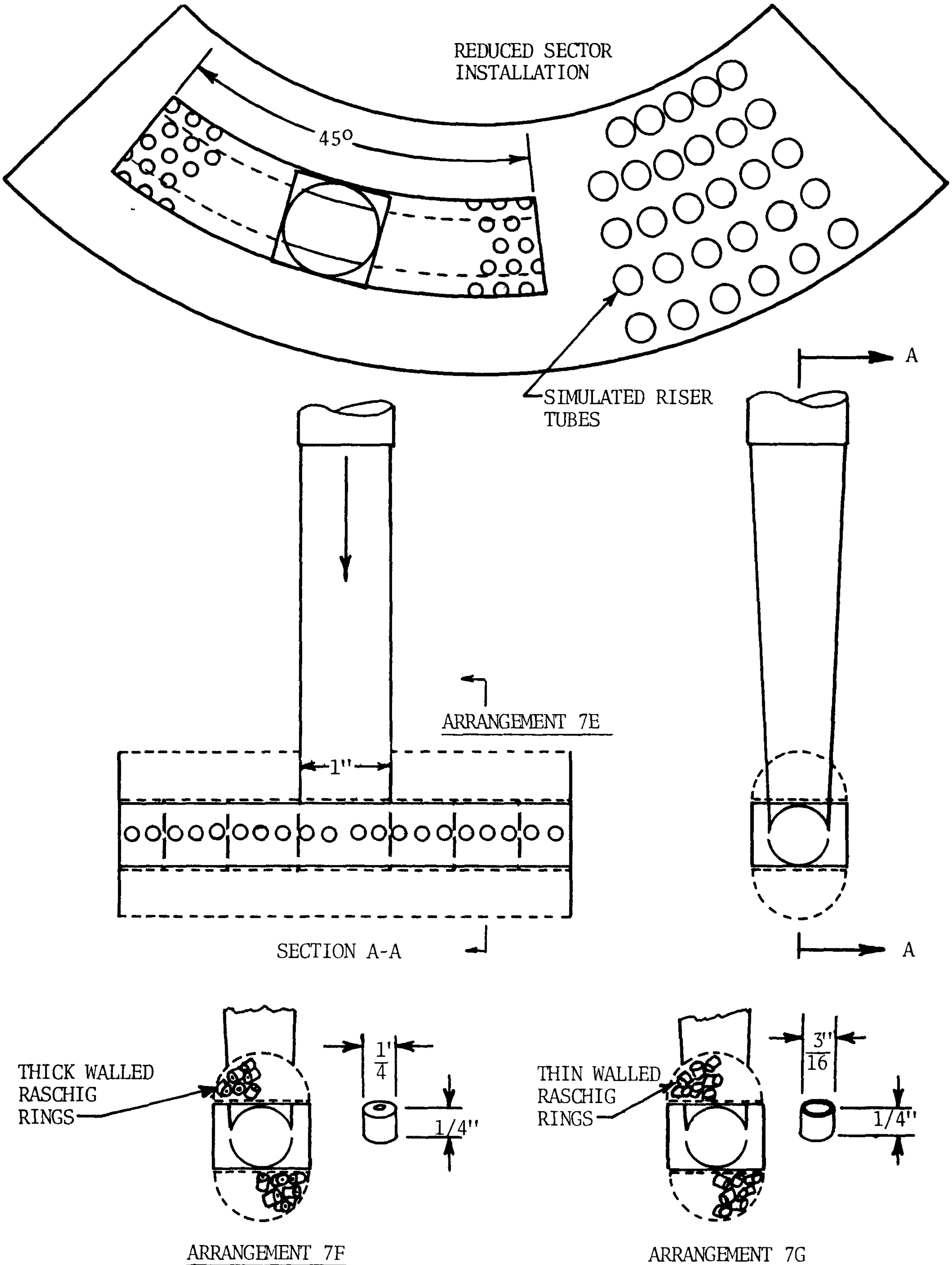
ARRANGEMENTS 6E, 6F, and 6G

FIGURE 12



ARRANGEMENT 6H WITH VELOCITY TRAVERSE RESULTS

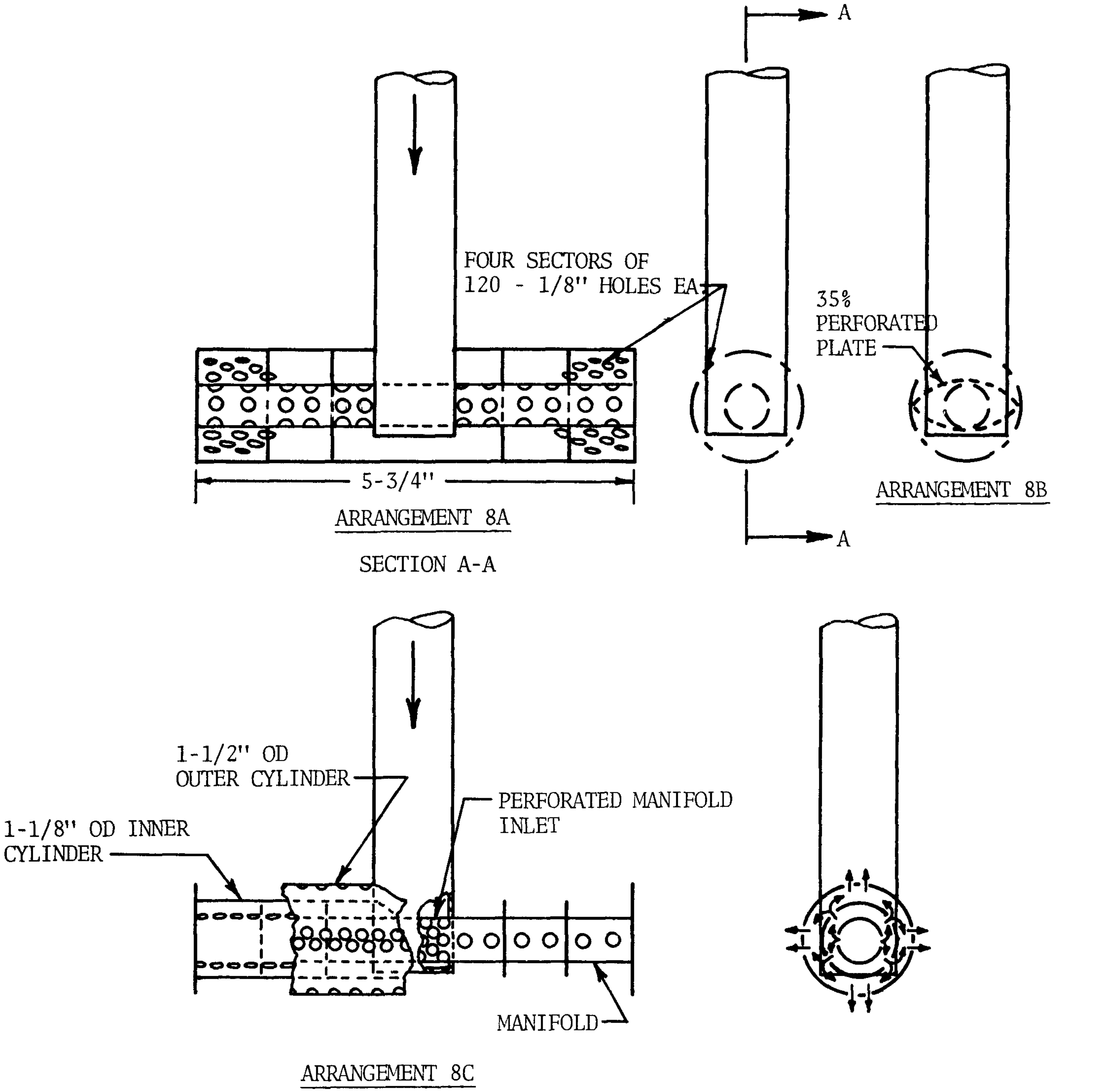
FIGURE 13



NOTE: NUMBER AND SIZE OF HOLES WAS THE SAME AS SHOWN IN FIGURE 11

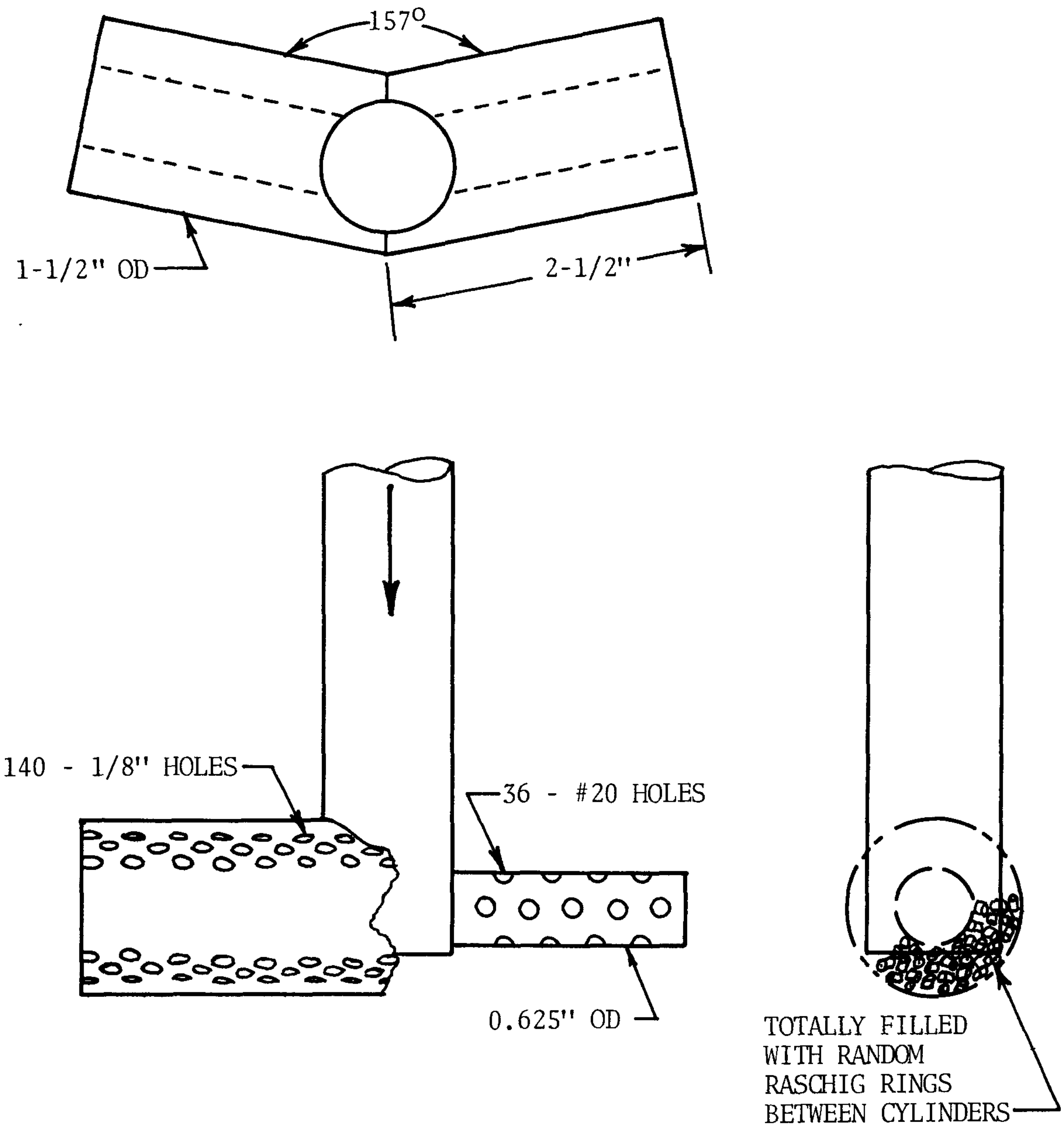
ARRANGEMENTS 7E, 7F, and 7G

FIGURE 14



