EVALUATION OF THE USE OF AIR CURTAINS TO INCREASE FACE VENTILATION

Prepared for:

United States Department of the Interior
Bureau of Mines

Prepared by:

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Final Report

on

Contract HO357097

June 1977

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M. L. Skow (signature) — M. L. Skow, WOSE — Date 8/8/77

(signature) — Program Division Chief, D. R. Forshey, Acting — Date 8/25/77

(signature) — Assistant Director--Mining, R. L. Marovelli, Acting — Date 11/3/77

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1 INTRODUCTION AND SUMMARY

This contract final report summarizes the design, fabrication and testing of a "line brattice air curtain" device under Bureau of Mines Contract HO357097. The purpose of this program was to develop the concept of using an air curtain for coursing ventilating air parallel with the air curtain from the last open crosscut to the face in exhausting ventilation systems to replace the line brattice cloth in room and pillar coal mining operations.

The final design of the air curtain device consists of a 10-foot long closed end pipe with a slot cut along its length. Pressurized air is delivered to the open end with a hydraulically-driven blower. A sheet of air emanates from the slot and is directed toward the mine roof. An invisible sheet of air is thus created between the top of the machine and mine roof and acts as an extension of the existing conventional line brattice.

The primary advantage of this device is that no manual advancement of the conventional fabric line brattice is required during coal cutting. Because this device is machine-mounted, it advances along with the machine. Upon making an entry into the coal, the conventional brattice is adjacent to the inby end of the air curtain. This permits ten feet of unattended advancement. If the conventional brattice is brought closer than ten feet to the face initially, even more unattended advancement is possible. Other advantages would include improved visibility and improved mobility resulting from the abscence of conventional brattice alongside the machine during much of the coal cutting.

The concept of using air curtains, as replacements for the line brattice, was shown to be valid. The device was designed, fabricated, laboratory tested and field demonstrated in two commercial coal mines. The field test results showed the amount of respirable dust, to which a continuous miner operator was exposed, can be reduced by as much as 31 percent when the conventional line brattice was replaced by an air curtain.

Performance of this contract began on 14 April 1975. The program consisted of twenty-three tasks covering concept evaluation, service requirement calculations, prototype testing, production model full-scale testing in the Bureau's Safety Research Coal Mine in Bruceton, Pennsylvania, and the underground testing of two complete systems at production mine site.

The calculations and preliminary laboratory tests on a 1/4-scale model conducted during Phase I and II indicated that a 100-foot long air curtain which would replace the entire line brattice cloth in a typical entry would not be practical because of the large quantity of airflow required; however, a shorter air curtain at the face end of the entry was deemed practical.

The Phase III laboratory tests in a full-scale mine entry simulator indicated that it is possible to replace the brattice cloth closest to the coal mine working face with an air curtain mounted on top of a continuous mining machine. The air curtain was found to improve face ventilation when compared to a line brattice cloth placed at 10 feet from the working face. Consequently, the requirement that ventilation brattice be maintained at no more than 10 feet from a coal mine working face can be increased by the length of the air curtain. The air curtain lengths tested were from 12 to 16 feet which is dictated by the amount of space available on a typical continuous mining machine.

Phase IV was devoted to the production model design, fabrication and testing at the Bureau of Mine's mine simulator and also at the Safety Research Mine, both located at Bruceton, PA. These tests indicated that the air curtain concept has merit. However, all the tests up to that time were under almost ideal conditions, either in the laboratory or in the Bureau's Safety Research Mine. Consequently, additional funding and time were allocated to the program for underground testing of the device at two working coal mines. This work, performed under Phase V, concluded the technical effort. At one test site, the dust samples indicated a 1.7 percent reduction in operator exposure. At the other site, the dust samples indicated 31 percent reduction in operator exposure with the air curtain in use as compared to normal operation without the air curtain.

A brief background of the problems associated with line brattice cloth face ventilation and the importance of a line brattice air curtain to help solve these problems is presented in Section 2 of this report. Section 3 outlines the contract objective, requirements and overall program plan. Sections 4 through 7 summarize the work done under Phases I through V.

Instructions for the operation and maintenance of the line brattice air curtain are presented in Section 8. Section 9 contains recommended changes to production models. A subject list of inventions is contained in Section 10. The final engineering drawings can be found in the Appendix.

2 BACKGROUND

Dust and methane control have historically been major challenges in the mining industry. The greatest occupational health hazard to underground coal miners is pulmonary pneumoconiosis (black lung disease). This disease is caused by long-term exposure to high concentrations of fine-sized dust generated during the extraction, loading, and transportation of coal underground. In addition, the major cause of disasterous explosions that occur in underground coal mines is the ignition of explosive mixtures of methane and air. When sufficient quantities of combustible, settled coal dust are present, this coal dust may be subsequently thrown into suspension by a methane-air explosion, resulting in an even more extensive explosion. The Federal Coal Mine Health and Safety Act of 1969 has set standards for controlling methane and respirable dust. In addition to the performance standards, it has specified that all coal mines shall be ventilated by mechanical ventilation equipment and that the minimum quantities of air circulating through production sections and single working faces be 9,000 cfm and 3,000 cfm respectively; minimum mean air entry velocity shall be 60 fpm. The Act also specifies that the line brattice used to partition the entry into an air intake and an air return be maintained within 10 feet of the advancing face in order to ventilate the face adequately.

The line brattice cloth is used commonly in the mines to partition the air to the face. However, this method has inherent problems which result in low efficiencies because of losses from leakage. The movement of machinery and the quality of the installation make it difficult to keep the brattice cloth at the desired positions. Consequently, the use of air curtains to replace the function of the brattice cloth at the face would have distinct advantages. Some of these advantages would be: (1) no interference with vision, (2) continual advancement along with machine advancement when mounted on the machine, (3) improved freedom of movement of equipment and (4) ability to maintain good air movement closer to the face. Disadvantages would include: (1) additional equipment to provide a source of air, (2) possible dust generation as the airflow impinges on the roof, (3) additional noise, and (4) loss of adequate face ventilation when miner backs away from face.

In order to evaluate the use of air curtains to improve face ventilation and replace the brattice cloth at the face, the Bureau of Mines awarded Contract HO357097, in April of 1975, to Donaldson Company, Inc. This final report summarizes the findings of this evaluation.

3 CONTRACT DEFINITION

3.1 Contract Objective

The objective of Contract HO357097 was to develop the concept of using an air curtain for coursing ventilating air parallel with the air curtain from the last open crosscut to the face in exhausting ventilation systems to replace the line brattice cloth in room and pillar coal mining operations.

3.2 Design Goals

The following design goals were adopted in order to make the air curtain device more readily compatible with an underground coal mine environment. These goals were not specifically requested in the contract but were considered in the design.

- Minimize power requirements
- Keep size to a minimum (easier to retro-fit)
- Keep profile to a minimum (operator visibility)
- Minimize noise levels
- Minimize maintenance and cost
- Suitably rugged for a coal mine environment (rock fall and impact protection)
- Minimum power requirements (keep airflow and airflow restriction to a minimum)
- Use hydraulic power in order to avoid problems with electrical permissibility

- Performance to be equivalent to or better than existing line brattice used in a six-foot coal seam at a full range of ventilation airflows

3.3 Program Plan

To attain the contract objective, Donaldson Company, in accordance with the contract, was responsible for the overall design, development and test effort. The program was carried out in five phases: Phase I - Concept Evaluation, Phase II - Service Requirements, Phase III - Prototype Design, Phase IV - Production Model Design, Fabrication and Testing, Phase V - Underground Testing of Two Units. A brief discussion of the effort carried out during Phases I through V is provided in the following paragraphs.

3.3.1 Phases I and II

Phases I and II were scheduled as a three month effort starting on 14 April 1975. These two phases were devoted to predicting the service requirements of an effective air curtain through mathematical formulas, flow visualization tests in the laboratory on a 1/4-scale model, air curtain manifold sizing, review of available technical literature, and a preliminary search of domestic patents. Following these tasks, a written summary was prepared and an oral presentation was given at the Bureau of Mines in Bruceton, PA. The calculations and preliminary laboratory tests indicated that a 100-foot long air curtain would not be practical because of the large quantity of airflow required; however, a shorter air curtain at the face end of the entry did appear practical. The Bureau of Mines subsequently granted approval for Phase III.

3.3.2 Phase III

Phase III was scheduled to last 3 1/2 months starting in July 1975. Phase III of this program was devoted to the build-up and test of a full-scale prototype air curtain. The laboratory tests in a full-scale mine simulator indicated that it is possible to replace the brattice cloth closest to the coal mine working face with an air curtain mounted on top of a continuous mining machine. The air curtain was found to improve face ventilation when compared to a brattice placed at 10 feet from the working face. The testing consisted of flow visualization tests and smoke purge time tests on roof-mounted and machine-mounted concepts. A Phase III Summary Report was then prepared and submitted to the Bureau of Mines. The Bureau of Mines subsequently gave approval for the Phase IV effort.