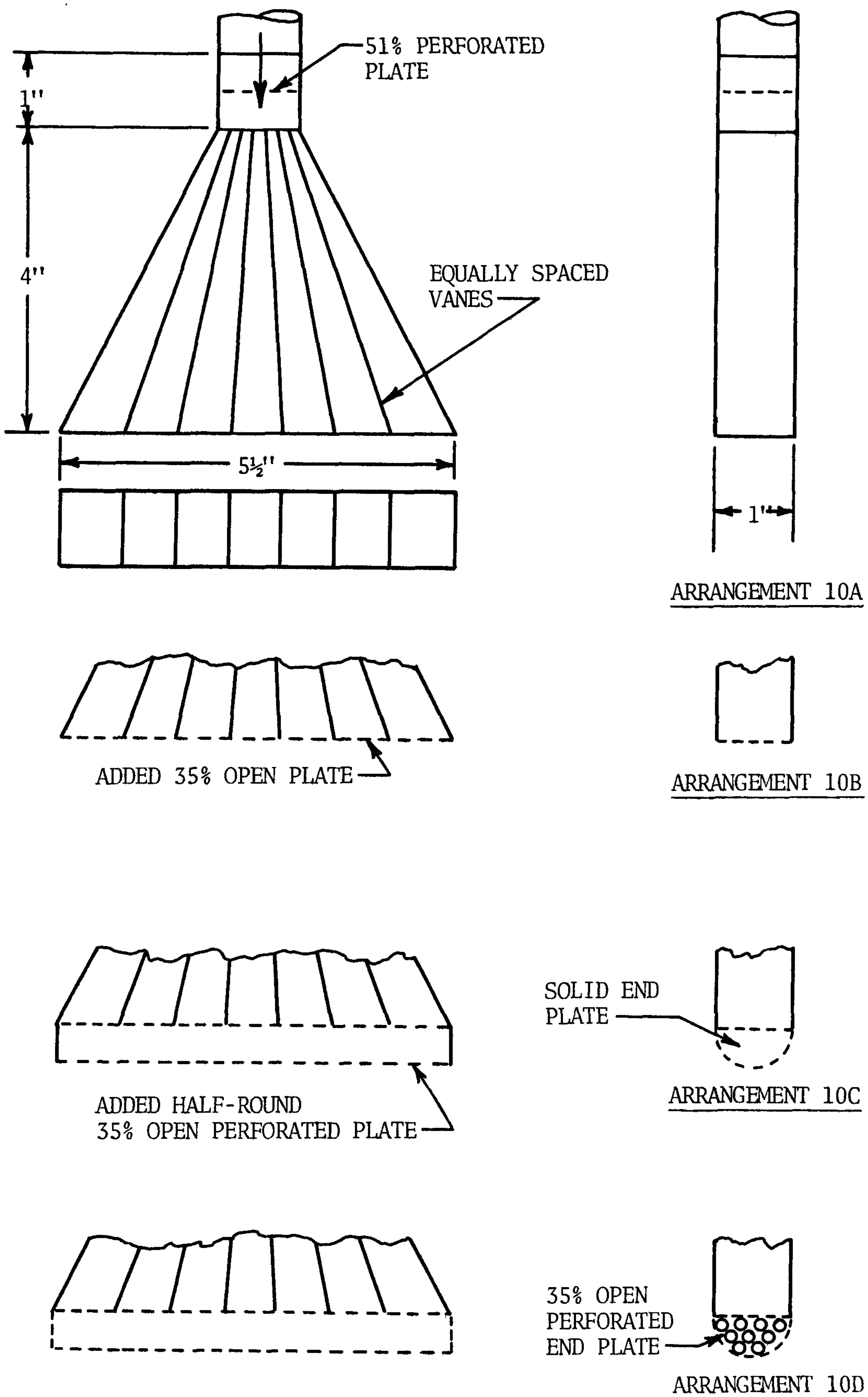
ARRANGEMENTS 8A, 8B, and 8C

FIGURE 15



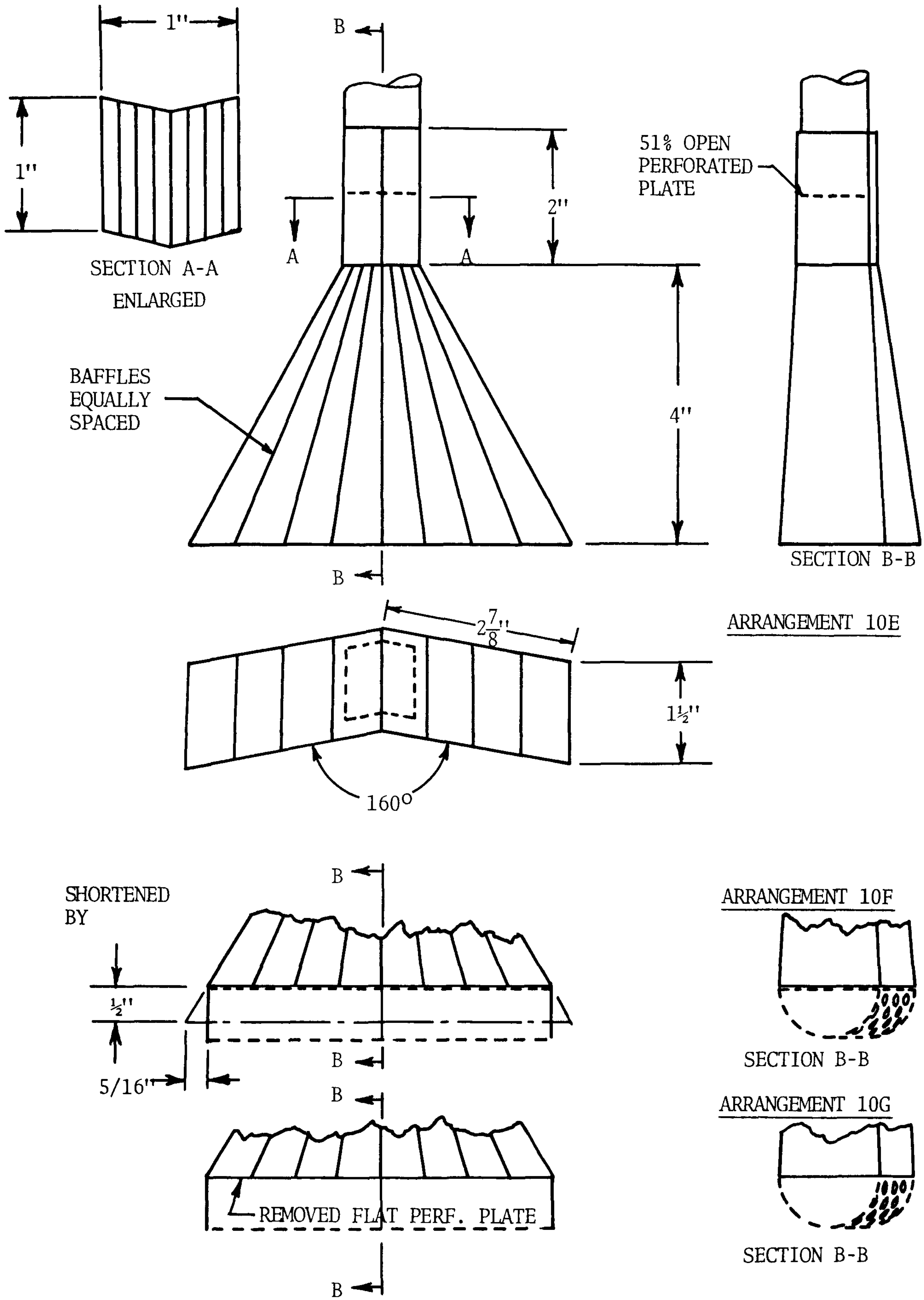
ARRANGEMENT 9

FIGURE 16



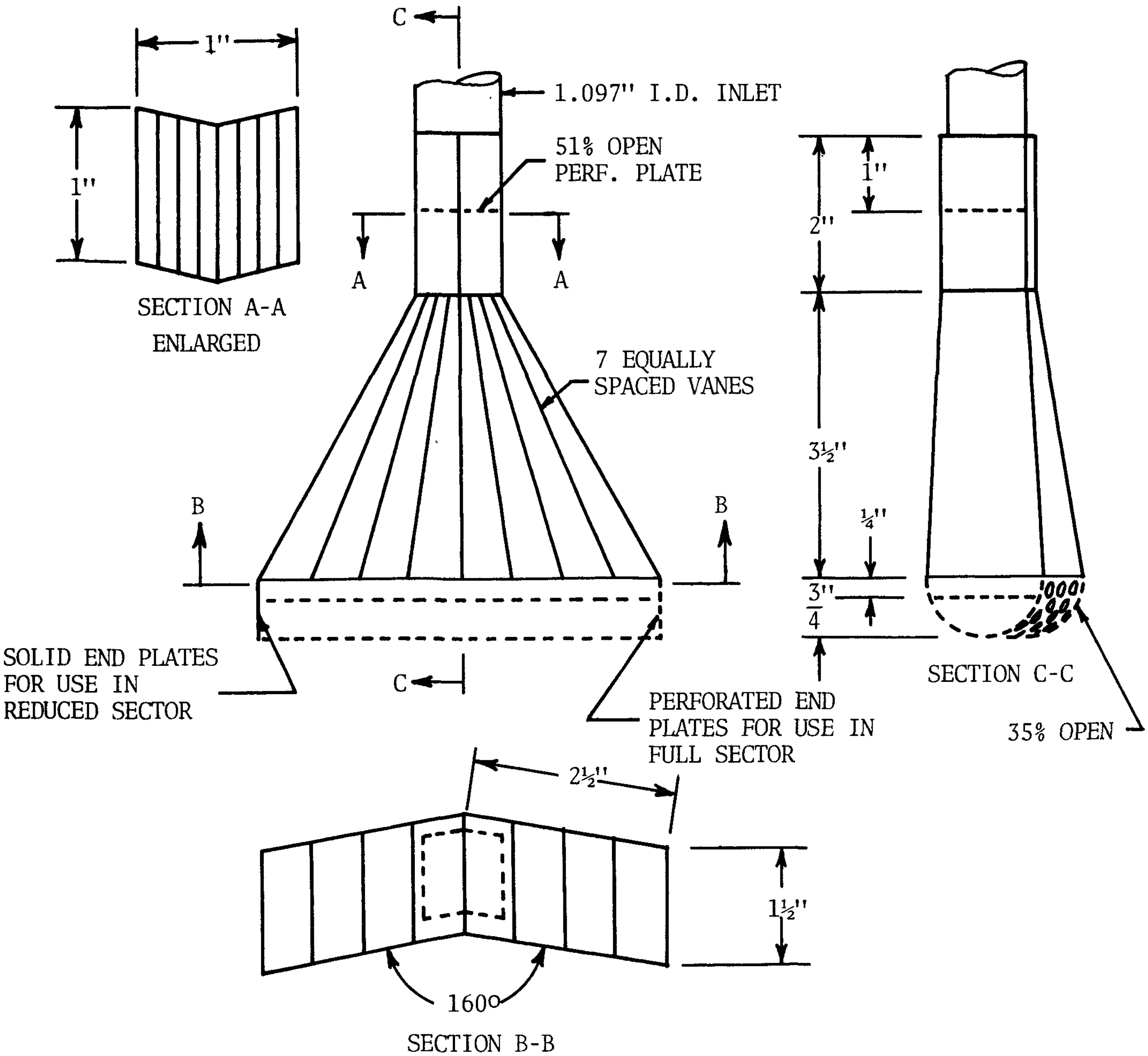
ARRANGEMENTS 10A, 10B, 10C, and 10D

FIGURE 17



ARRANGEMENTS 10E, 10F, and 10G

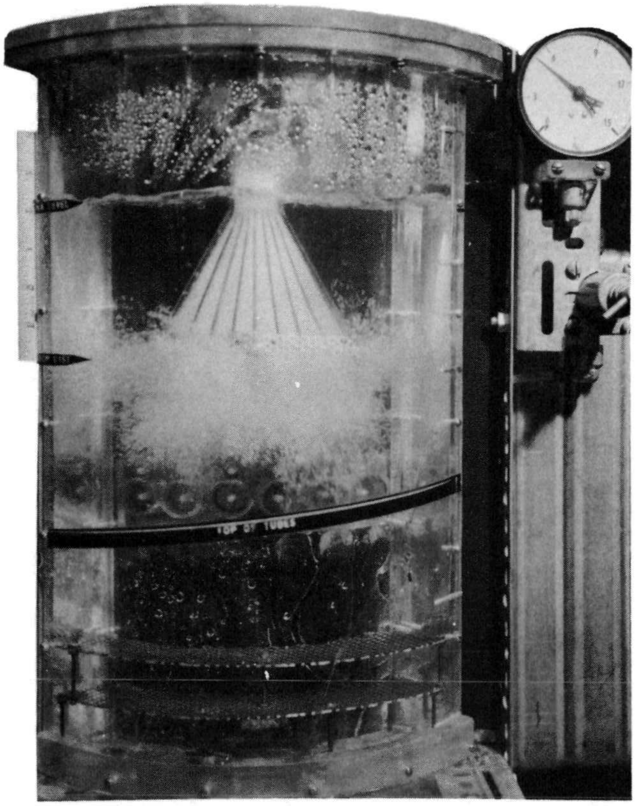
FIGURE 18



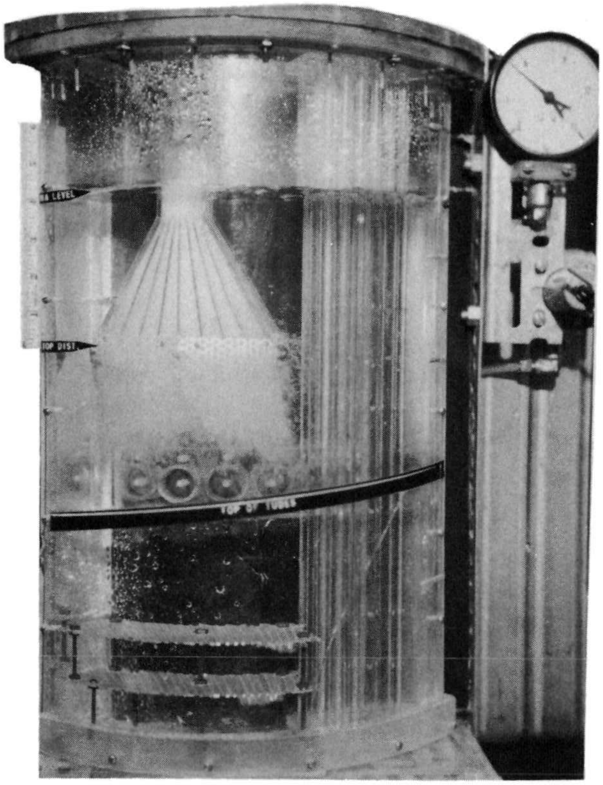
(NOTE: For a Drawing of the Prototype Sodium Distributor see Figure 24)

FINAL ARRANGEMENT (10H)
OF MODEL DISTRIBUTOR

FIGURE 19



DISTRIBUTOR IN THE FULL SECTOR
(WITH PERFORATED END PLATES)



DISTRIBUTOR IN THE REDUCED SECTOR
(WITH SOLID END PLATES)

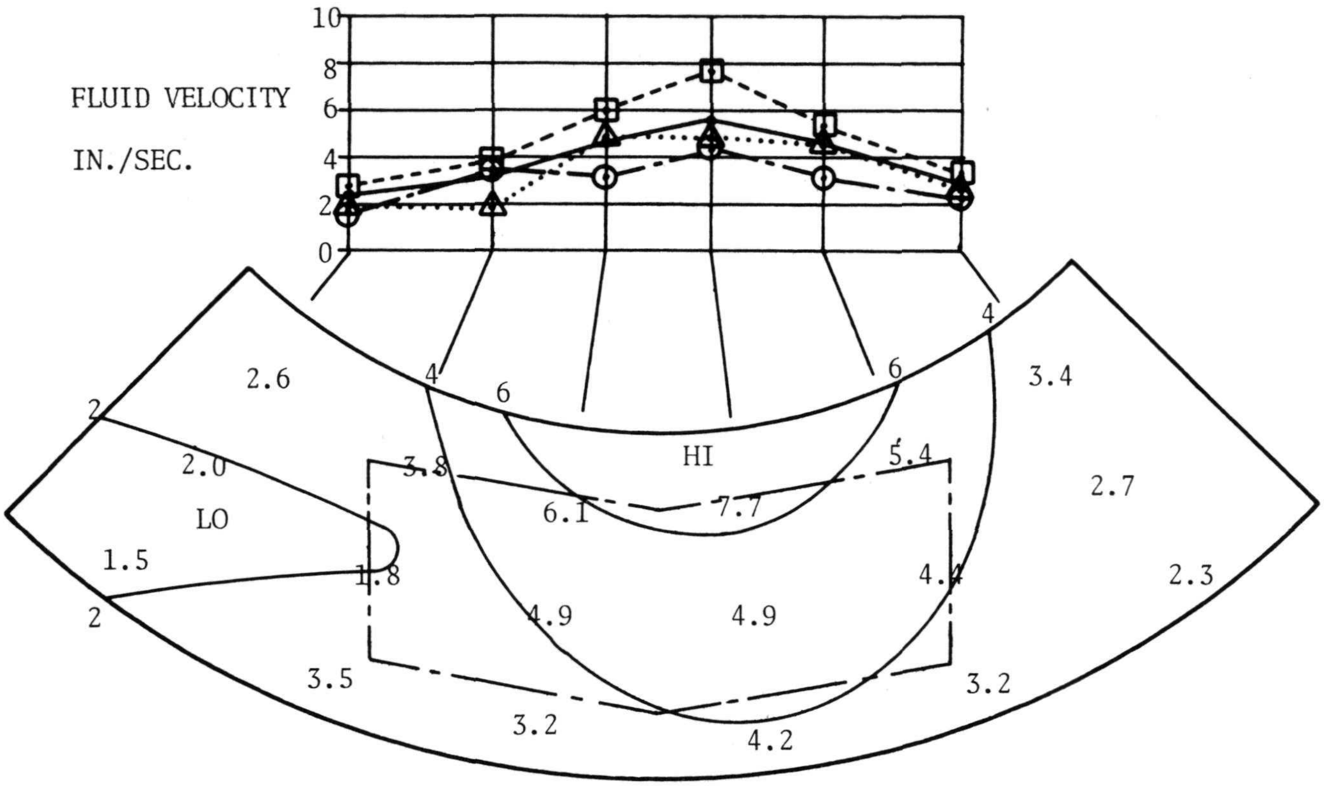
NOTE: AIR INJECTION USED TO MAKE FLOW PATTERNS VISIBLE