3.3.3 Phase IV

Phase IV, including the preparation and submission of the draft final report was scheduled to last four months. The Bureau of Mines approval of the draft final report, submission of the final report, and the shipment of the equipment and operation and maintenance manuals was scheduled for the next 1 1/2 months. Phase IV technical effort was devoted to the design, fabrication and testing of a production model air curtain. The test program was in three stages. First, the air curtain was subjected to operational checkout tests, smoke purge time tests and noise tests at Donaldson Company's facility. The air curtain was then tested at the mine simulator in Building 19 at the Bureau of Mines facility in Bruceton, PA. These tests were inconclusive and further testing was required. Additional tests were performed at the Bureau of Mines Safety Research Mine in Bruceton, PA. These additional tests required a time extension of two months. Upon completion of these tests, the air curtain indicated that it had enough merit to warrant field tests at actual working underground coal mines. Consequently, an unsolicited proposal was submitted to the Bureau of Mines in May 1976 for an underground test program at two sites. Approval was received in June 1976 for an underground test program. A modification was made to the contract allowing for additional funds and an additional 5 1/2 months.

3.3.4 Phase V

Phase V, including the final report submission and the shipment of the equipment and manuals, was scheduled to last 5 1/2 months. However, two modifications were required for a total effective time extension of 4 1/2 months. These time extensions were required because of difficulties in locating test sites. Additional funding of $2,955 was also required. Phase V consisted of the fabrication and underground testing of two air curtains. The test sites were the Florence No. 1 Mine near Armagh, Pennsylvania and an anonymous Mine A. The tests consisted of dust sampling at the mining machine operator's position and in the intake airway for five shifts with the air curtain in use and five shifts under normal operation at Florence No. 1 . At

Mine A, four shifts of data were taken with the air curtain in use and six shifts without the air curtain. The results from the Florence No. 1 Mine indicated that the air curtain reduced the operator's dust exposure by 31 percent. The test at Mine A indicated a 1.7 percent reduction in operator exposure. One shift, of the six "OFF" shifts at Mine A was eliminated (the entry was in the intake airway, no brattice was used, and the volume of air was inordinately high). Consequently, this shift had a very low total operator dust exposure.

These tests concluded the technical effort on this contract.

4 PHASES I AND II

Phases I and II of this program were devoted to predicting the service requirements of an effective air curtain through mathematical formulas, flow visualization tests in the laboratory on a 1/4-scale model, air curtain manifold sizing, review of available technical literature, and a preliminary search of domestic patents. The results of this effort are described in the following paragraphs.

4.1 Air Curtain Calculations

Calculations were performed to determine the following parameters:

- Pressure differential across air curtain
- Air curtain airflow per linear foot required to resist the pressure differential
- Air curtain jet pressure
- Manifold and ducting restriction
- Fan selection and power requirements
- Fan noise generation

4.1.1 Pressure Differential

The pressure differential across the air curtain was calculated for face ventilation of 30,000 cfm at rib distances of 2 ft and 6 ft and also for 10,000 cfm at rib distances of 2 ft and 6 ft. The Atkinson equation for friction was used:

$$H_f = \frac{KPLQ^2}{5.2A^3}$$

where: Q = ventilation airflow, cfm

A = area, ft^2

L = airway length, ft

P = wetted perimeter, ft

K = friction factor for air at standard density = 70×10^{-10} (from Mine Ventilation and Air Conditioning Table 5-1, pg. 90)

Le = equivalent length for sources of shock loss, ft (replaces L)

The total pressure differential for a 100 ft entry can be expressed by:

$$\Delta P_{total} = H_1 + H_B + H_M + H_2$$

where: H_1 = 100 foot length airway to face

H_B = acute bend of airway at face

H_M = loss due to machine blocking 40 percent of area

H_2 = 100 foot length airway from face

Table 1 below presents the total pressure differentials calculated and also the equivalent wind velocity that would cause such a dynamic pressure. These parameters give one a "feel" for the resistance an air curtain presents.

Table 1. Air Curtain Pressure Differential

Ventilation Airflow	10,000 cfm		30,000 cfm	
Rib Distance	2 ft	6 ft	2 ft	6 ft
ΔP_{total}	0.14 in. wg	0.027 in. wg	1.25 in. wg	0.24 in. wg
Equivalent Velocity	16.9 mph	7.4 mph	50.4 mph	22.1 mph

Figure 1 presents the entry pressure versus the distance into the entry up to a maximum of 110 feet. This plot shows that the least pressure differential is at the face end of the entry. This means that the air curtain requirements would be lower at the face end.

4.1.2 Air Curtain Airflow

The equations used to determine the air curtain airflow and jet pressure are based on the air cushion vehicle principle as used by Gerard Grassmuch in his paper, "The Applicability of Air Curtains as Air Stoppings and Flow Regulators" (given at the 71st Annual General Meeting, Canadian Institute of Mining and Metallurgy, April 22, 1969, Montreal, Canada).

The expression for jet pressure is given by:

$$H = hPc \frac{[1 + {}^{t}/h\ (1 + \cos\theta)]}{2t\ (1 + \cos\theta)}$$

H = jet pressure, lb/ft^2
h = jet throw or ceiling height, ft
Pc = pressure differential across air curtain, lb/ft^2
t = slot width, ft
θ = slot angle from horizontal

After solving H, one can solve for the air curtain airflow per foot:

$$Q = VA = t\left[\frac{2}{\rho}(H - Pc/2)\right]^{1/2}$$

$\rho = 2.378 \times 10^{-3}\ slugs/ft^3$ = air density at standard conditions

Tables 2 and 3 present the jet airflows and pressures for various slot angles and widths. Most of the data is for an air curtain throw of h = 6 ft. However, if the air curtain is mounted on top of a mining machine and directed at the ceiling, the throw is assumed to be h = 3 ft. Note the significant reduction in airflow requirements. In addition, the pressure differential (Pc) used for these calculations was for the face end of the entry which lowers the airflow requirements of the air curtain.

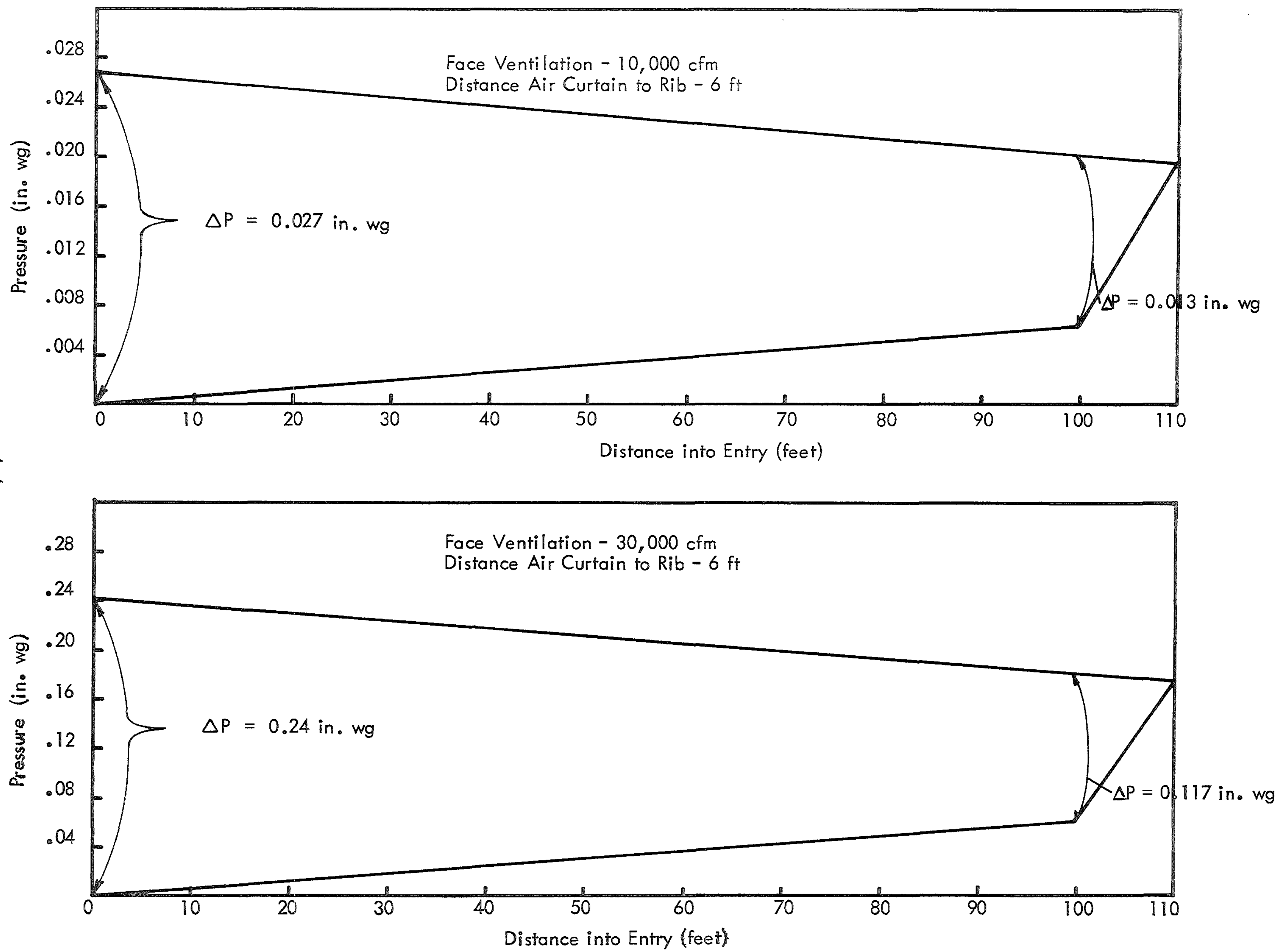
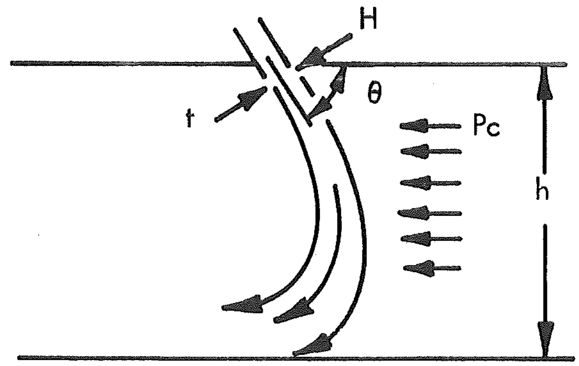