SUBSURFACE CONDITIONS - FINAL ARRANGEMENT

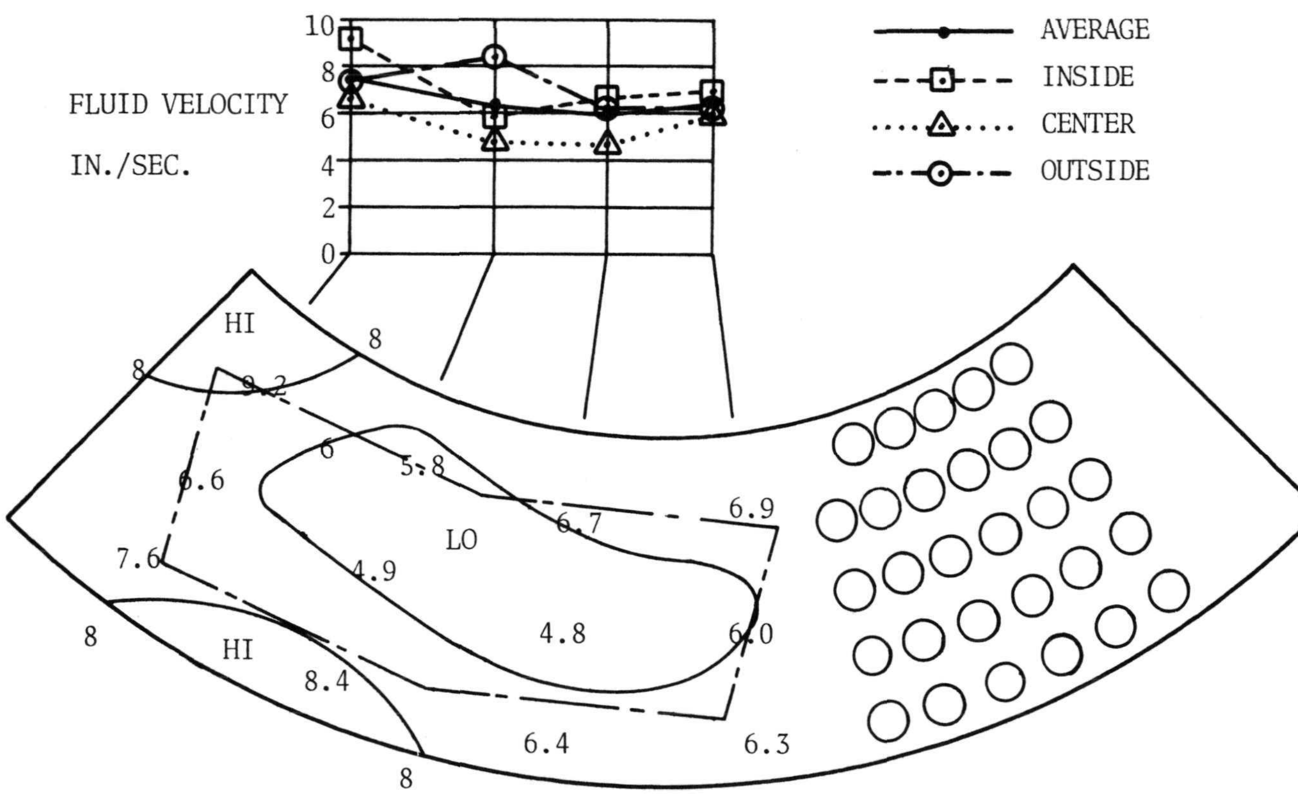
$$V_m = 1.8\ V_p\ [Re_m = .145\ Re_p]$$

COVER PRESSURE = 5 PSIG $\left[\left(\frac{\rho_g}{\rho_L}\right)_m = \left(\frac{\rho_g}{\rho_L}\right)_p\right]$

FIGURE 20



FULL SECTOR

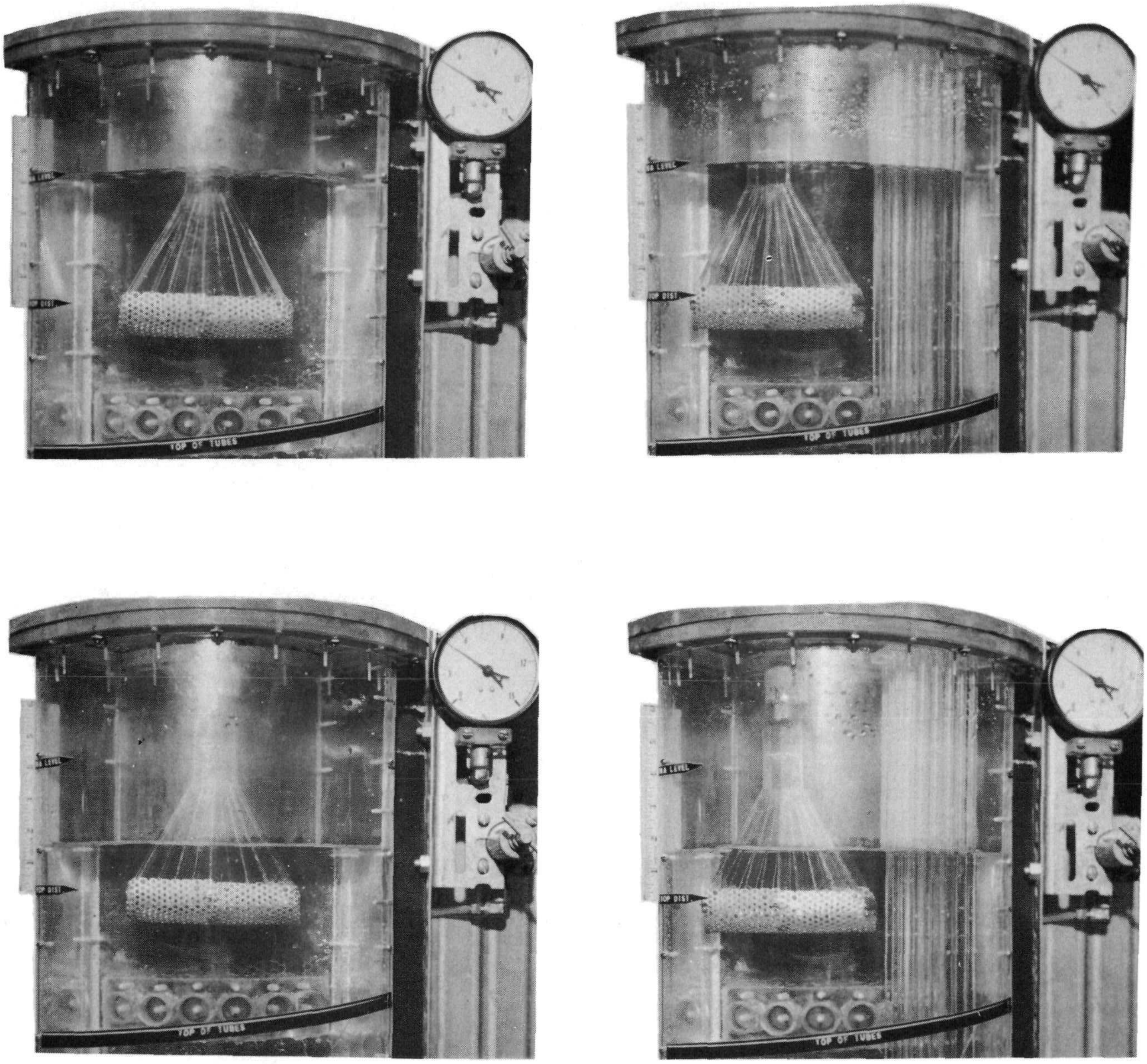


REDUCED SECTOR

VELOCITY PROFILE - FOUR DOWNCOMER PIPE DIAMETERS
BELOW DISTRIBUTOR DISCHARGE PLANE

FINAL ARRANGEMENT

FIGURE 21



DISTRIBUTOR IN FULL SECTOR

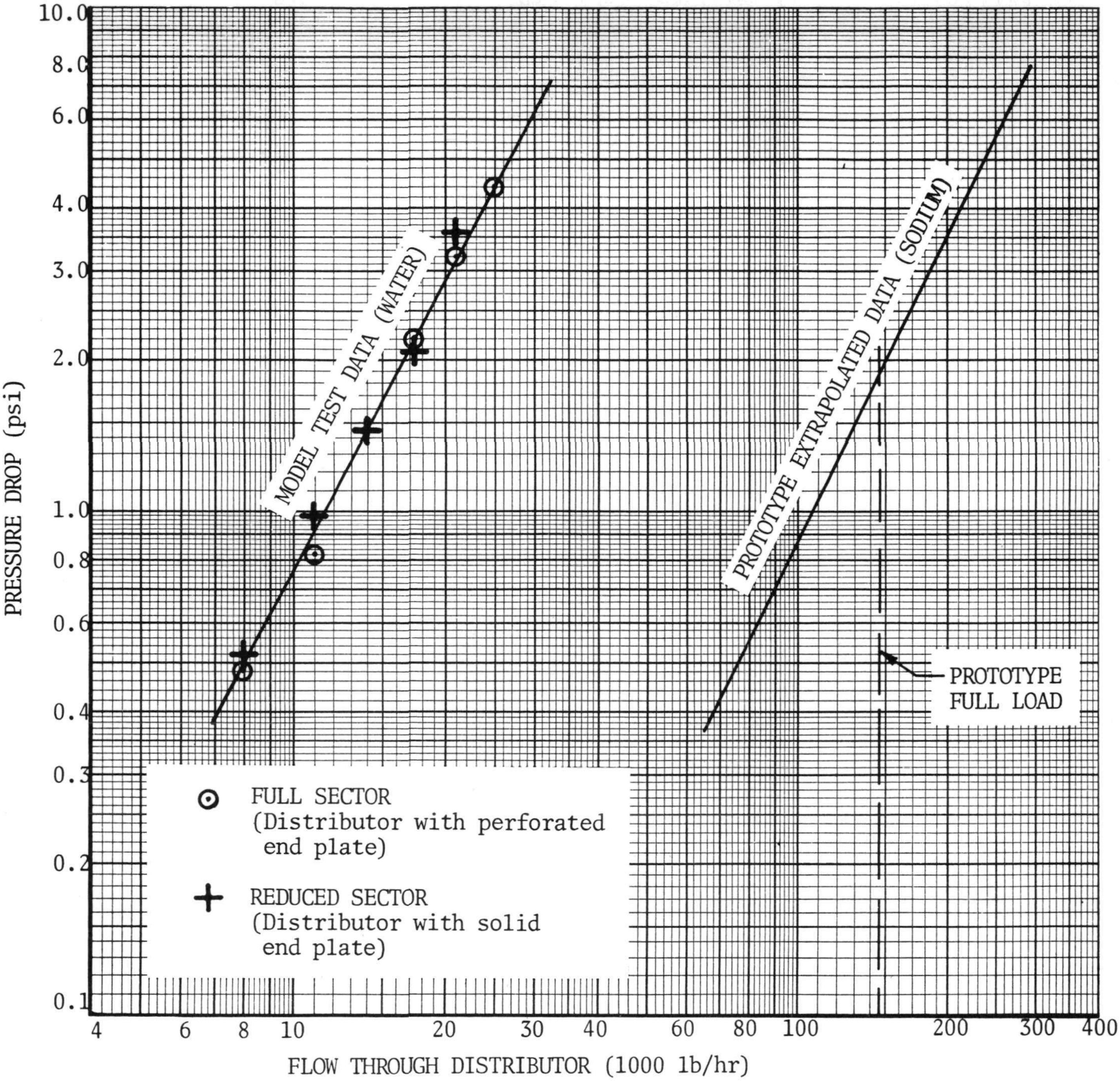
DISTRIBUTOR IN REDUCED SECTOR

SURFACE CONDITIONS - FINAL ARRANGEMENT

$V_m = .55\ V_p\ [Fr_m = Fr_p]$

COVER PRESSURE = 5 PSIG $\left[\left(\frac{\rho_g}{\rho_L}\right)_m = \left(\frac{\rho_g}{\rho_L}\right)_p\right]$

FIGURE 22



MODEL DATA

60° Water
1.097" Pipe Diam.

PROTOTYPE DATA

1140° Sodium
3.548" Pipe Diam.

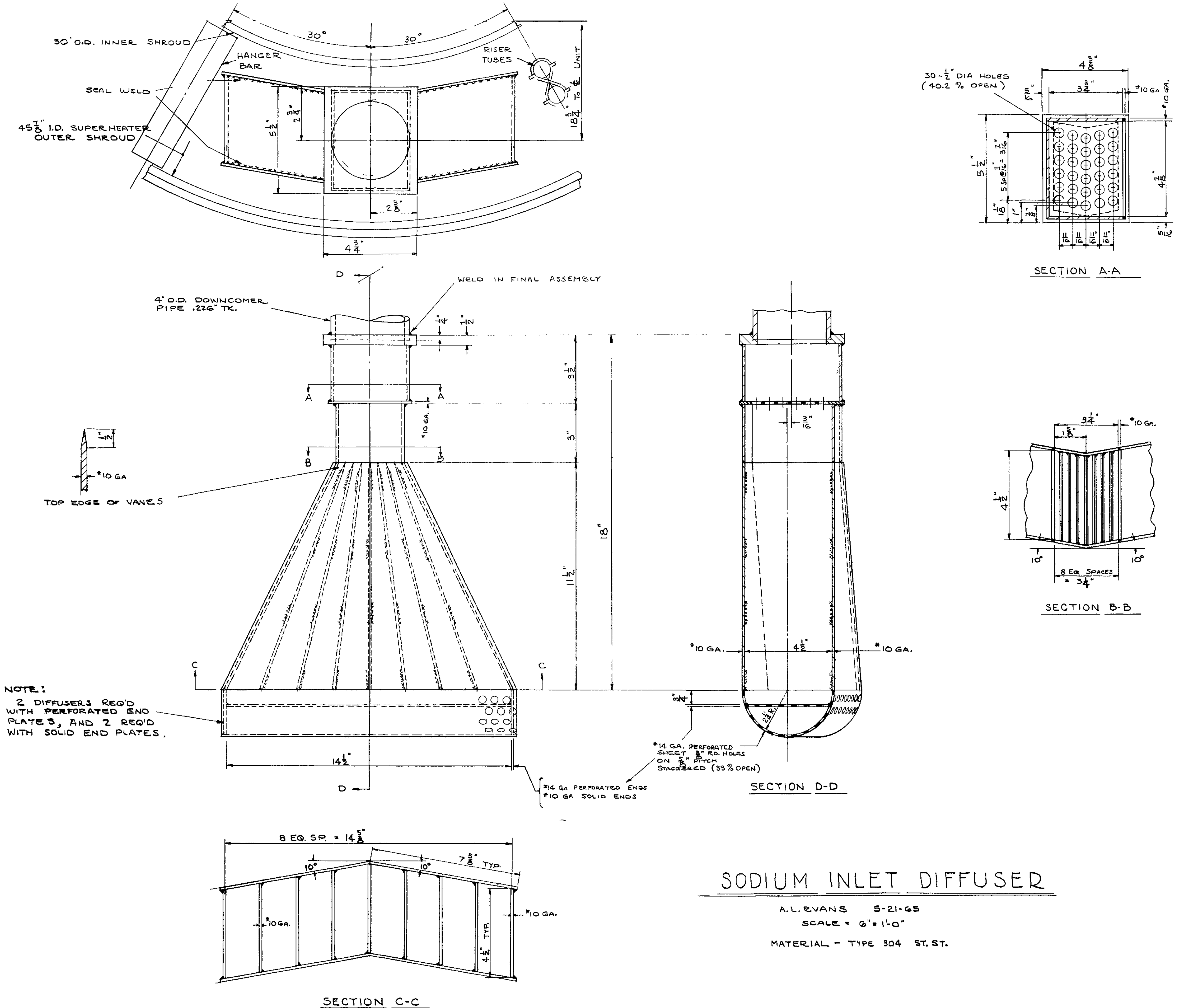
EXTRAPOLATION EQUATION

$$\Delta P_p = \Delta P_m \left[\frac{W_p}{W_m}\right]^2 \left[\frac{D_m}{D_p}\right]^4 \left[\frac{\rho_m}{\rho_p}\right]$$

FLOW vs DISTRIBUTOR PRESSURE DROP *

*Excluding Downcomer Pipe Friction

FIGURE 23



SODIUM INLET DIFFUSER

A. L. EVANS 5-21-65
SCALE = 6" = 1'-0"
MATERIAL - TYPE 304 ST. ST.

"PROTOTYPE"
610-0067-45
CHKD 6-11-65 F. ALLMAN

SK-1552-0

FIGURE 24

TABLE 1

Arrangement	Figure	Sector	Change from Previous Arrangement	Results
1	5	Full		At $V_m = V_p$, the surface was relatively undisturbed but high velocity subsurface jets extended to the superheater tubes.
2A	6	Full	Horizontal legs added to distribute fluid to extremes of sector.	The high inlet velocity carried to the ends of the distributor and up to the liquid surface. This resulted in extreme surface disturbances.
2B	6	Full	Half round perforated plate was added over the fluid discharge area.	The high velocity fluid propagated thru both plates at the extremes of the legs.
3A	7	Full	Two discharge areas were provided to lower the fluid velocity.	Poor internal distribution allowed jets to disturb the surface.
3B	7	Full	Internal perforated plate baffles added vertically.	The baffles acted like vanes and turned the high velocity jets both up toward the surface and down toward the superheater tubes.
3C	7	Full	Internal perforated plate baffles added horizontally.	Best of any so far. The surface was calm but poor distribution of fluid created large eddy currents below the distributor.
3D	8	Full	Half round perforated plate was added over the discharge areas (inner baffles removed).	Internal eddy currents were present which created uneven distribution in the sector.
3E	8	Full	Stepladder internal vanes were added (half round plate removed).	The stepladder vanes turned the inlet flow greater than 90° - most of the flow went out the top.
3F	8	Full	Half round plate replaced.	Same general flow pattern as 3E still present.