Figure 1. Entry Pressure versus Distance into Entry

Table 2. Airflow Requirements (Ventilation Flow 10,000 cfm)



Conditions:

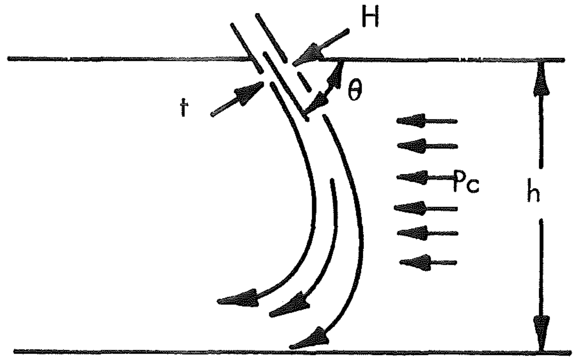
Ventilation Flow 10,000 cfm

Rib Distance 6 feet

Slot Angle, θ	Slot Width t (inches)	Jet Pressure H (in. wg)	Jet Airflow Q (cfm/ft)		
90°	0.125	1.87	56.4		
80°	0.125	1.59	52.1		
60°	0.125	1.25	46.1	- *56.9	h = 3 ft
45°	0.125	1.10	43.2		
30°	0.125	1.00	41.3		
90	0.125	3.73	79.8		
80	0.125	3.18	73.7		
60	0.125	2.49	65.2	- *80.5	h = 6 ft
45	0.125	2.19	61.1		
30	0.125	2.00	58.4		
90	0.250	1.87	112.9		
80	0.250	1.59	104.2		
60	0.250	1.25	92.1	- *113.8	h = 6 ft
45	0.250	1.10	86.4		
30	0.250	1.00	82.6		
90	0.500	0.94	159.6		
80	0.500	0.80	147.3		
60	0.500	0.68	135.8	- *160.9	h = 6 ft
45	0.500	0.55	122.2		
30	0.500	0.51	116.8		

* Theory by Y. Nitsu & T. Katoh

Table 2. Airflow Requirements (Ventilation Flow 10,000 cfm) (continued)

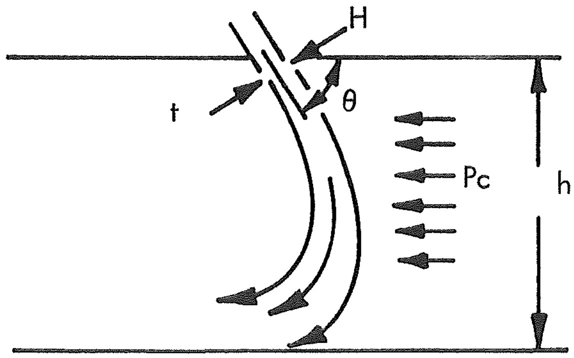


Conditions:
Ventilation Flow 10,000 cfm
Rib Distance 6 feet

Slot Angle, θ	Slot Width t (inches)	Jet Pressure H (in. wg)	Jet Airflow Q (cfm/ft)	
90	0.750	0.63	195.5	
80	0.750	0.54	180.4	
60	0.750	0.42	159.6 - *197.1	
45	0.750	0.37	149.6	h = 6 ft
30	0.750	0.34	143.1	
90	1.00	0.47	225.7	
80	1.00	0.40	208.3	
60	1.00	0.32	184.3 - *227.6	
45	1.00	0.28	172.8	h = 6 ft
30	1.00	0.26	165.2	

* Theory by Y. Nitsu & T. Katoh

Table 3. Airflow Requirements (Ventilation Flow 30,000 cfm)



Conditions:
Ventilation Flow 30,000 cfm
Rib Distance 6 feet

Slot Angle, θ	Slot Width t (inches)	Jet Pressure H (in. wg)	Jet Airflow Q (cfm/ft)	
90	0.125	34.61	243.0	h = 6 ft
80	0.125	29.50	224.3	
60	0.125	23.09	198.4 - *245.5	
45	0.125	20.30	186.0	
30	0.125	18.57	177.9	
20	0.500	4.50	348.9 - *358.2	h = 6 ft
80	0.750	4.97	546.0	

* Theory by Y. Nitsu & T. Katoh

An alternate equation for air curtain calculations was found in "Performance and Design of Air Curtains", by Y. Nitsu and T. Katoh, (Society of Heating, Air Conditioning and Sanitary Engineers of Japan, Transactions, Vol. 1, 1963, p. 1).

$$Ha = \frac{2 \rho A'o \, Uo^2 \sin \beta o}{Ps}$$

where:

Ha = air curtain throw, ft

$A'o$ = slot width, ft

Uo = jet velocity at outlet, ft/sec

Ps = side pressure, lb/ft^2

βo = jet angle from vertical, deg

ρ = air density, $slugs/ft^3$

solving for airflow ($Q = Uo \, A'o$, cfm/ft) the equation becomes:

$$Q = \left[\frac{1800 \, HaPsA'o}{\rho \sin \beta o} \right]^{1/2}$$

This equation was found to be within about 20 percent of the air cushion equation. One point at $\theta = 60^{\circ}$ (or $\beta o = 30^{\circ}$) was chosen as a comparison and is also presented on Tables 2 and 3.

4.1.3 Manifold and Ducting Restriction

In order to determine the fan size and power requirements, one must determine the head and flow requirements. Consequently, three different configurations were selected which appear to be the most feasible. These configurations are described on Table 4. A 6-inch diameter manifold was selected because it is felt that anything larger would be cumbersome and subject to damage. The 15-foot length was chosen because this is the approximate length available for mounting on a typical continuous mining machine. Figure 2 illustrates a machine-mounted air curtain. This configuration would also generate less dust than would the others which impinge on the mine floor.

Table 4. Fan Size and Power Requirements

FAN PARAMETERS	CONFIGURATION A		CONFIGURATION B		CONFIGURATION C	
	1725 rpm	3450 rpm	1725 rpm	3450 rpm	1725 rpm	3450 rpm
-AIRFLOW (cfm)	1197	1197	1197	1197	846	846
-FAN HEAD (in. wg)	18.01	18.01	7.96	7.96	3.09	3.09
-FAN DIAMETER/POWER to FAN						
backward-curved centrifugal (high W/D)	-NA-	-NA-	-NA-	26.7" 2.2 hp	31.2" 0.61 hp	18.9" 0.66 hp
backward-curved centrifugal (low W/D)	47.9" 7.4 hp	26.7" 6.5 hp	34.8" 2.8 hp	-NA-	-NA-	-NA-
forward-curved centrifugal	-NA-	23.0" 7.7 hp	30.6" 3.7 hp	16.5" 3.0 hp	19.8" 0.79 hp	-NA-
vane-axial	-NA-	-NA-	-NA-	-NA-	-NA-	11.3" 0.61 hp

-NA- not applicable

CONFIGURATION A -
Air curtain throw - 6 ft
Distance to rib - 6 ft
Face ventilation - 10,000 cfm
Manifold - 15 ft long, 6 in. dia, 1/8 in. slot
Ducting - 100 ft long, 6 in. dia, one 90° elbow

CONFIGURATION B -
Same as Configuration A above except,
Ducting - 12 ft long, 6 in. dia, two 90° elbows

CONFIGURATION C -
Air curtain throw - 3 ft
Distance to rib - 6 ft
Face ventilation - 10,000 cfm
Manifold - 15 ft long, 6 in. dia, 1/8 in slot
Ducting - direct connect to manifold with one 90° elbow (machine-mounted)

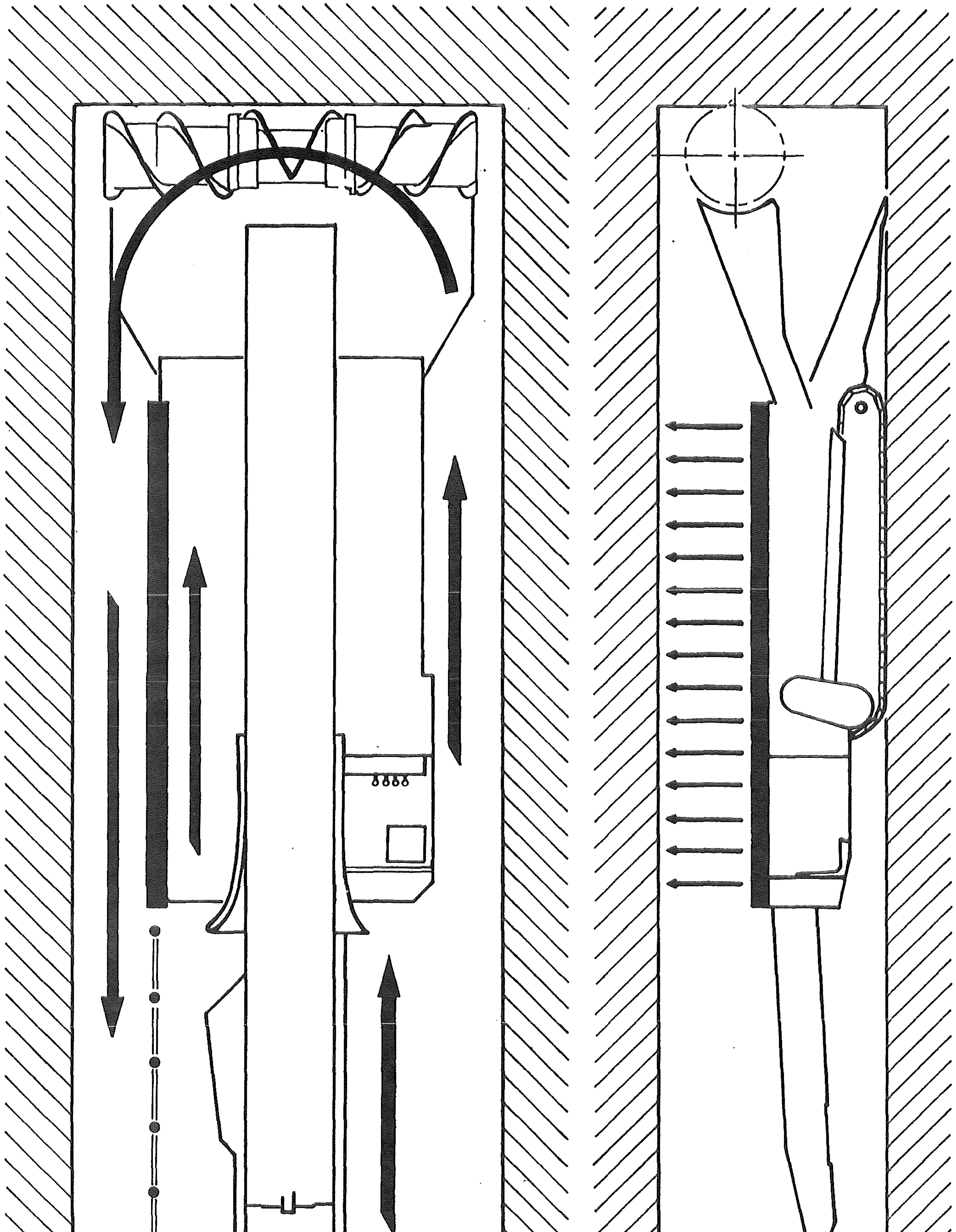


Figure 2. Machine-Mounted Air Curtain

The total air curtain airflows were determined by multiplying 15 feet by the airflow per foot from Table 2 for $\theta = 90^\circ$ (worst case). The ducting was assumed to be a commercially available helical wire-covered hose. The restriction of Configurations A, B and C were then calculated.

The discharge angle of the manifold will be something less than 90° according to the equation,

$$\cot \theta = \frac{AsCd}{Ad}$$

where:

- θ = discharge angle from a long slot
- As = area of slot
- Ad = area of manifold duct
- Cd = discharge coefficient

This equation was taken from "The Control of Air Streams from a Long Slot", by Alfred Koestel and Chia-Yung Young, (presented at semi-annual meeting of The American Society of Heating and Ventilating Engineers, Portland, Oregon, July 1965). See Figure 3 for representation of discharge angle and Figure 4 for air-stream envelope shape taken from Koestel's paper entitled "The Discharge of Air from a Long Slot". Testing will have to be conducted to determine the effect of discharge angle on the air curtain effectiveness.

4.1.4 Fan Selection and Power Requirements

After finding the total airflow and fan head required, the fan size and power requirements were calculated for 1725 rpm and 3450 rpm. The data is presented on Table 4. Configuration C requires a fan size and power that appears workable for mounting on a typical mining machine. Configuration B appears to be feasible for a floor-mounted fan. It would be small enough so as not to be in the way of machine movement.

The fan sizing equations were obtained from "Packing the Maximum Fan in the Minimum Space:, by Carlos C. Chardon and Ira J. Ray, Machine Design, September 20, 1973, pg. 152-156.

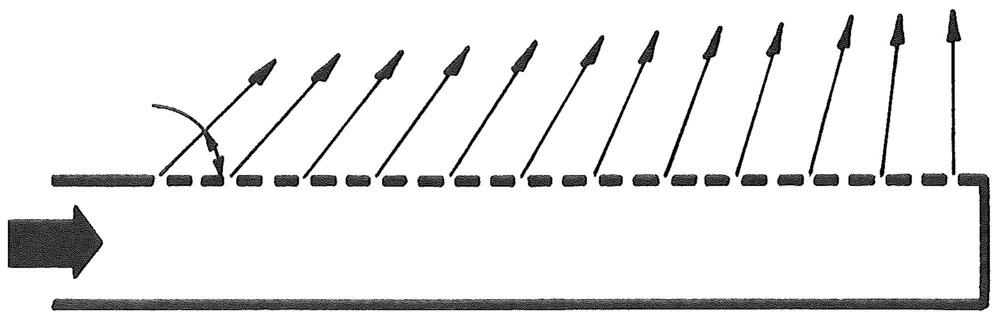


Figure 3. Discharge Angles

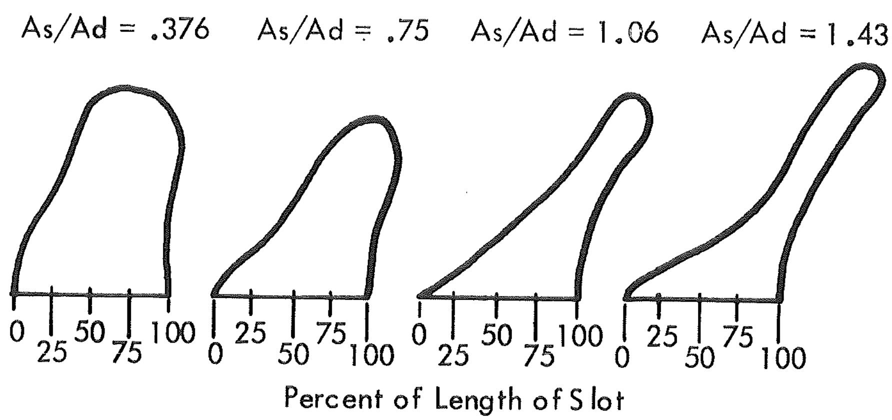


Figure 4. Shape of Air-Stream Envelopes As Slot Area Is Increased*

*Taken from "The Discharge of Air From a Long Slot", pg. 96 Figure 11.