TABLE 1

TABLE 2

Arrangement	Figure	Sector	Change from Previous Arrangement	Results
3G,H,I	9	Full	Several arrangements of internal baffles were added to reduce local velocities.	The addition of baffles only moved the areas of high velocities and eddy currents. Maldistribution was still present.
4	10	Full	An offset inlet was used to create an internal vortex flow.	Centrifugal force on the spinning fluid created high velocity jets out of the perforated cylinders.
5	10	Full	A high pressure drop internal manifold with holes was baffled with perforated plate.	Best so far. But uneven distribution was present along the length of the manifold.
6A,B,C,D		Full	A round internal manifold was fabricated.	Corrections were being made from flow measurements to obtain even flow out of the distributor manifold holes.
6E	12	Full	Solid sides and perforated plate half rounds were added around the manifold.	Flow was taking place out of the extreme top and bottom of the half round perforated plate. This created eddy currents.
6F	12	Full	A 51% open flat perforated plate was added.	The full area of the half round was still not being used efficiently.
6G	12	Full	Vertical baffles were added between the flat plate and the half round plate.	The fluid was concentrated into more distinct fluid jets by this addition.
6H	13	Full	The baffle was removed and the flat plate changed to 35% open.	This produced an acceptable flow distribution and an undisturbed surface. This arrangement was acceptable for use in the full sector.

TABLE 3

Arrangement	Figure	Sector	Change from Previous Arrangement	Results
7A,B,C,D		Reduced	The manifold was shortened to a 45° arc keeping the same number and size of holes as Arrangement 6H.	This was the first trial in the reduced sector. Distribution out of the short manifold was considerably different than that out of the long manifold. Corrections to hole sizes were made from flow measurements to obtain uniform discharge along the manifold.
7E	14	Reduced	The distributor was assembled identically to Arrangement 6H.	The same flow through this smaller distributor produced high velocity regions which disturbed the surface and created subsurface eddy currents.
7F,G	14	Reduced	Raschig rings (random packed cylinders) were added between the flat and half round perforated plates.	These packings produced uniform distribution out of the distributor. The surface was calm and there were no high velocity jets. This arrangement would meet the objectives of the program.
8A	15	Reduced	Large volume cylinder, partially perforated was built around a short straight manifold.	This produced jets which disturbed the fluid surface considerably.
8B	15	Reduced	Perforated plate shielding was added around the manifold.	This only reduced the velocity of the jets slightly.
8C	15	Reduced	An intermediate perforated tube was added to change the path of the fluid flow.	The velocities were still too high. Also the straight distributor created high flows near the sector walls and thus subsurface eddy currents.
9	16	Reduced	The inner manifold legs were attached to the distributor pipe at an angle to fit the curved sector. Also the volume between the inner and outer cylinders was filled with Raschig rings.	The random packings (Raschig rings) occupied too much volume therefore the high velocities were not reduced.

TABLE 4

Arrangement	Figure	Sector	Change from Previous Arrangement	Results
10A	17	Reduced	A simple vaned diffuser was tried.	This resulted in very little surface disturbance but the discharge pattern was upset.
10B	17	Reduced	A flat perforated plate was added across the discharge area.	The discharge pattern was improved but some eddy currents were created which disturbed the surface.
10C	17	Reduced and Full	A half round perforated plate was added onto the discharge area. Solid end plates were used.	Visual observation showed that the surfac was calm and no high velocity jets were present. Velocity measurements in the full sector showed large subsurface eddy currents with up flow at the ends of the sector.
10D	17	Full	The solid end plates were changed to perforated end plates.	This reduced the eddy current velocities. However, the straight discharge area bein closer to the sector walls in some region tended to create eddy currents.
10E	18	Full and Reduced	The distributor was built as though folded around a vertical center line to fit the curved sector better. The flat and the half round perforated plates were added using solid end plates for the reduced sector and perforated end plates for the full sector.	The best results so far were obtained witl this arrangement, however, there were stil some minor upset flow conditions in the fluid below the distributor.
10F	18	Reduced	To more easily fit into the sector, the model was reduced in size slightly.	This reduction changed the flow pattern slightly. Further improvements were desired.

TABLE 5

Arrangement	Figure	Sector	Change from Previous Arrangement	Results
10G	18	Reduced	The flat perforated plate was removed.	It was readily apparent that the single half round perforated plate on the discharge area was not sufficient for good distribution.
10H Final	19	Full and Reduced	The flat perforated plate was replaced 1/3 of the way down the half round. Solid ends used for the reduced sector and perforated ends used for the full sector.	There is negligible surface disturbance in the model and the discharge pattern is as uniform as can be expected. This is true at all flows and for both the full and reduced sectors. The fluid level can be dropped very low (see "Results" for Fluid Height Restrictions).

FLOW MODELING AS IT APPLIES TO THE SODIUM DISTRIBUTOR

FLUID MODELING AS IT APPLIES TO THE SODIUM DISTRIBUTOR

To assure satisfactory performance and trouble-free operation of Sodium Heated Steam Generators, uniform distribution of sodium over the heat transfer surface is considered essential.

In connection with the development of sodium heated steam generators, the Fluid Mechanics Section of the Alliance Research Center has undertaken the development of a sodium distributor using water modeling techniques.

The objectives of this program are as follows:

a. Develop a sodium distributor arrangement that provides uniform distribution entering the superheater, as determined by visual inspection of the model and photographic records.

b. Establish visually and photographically that the distributor does not result in high velocity impingement on tube surfaces that might lead to vibration problems.

c. Determine visually the general extent of cover gas entrainment and establish a minimum liquid level for acceptable performance from this standpoint.

The following pages present a discussion of modeling in general, and show how pertinent criteria apply in the development of a sodium distributor.

Modeling is based on principles of similarity dealing with the relations between physical systems of different sizes. In more precise terms, it can be stated that spatial configurations of a physical system are determined by ratios of quantities within the system itself and are not dependent upon the size or nature of the units in which these quantities are measured:

The four major similarity states are:

(1) Geometric
(2) Mechanical
(3) Thermal
(4) Chemical

Geometric similarity is best defined in terms of correspondence. Two bodies are geometrically similar when for every point in the one body there exists a corresponding point in the other. The prototype and full-size distributor will be extrapolated from the model in this manner.

Mechanical similarity comprises static or static-force similarity, kinematic similarity, and dynamic similarity. Each of these can be regarded as an extension of the concept of geometrical similarity to stationary or moving systems subjected to forces. Static similarity is concerned with solid bodies and is of no importance with respect to the sodium distributor. Kinematic similarity is concerned with solid or fluid systems in motion and is thus applicable to our problem. It can be said that geometrically similar moving systems are kinematically similar when corresponding particles trace out geometrically similar paths in corresponding scaled intervals of time. Since the distributors of the prototype and the full-size unit are to be geometrically similar to the model and the velocities in the distributor are being held identical with those required in the larger units, kinematic similarity will be maintained. Dynamic similarity, which is concerned with the forces that accelerate or retard moving masses in dynamic systems, is of direct importance in fluid flow systems. It has been found that geometrically similar moving systems are dynamically similar when the ratios of all corresponding forces are equal. In fluid systems, such as the system involving the sodium distributor, the principal forces acting are pressure, inertia, gravity, viscosity, and surface tension.

Thermal similarity is concerned with systems in which there is a flow of heat. In our system, heat is transferred only by the bulk movement of matter. No appreciable temperature differences are present and thus thermal similarity is of no concern for this model.

Chemical similarity is concerned with chemically reacting systems in which the composition varies from point to point. This is also of no concern to our model.

Similarity between geometrically similar systems can be specified in terms of criteria which are ratios of measurements, forces, or rates within each system. Since these are ratios of like quantities, dimensional analysis can be used to establish these criteria. This is a mathematical technique for expressing the behavior of a physical system in terms of the minimum number of independent variables and in a form that is unaffected by changes in the magnitude of the units of measurement. The physical quantities are arranged in dimensionless groups consisting of ratios of like quantities such as lengths, velocities, forces, etc., which characterize the system.

The physical variables that influence the isothermal flow of a fluid are:

1. Fluid Velocity v
2. Linear Dimension L
3. Force F
4. Density ρ
5. Viscosity μ
6. Surface Tension σ
7. Acceleration of Gravity g

Using dimensional analysis, the equation of motion of an isothermal fluid flow which is applicable to the sodium distributor must have the form

$$\phi\left(\frac{F}{\rho\ v^2\ L^2},\ \frac{v\ L\ \rho}{\mu},\ \frac{\rho\ v^2\ L}{\sigma},\ \frac{v^2}{Lg}\right) = \text{const.}$$

where the function ϕ is undetermined. These groups are all well known in connection with fluid dynamics and are given the following names:

1) $\frac{F}{\rho\ v^2\ L^2} = \frac{\Delta P}{\rho\ v^2}$ = pressure coefficient, which is the ratio of pressure to inertial forces.

2) $\frac{v\,L\,\rho}{\mu}$ = Reynolds number, which is the ratio of inertial to viscous forces.

3) $\frac{\rho\,v^2\,L}{\sigma}$ = Weber group, which is the ratio of inertial to surface tension forces.

4) $\frac{v^2}{L\,g}$ = Froude group, which is the ratio of inertial to gravitational forces.

For homologous systems (geometrically similar) the three dimensionless groups, Reynolds number, Froude group,and Weber group, are mutually incompatible. That is, in any geometrically scaled system whether larger or smaller than its prototype, it is impossible to satisfy all of the similarity criteria at the same time. For this reason, it is necessary to establish the principal criteria and to investigate them singly or in combinations if possible. The required relations between corresponding velocities and corresponding lengths are:

1. Reynolds number $v \sim \frac{1}{L}$
2. Froude group $v \sim \sqrt{L}$
3. Weber group $v \sim \frac{1}{\sqrt{L}}$

This leads to three principal subdivisions of the fluid dynamic regimes which may be described as viscosity-controlled, gravity-controlled, and surface-tension controlled. These shall be discussed individually with respect to the modeling of the sodium distributor.