The major dimension, A, is determined first by calculating the specific speed, Ns, and then referring to Figure 2 in the above document for the apparent pressure coefficient, ψ_a.

$$Ns = \frac{N (Q)^{1/2}}{(Ps\, \rho o/\rho)^{0.75}}$$

where:

N = fan speed, rpm
Q = airflow, cfm
Ps = head, in. wg
ρo = air density at sea level, lb/ft^3
ρ = density corrected for altitude, lb/ft^3

$$A = \left[\frac{2.35 \times 10^8\ Ps}{N^2\ \psi_a}\right] (\rho o/\rho)$$

The power delivered to the fan is expressed by:

$$Pf = QPs/8.52\ \eta f$$

where: ηf = fan efficiency (from Figure 1 of above document)

The electrical power input is defined by:

$$Pi = Pf/\eta m$$

where: ηm = motor efficiency

4.1.5 Fan Noise Generation

The sound power level for four of the fans described on Table 4 was calculated. The fan noise estimation method is presented is in the magazine article "How to Estimate Fan Noise" by J. Barrie Graham, Sound and Vibration, May 1977, pg. 24-28.

The method utilizes Table 1 in the above article for specific sound power levels and blade frequency increments for various types of fans. In addition, the following equation for the estimated sound power level, Lw, is used:

$$Lw = Kw + 10 \log Q + 20 \log P$$

where: Q = airflow, cfm

P = pressure, in. wg

The blade frequency, Bf, is determined by:

$$Bf = rpm \times no.\ blades/60$$

This blade frequency indicates which octave band to add the "blade frequency increment", BFI. The BRI is obtained from Table 1 of the above article.

The calculations were performed and the results are shown below.

Configuration A		
	backward-curved centrifugal (3450 rpm)	97.1 dB(A)
Configuration B		
	backward-cruved centrifugal (3450 rpm)	90.0 dB(A)
Configuration C		
	backward-curved centrifugal (3450 rpm)	80.2 dB(A)
	vane-axial (3450 rpm)	90.0 dB(A)

4.2 Flow Visualization Tests

Because of a lack of prior technology on the use of an air curtain as a partition between two parallel and opposite flowing streams of air, a 1/4-scale model of a mine entry was fabricated for flow visualization tests. This model enabled visible white smoke to be injected at various points along the simulated entry and also into the air curtain itself. The smoke was generated by means of mixing anhydrous ammonia and sulphur dioxide together with two impinging nozzles. The resulting mixture is a highly visible white smoke - ammonium sulfite. Ventilation air was introduced on one side (intake side) and the smoke-laden air on the return side was directed outdoors. The ventilation airflow was adjusted such that its velocity was 100 ft/min which is typical of a coal mine. The air curtain construction consisted of a 3-1/2 in. i.d. x 42 in. long closed-end tube with a

0.05 in. slot cut along its length. The airflow to the curtain and the jet angle were adjusted until a viable jet profile was attained. The airflow was 110 cfm at an angle of less than 10 degrees. Photographs were taken of the smoke tests. Five of the most representative views were included on Figures 5 through 9. An explanation of each is given on the following page.

Figure 5: Air Curtain Profile - This photograph illustrates the shape of the air curtain with incoming air on the left (higher pressure) and the return air on the right.

Figure 6: Smoke Injected at Intake Side (Air Curtain Off) - This photograph indicates that without the air curtain there is no apparent movement of ventilation air to the face.

Figure 7: Smoke Injected at Intake Side - This view can be compared to the previous photograph in that it represents the same point of smoke injection only with the air curtain in operation. Note that there is a definite migration of smoke across the face and out the return side on the right and that the intake side is free of smoke. This photograph indicates that the concept does provide a viable barrier between the intake and return sides.

Figure 8: Smoke Injected at Face - This photograph shows there is little if any cross-over of smoke into the intake side. It also shows the direction of air movement.

Figure 9: Smoke Injected at Return Side - This again shows the airflow direction and that the face is indeed being coursed with ventilation air.

4.3 Manifold Design

In order to deliver and distribute a sheet of air, some type of long manifold is required which has a relatively uniform airflow along its length. To obtain an even airflow along the length of a manifold with either a series of holes or a continuous slot, one must balance two factors: 1) Inertia, and 2) friction. Inertia corresponds to the change in velocity head. As the air is discharged along the length of the manifold, the airflow is decelerated. According to Bernoulli's theorem, this tends to increase the pressure. On the other hand, friction results in loss of pressure along the length. Consequently, it is possible to proportion the area along the length of the manifold to balance these two opposing factors.

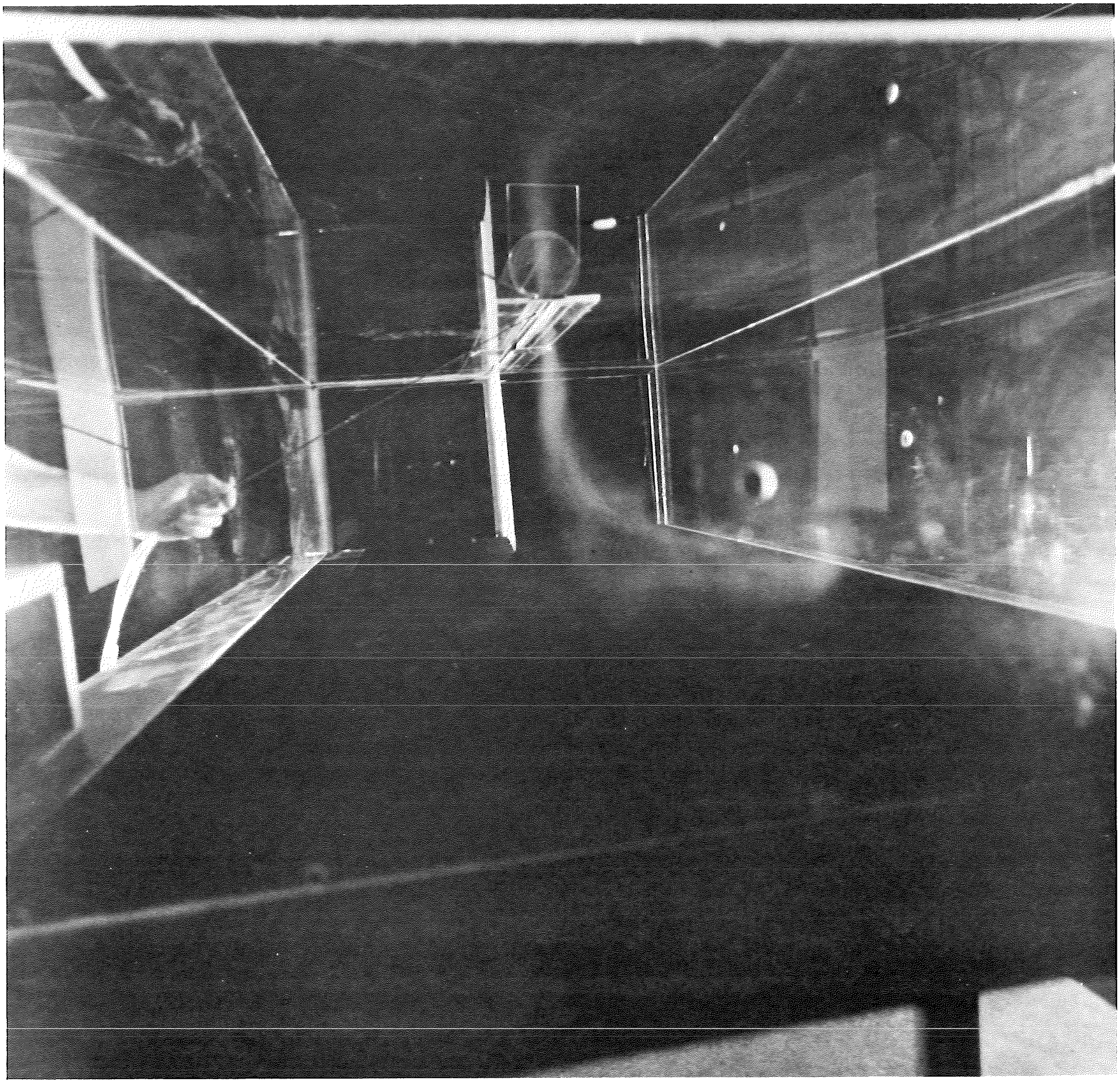


Figure 5. Air Curtain Profile

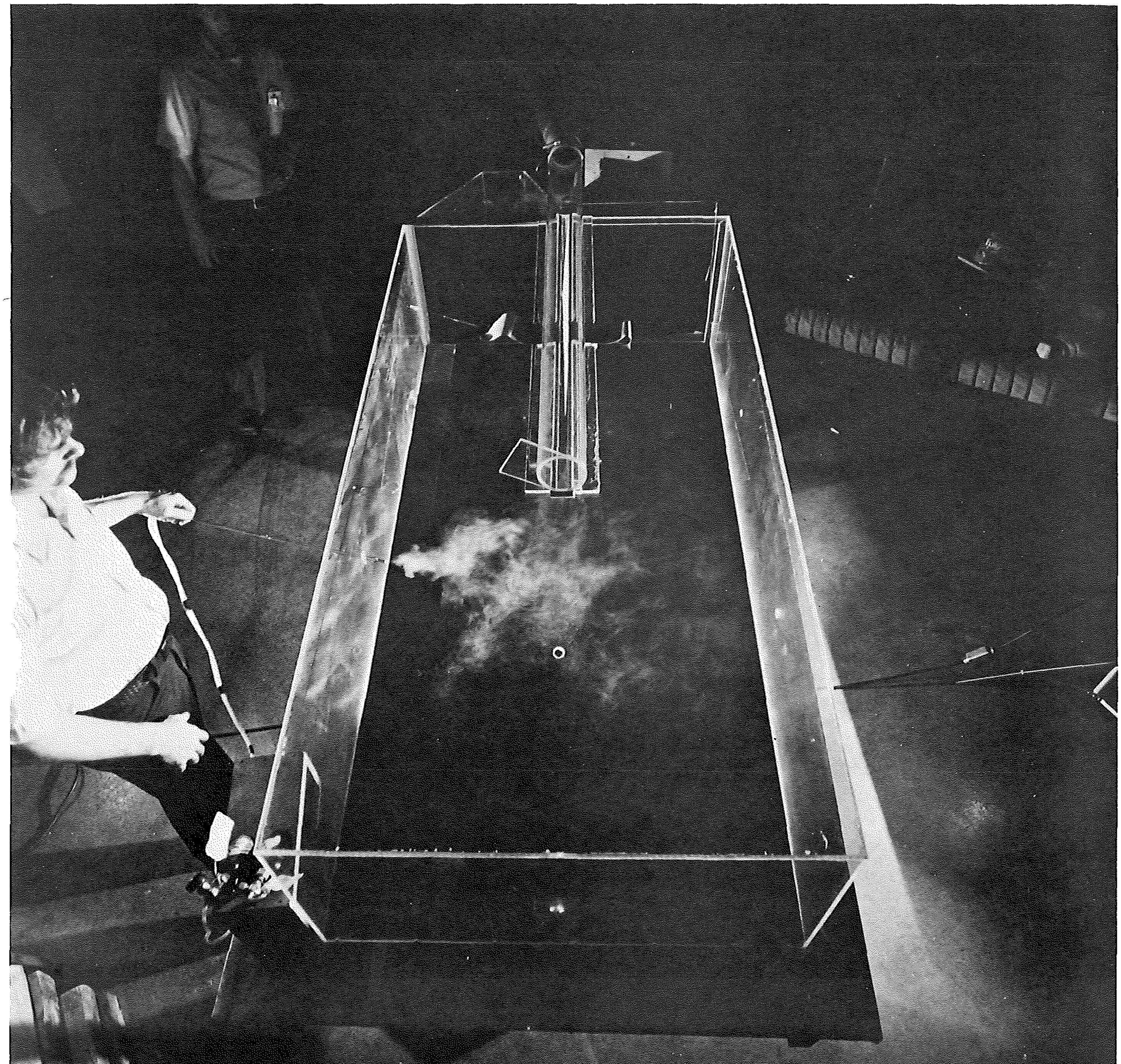


Figure 6. Smoke Injected at Intake Side
(Air Curtain Off)