VISCOSITY CONTROL

The viscosity-controlled dynamical regime is one of the most important. Reynolds number is the criterion to be used to model a viscosity-controlled process. Reynolds number through the 12-in. nom. inlets of the full size unit is 4.96×10^6. For the 3½in. nom. inlets of the prototype the Reynolds number is 1.26×10^6*, and through

*Full load Reynolds number [inlet velocity (v_p) = 11.7 ft/sec] the 1-inch nom. inlet of the model the Reynolds number is 1.82×10^5 (at $v_m = 1.8\ v_p$). Although this appears drastically different, it is quite suitable for modeling techniques.

When the Reynolds number in a flow system exceeds about 10,000 and the system consists mainly of rough pipes, bends, and irregular changes of section rather than long smooth channels, the flow pattern and friction factor, f, become substantially independent of Reynolds number. In these circumstances, a model can often give accurate information even though it is operated at a Reynolds number very much below that of the prototype, provided always that the value in the model exceeds 10,000(1). In geometrically similar envelopes with corresponding velocities, the fluid flow patterns will also be geometrically similar(2).

The preceding principle of similtude pertains mostly to flow within a solid boundary such as inside the Sodium Distributor.

GRAVITY CONTROL

In liquid systems, gravity control is found where a free liquid surface is subject to disturbance. In such a case, the Froude group is the criterion of similarity. This criterion can be achieved by decreasing the model distributor inlet velocity to 55% of that in the prototype (see page vii).

In order to retain the ratio of the density of the cover gas to that of the working fluid, the air over the model surface must be pressurized to 5 psig. This criterion is being met.

When these criteria are met the flow requirements for liquid surface modeling will be satisfied.

---

(1) Johnston, and Thring, "Pilot Plant Models and Scale Up Methods", 1957.

(2) This has been investigated by the Alliance Research Center and has been verified. Attached to this writing is a photograph of a duct turn test set up and a graph showing the results of variation of velocity profile with various Reynolds numbers and fluids.

SURFACE TENSION CONTROL

The effects of surface tension are predominant when two immiscible liquids are agitated together. The Weber number is the criterion used for comparison. Since the surface of the sodium in the steam generator is to be undisturbed there will not be any effect such as stated above. Even at that, the ratio of the prototype to the model is almost unity (see page viii).

GEOMETRIC SIMILARITY

Modeling is used extensively in many industries. For example, the ship building industry models large ships at scales up to 1/100. B&W conducts model studies of large boilers at a scale of 1/48. The sodium distributor being 1/3.2 geometrically scaled is much closer to full scale than most models are.

A 90° sector model of the sodium heated steam generator was chosen for testing since the tube supports of the prototype segregate the flow areas into four separate vertical channels.

The following pages give the similarity ratios between the prototype and the model. Also attached is a photograph showing the distributor, model set up, and one proposed distributor model at various conditions.

The values used in calculations are as follows:

	PROTOTYPE (p)	MODEL (m)
Inlet pipe dia. D (in)	3.548 (ID)	1.097 (ID)
Fluid density ρ (lb/ft^3)	50.3 (sodium)	62.4 (water)
Viscosity μ (lb/sec ft)	(138.9×10^{-6} @ 1140°F)	(661×10^{-6} @ 70°F)
Gas density ρ (lb/ft^3)	(.081 argon @ 1140°F & 20 psig)	(.075 air @ 70°F & 0 psig)
Surface tension σ (Dynes/cm)	(156 or less @ 1140°F)	(72.8 @ 70°F)
Fluid velocity v (ft/sec)	(11.7 @ 145,750 lb/hr)	(11.7 @ 17,300 lb/hr)

GEOMETRIC SIMILARITY

$$K\ (D_p) = (D_m)$$

$$K = \frac{D_m}{D_p}$$

$$= \frac{1.097}{3.548}$$

$$= \frac{1}{3.23}$$

$$= .31$$

REYNOLDS NUMBER SIMILARITY (at $v_m = 1.8\ v_p$)

$$K \cdot \left(\frac{\rho\ v\ D}{\mu}\right)_p = \left(\frac{\rho\ v\ D}{\mu}\right)_m$$

$$K = \frac{\rho_m}{\rho_p} \cdot \frac{D_m}{D_p} \cdot \frac{\mu_p}{\mu_m} \cdot \frac{v_m}{v_p}$$

$$= \frac{62.4}{50.3}\left(\frac{1}{3.23}\right)\left(\frac{138.6 \times 10^{-6}}{661 \times 10^{-6}}\right)\left(\frac{21.1}{11.7}\right)$$

$$= \frac{1}{6.9}$$

$$= .145$$

RATIO OF FROUDE GROUP (at $v_m = .55\ v_p$)

$$K\left(\frac{v^2}{Lg}\right)_p = \left(\frac{v^2}{Lg}\right)_m$$

$$K = \left(\frac{v_m}{v_p}\right)^2\left(\frac{L_p}{L_m}\right)\left(\frac{g_p}{g_m}\right)$$

$$= \left(\frac{6.5}{11.7}\right)^2 \left(\frac{3.548}{1.097}\right)\left(\frac{32.2}{32.2}\right)$$

$$= 1.0$$

WEBER NUMBER SIMILARITY (at $v_m = v_p$)

$$K \left(\frac{\rho\, v^2\, L}{\sigma}\right)_p = \left(\frac{\rho\, v^2\, L}{\sigma}\right)_m$$

$$K = \left(\frac{v_m}{v_p}\right)^2 \left(\frac{\rho_m}{\rho_p}\right) \cdot \left(\frac{L_m}{L_p}\right) \cdot \left(\frac{\sigma_p}{\sigma_m}\right)$$

$$= \left(\frac{11.7}{11.7}\right)^2 \left(\frac{62.4}{50.3}\right)\left(\frac{1}{3.23}\right)\left(\frac{156}{72.8}\right)$$

$$= \frac{1}{1.21}$$

$$= .83$$

DENSITY RATIOS OF WORKING FLUID

a) Without pressurization

$$K \left(\frac{\rho \text{Argon}}{\rho \text{Sodium}}\right) = \left(\frac{\rho \text{ Air}}{\rho \text{ } H_2O}\right)$$

$$K = \left(\frac{50.3}{.081}\right) \cdot \left(\frac{.075}{62.4}\right)$$

$$= \frac{1}{1.33}$$

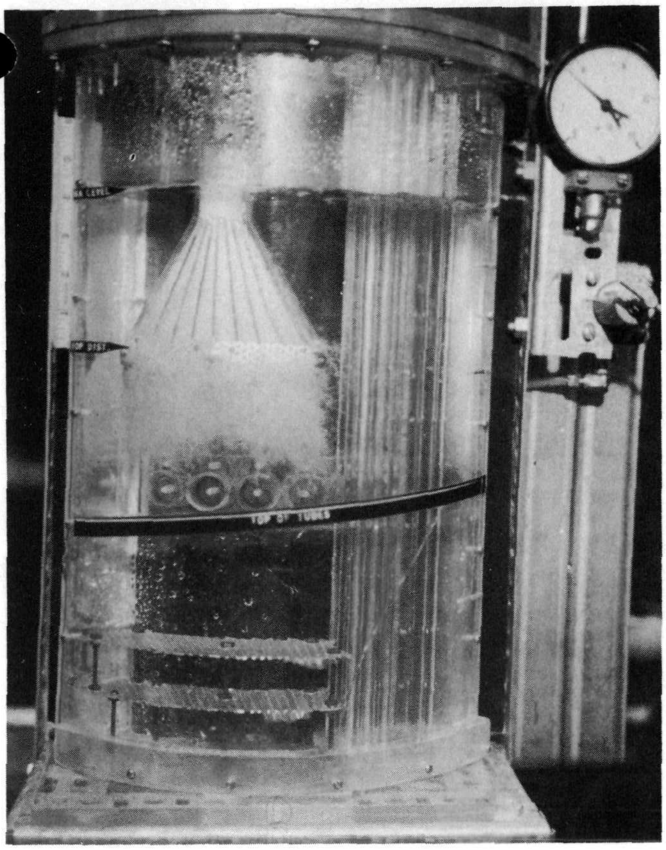
$$= .75$$

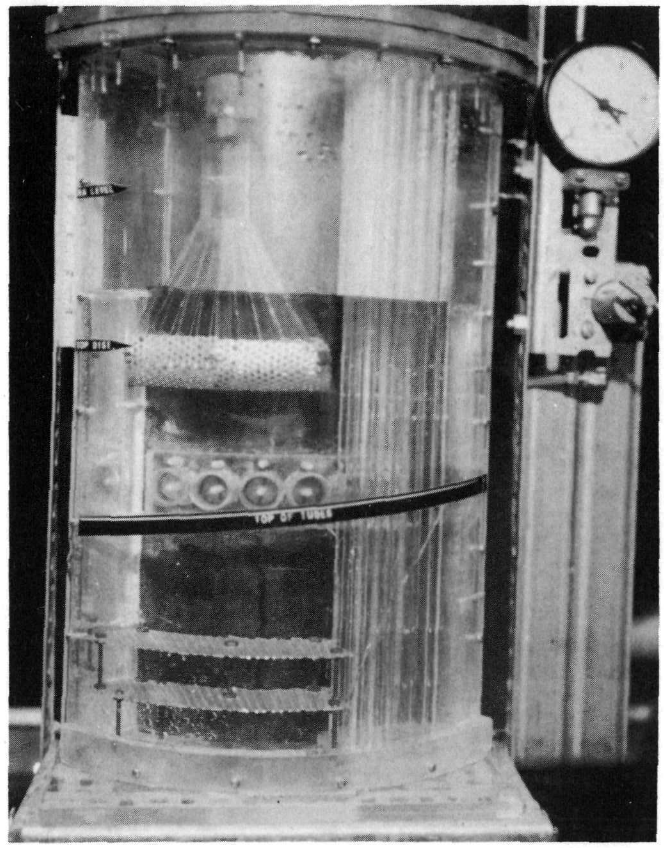
b) With pressurization (5 psig)

$$K = \left(\frac{50.3}{.081}\right)\left(\frac{.1005}{62.4}\right)$$

$$= \frac{1}{1.01}$$

$$= .99$$





FLUID CONDITIONS*

$V_m = 1.8\ V_p$

$Re_m = .145\ Re_p$

(viscosity control)