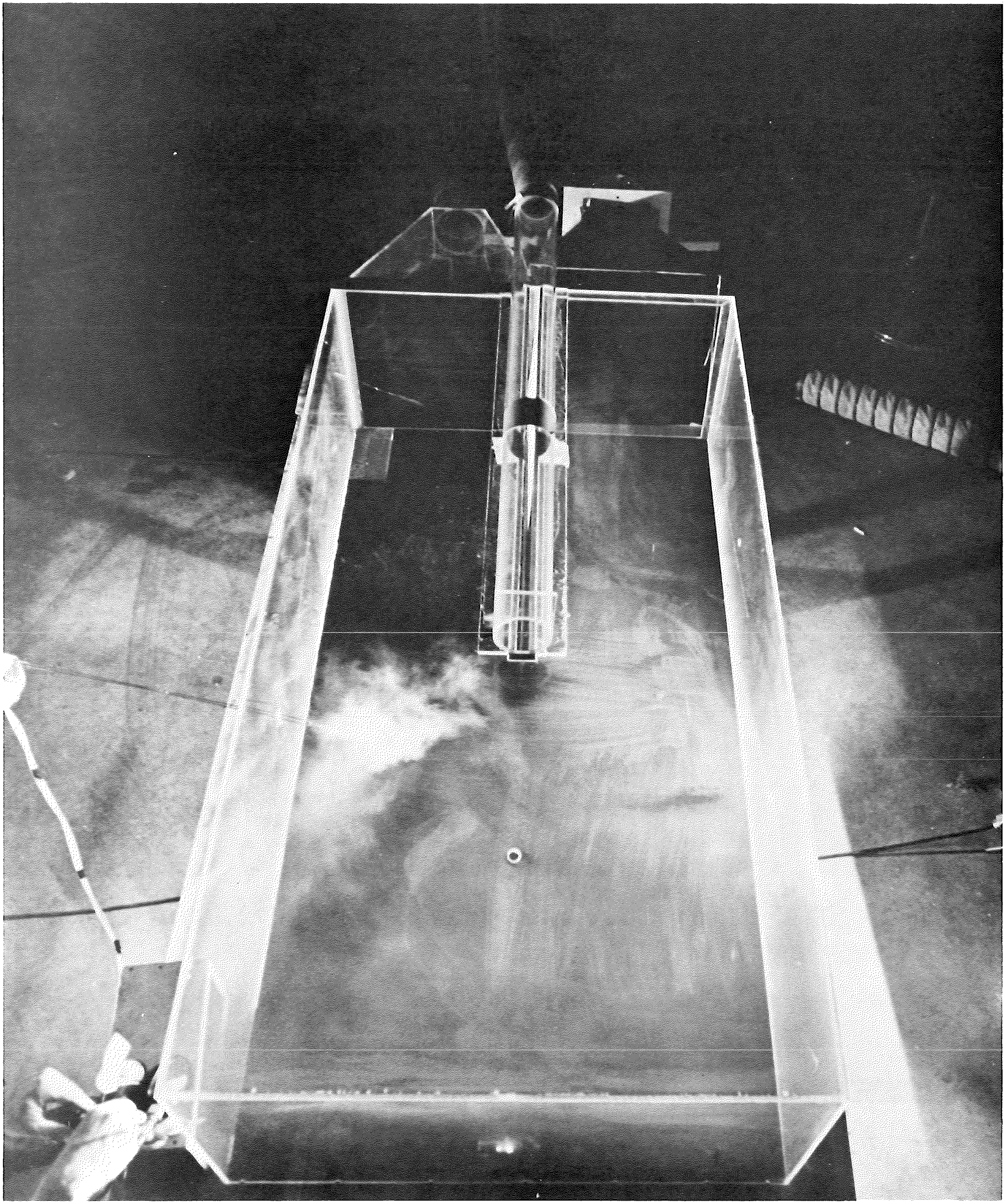


Figure 7. Smoke Injected at Intake Side

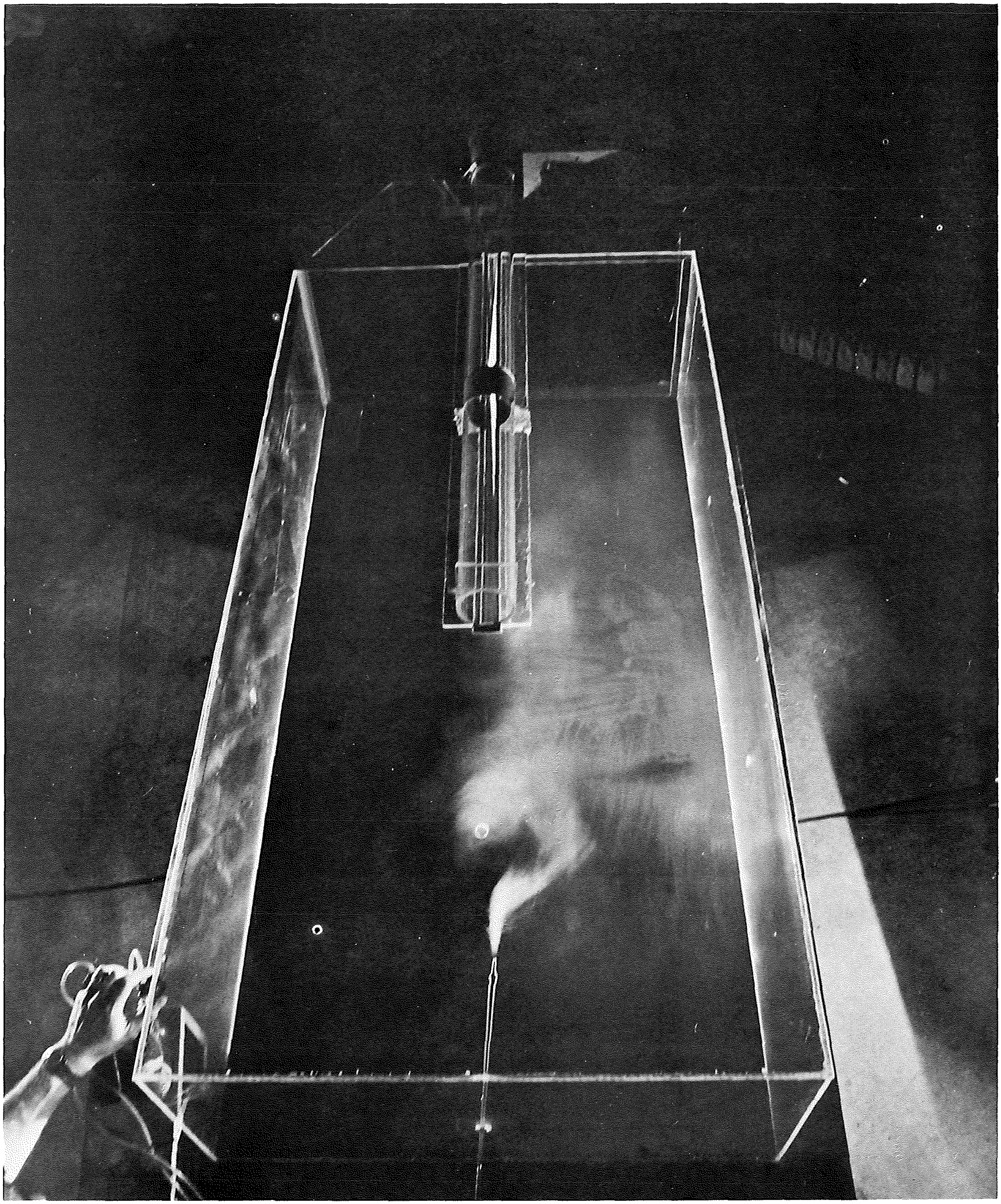


Figure 8. Smoke Injected At Face

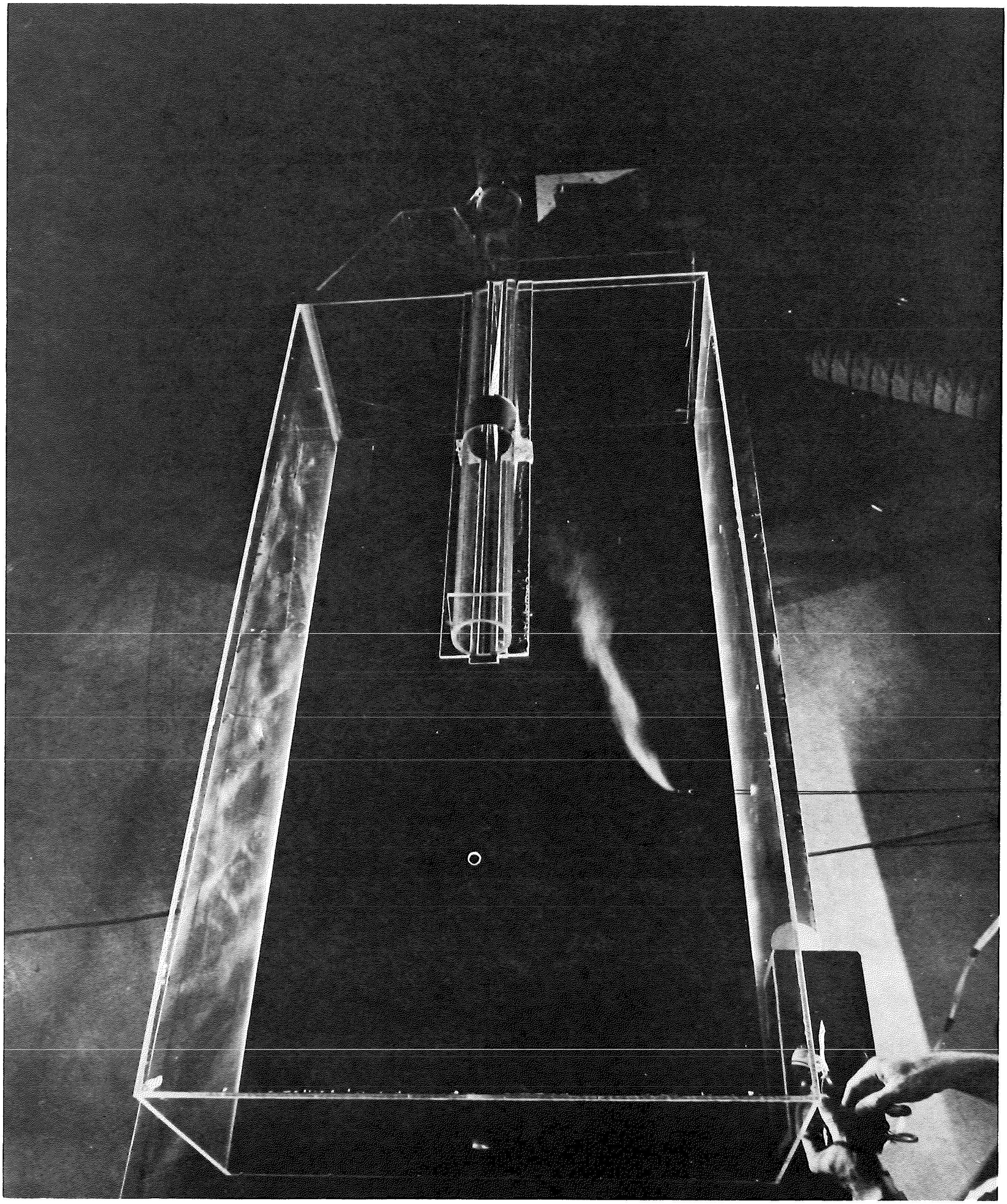


Figure 9. Smoke Injected at Return Side

Another parameter that must be considered in the design of an air curtain is the discharge angle of the air flowing from a slot in the face of the duct. A paper by Alfred Koestel and G. L. Tuve (see bibliography) presents a study which describes the effects of the ratio of the slot area to the area of the duct on the air discharge angle. It was found that for area ratios of As/Ad less than 0.4, the air will discharge at angles approaching 90 degrees along the length of the slot. The shape of the airstream envelope changes as the area ratio changes. As the area ratio increases, the shape becomes more distorted. In other words, with a high As/Ad, the throw of the air at the end of the duct becomes more concentrated. Laboratory tests later in the program indicated that discharge angles of less than 90 degrees did not cause efficiency problems. In fact, this angle was used to aid the performance by directing the angle toward the return side of the airway.

There are many ways to proportion the open area of the manifold to get an even airflow. The simplest method is to use a closed-end tube with a slot along its length and the ratio of slot area to duct area as low as possible. This method can result in a fairly even airflow, but there will always be some distortion. Also, the discharge angle will be something less than 90 degrees. Another approach would be to vary the open area along the manifold length by tapering the slot width or using varying sizes of holes along its length. Both of these methods are impractical from a manufacturing standpoint.

Still another approach would be to vary the cross section of the manifold along its length. This can be done by tapering a rectangular duct or by approximating a tapered tube by attaching decreasing diameter of tubes end-to-end. Figures 10 and 11 illustrate these two concepts. A computer program was used to determine a profile for these two concepts. The following assumptions were used to determine the best profile:

Manifold length	-	15 feet
Airflow	-	60 cfm/ft
Maximum diameter	-	6 inches

Figure 11 presents the profile for the best fit of a segmented pipe manifold. Figure 12 presents the profile for the best fit of a tapered rectangular manifold which is curved. A linear taper is also shown which results in a very close approximation and would be easier to manufacture.