*(Shown with air bubbles being introduced)

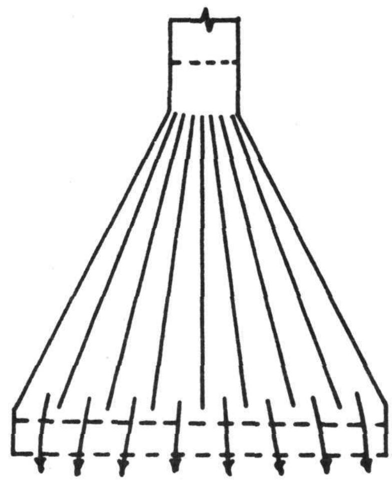
SURFACE CONDITIONS

$V_m = 0.56\ V_p$

$Fr_m = 1.0\ Fr_p$

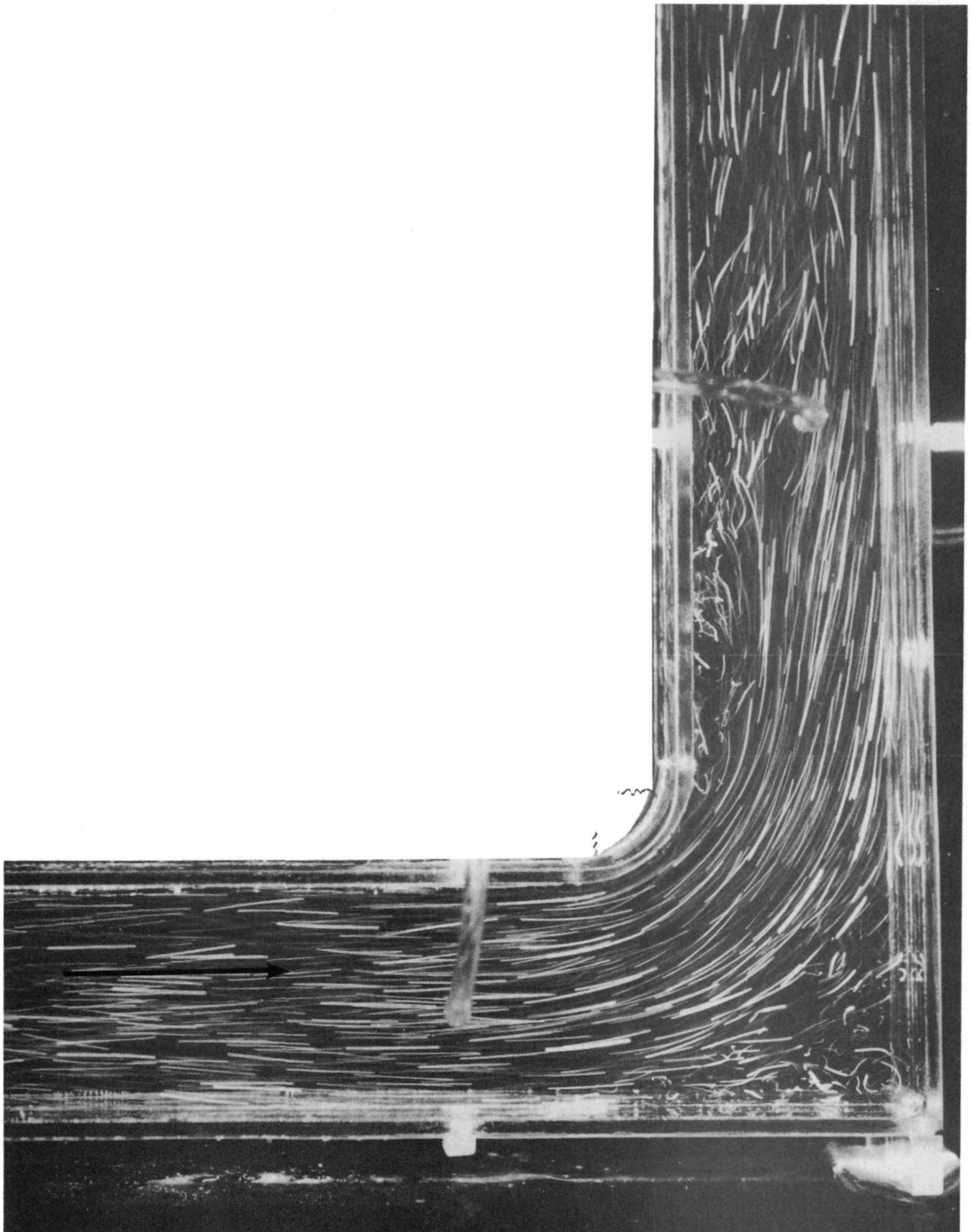
(gravity Control)

1:3.23 Scale Model of Proposed Sodium Distributor Shown in Operation in the Reduced Sector Model



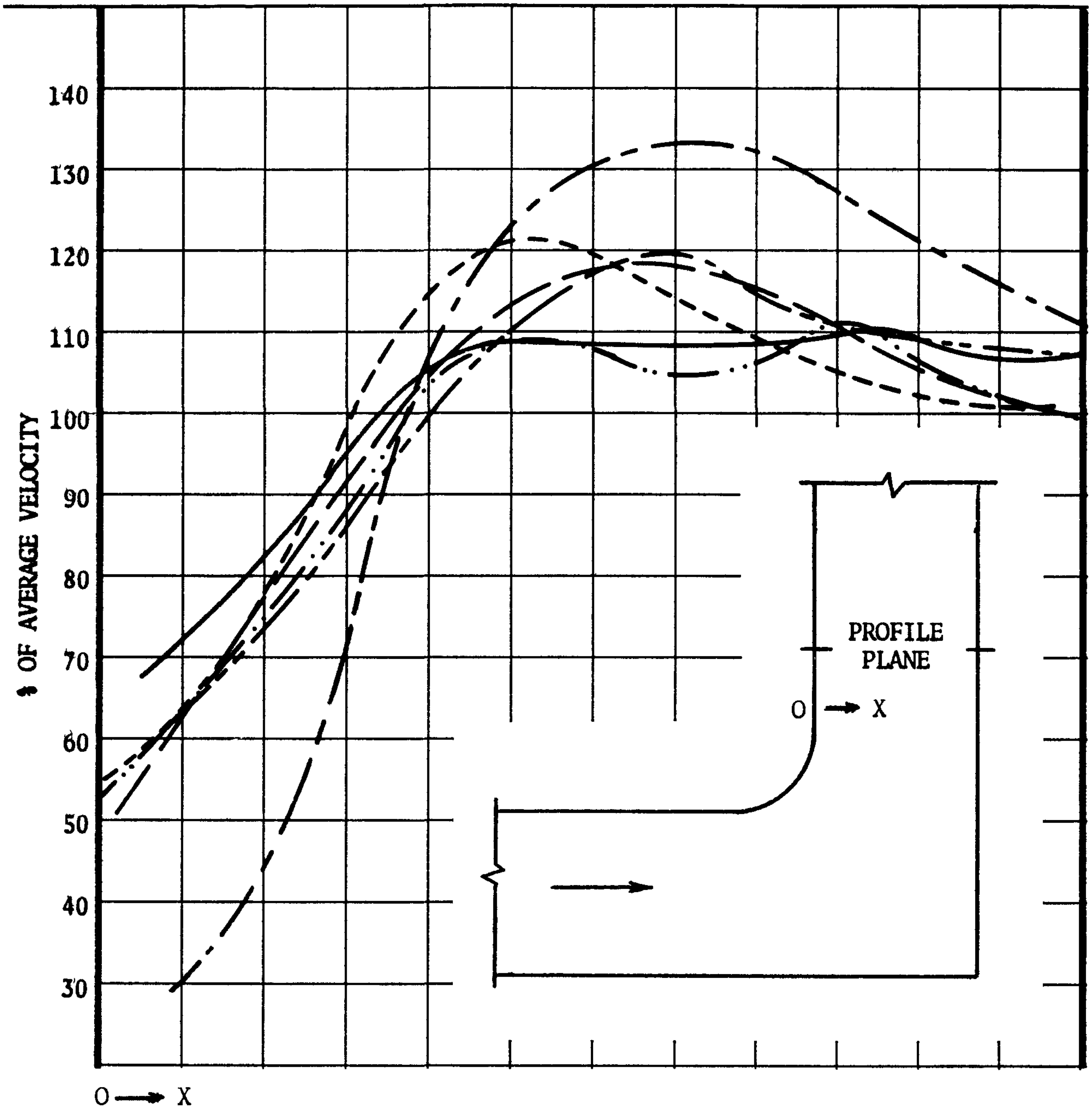
30 MWt PROTOTYPE STEAM GENERATOR SODIUM DISTRIBUTOR

FIGURE A1



FLOW PATTERNS OF A DUCT TURN
(4" x 4" WATER MODEL AT
REYNOLDS NUMBER = 13,100)

FIGURE A2



——— · ———	WATER	Re = 13,100
— — — — — —	WATER	Re = 25,000
——— · · ——— · · —	WATER	Re = 50,000
——— ———	WATER	Re = 75,000
——— · · · ——— · · · —	WATER	Re = 87,500
———————	AIR	Re = 780,000

(NOTE: Air Model was 12" x 12")
Water Model was 4" x 4"

VELOCITY PROFILE FOLLOWING A DUCT TURN AT VARIOUS REYNOLDS NUMBERS WITH AIR & WATER

FIGURE A3