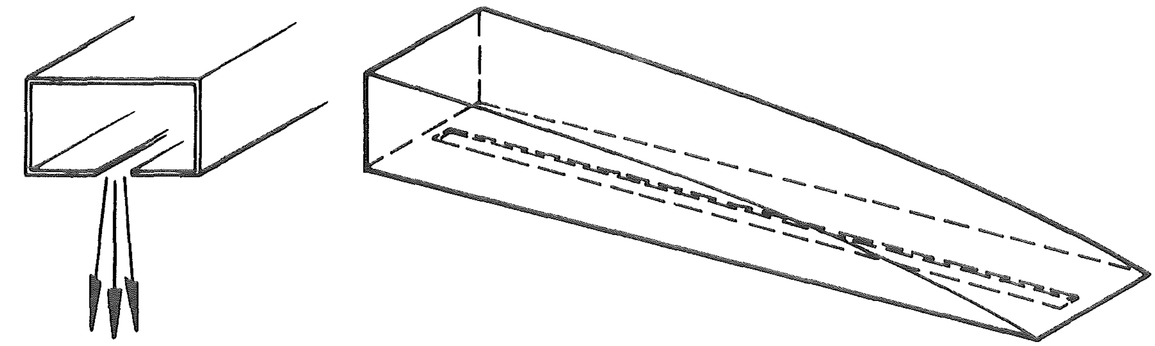


Figure 10. Tapered Rectangular Duct

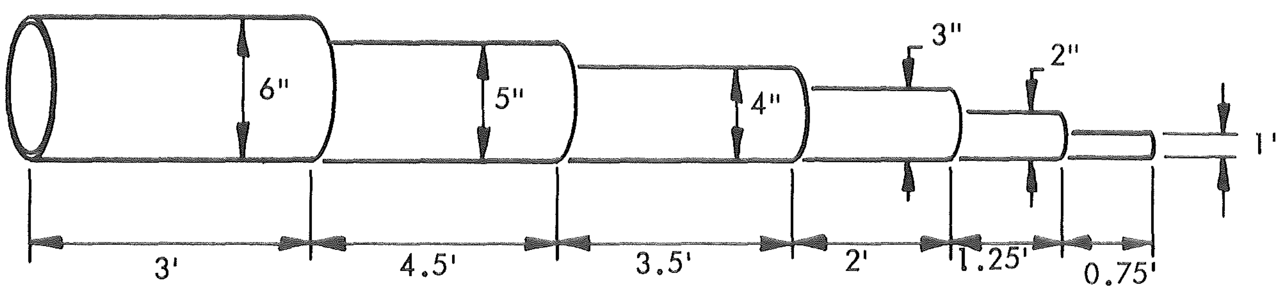


Figure 11. Segmented Pipe Approximation

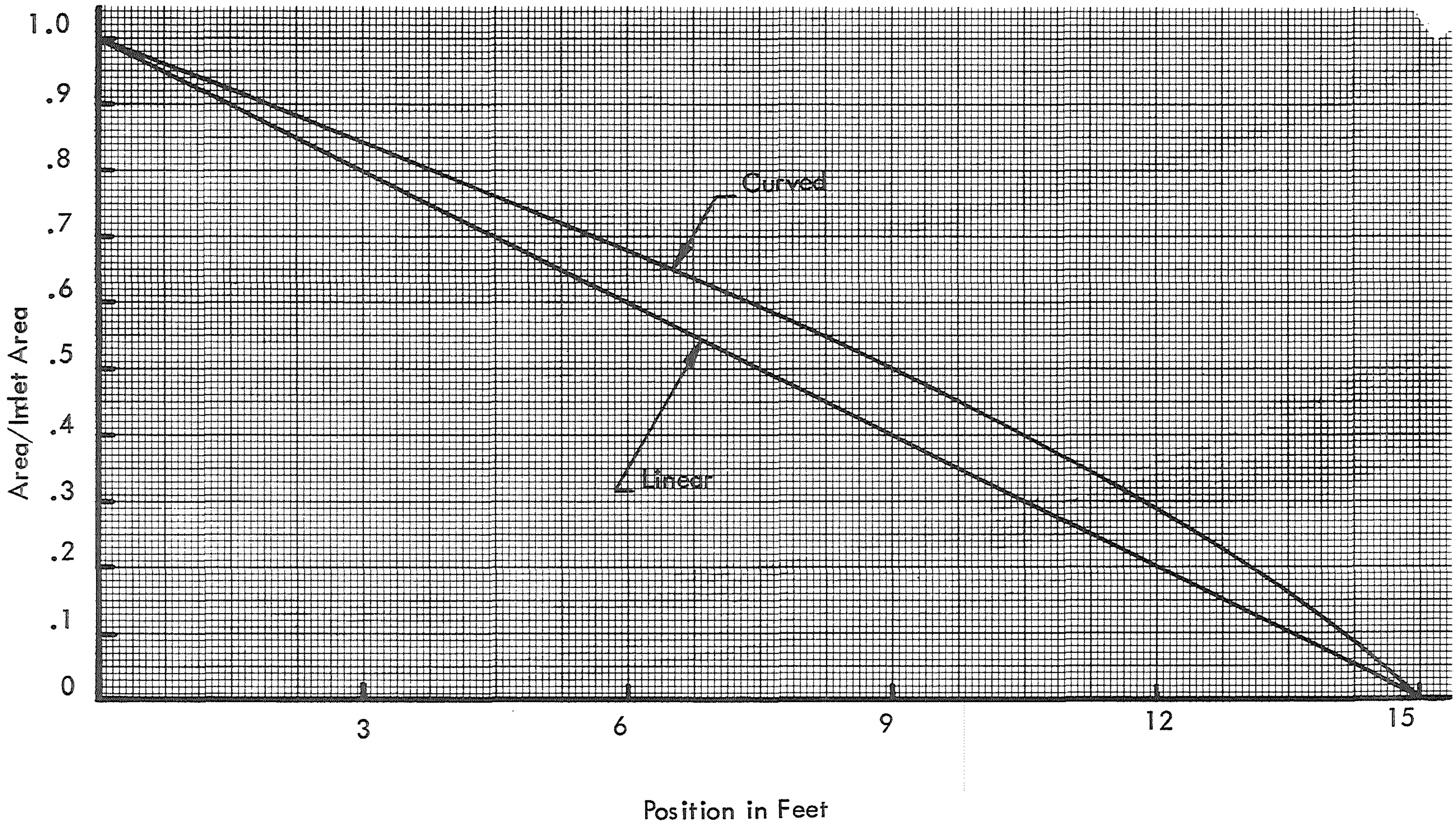


Figure 12. Profile For Tapered Rectangular Duct

4.4 Literature and Patent Search

A search of domestic patents was conducted in the U.S. Patent Office to determine if air curtains have been used as a substitute for line brattice in underground mines. The following U.S. Patents were uncovered: #3,289,567; #2,059,630; #3,603,644; #3,464,756; #3,824,911; #3,558,193; #3,863,554; #3,640,580; and #3,715,969.

The subject patents disclose "state of the art" devices for ventilating the working face of an underground mine; however, the specific concept in question was not found. Patents #3,289,567 and #2,059,630 appeared to be the most pertinent but were not specifically applicable.

The classes searched include:

- Cl. 55 "Gas Separation"
  - Digest 29 "Air Curtain"
- Cl. 98 "Ventilation"
  - Subclass 36 "Protecting Air Current"
  - Subclass 49 "Railway Tunnels and Subways"
  - Subclass 50 "Mines"
- Cl. 61 "Hydraulic and Earth Engineering"
  - Subclass 42 "Tunnels"
  - Subclass 84, 85 "Tunnel Shields"
- Cl. 229 "Mining or in Situ Disintegration of Hard Material"
  - Subclass 12 "Mine Safety"
  - Subclass 19 "Mine Layouts"

A literature search was also conducted. A bibliography of the literature obtained is given on the following pages.

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5 PHASE III

Phase III of this program was devoted to the build-up and test of a full-scale prototype air curtain. In order to simulate a coal mine face and brattice ventilation system, a 32 ft long by 12 ft wide by 6 ft high chamber was constructed. In addition, a plywood mock-up of a mining machine was installed in the chamber for the machine-mounted air curtain tests. This mock-up was 26 ft long by 8 ft wide by 3 ft high which is typical of a continuous mining machine. Exhaust fans were built into the return side and were ducted to the outside; consequently, the ventilation air which was smoke-laden from flow visualization tests was separated from the intake side. The set-up, depicted in Figure 13, proved effective for flow visualization tests using white smoke. The face end of the chamber was painted flat black to improve visibility.

The air curtain manifold assembly consists of a 6 in. i.d. by 16 ft long PVC plastic pipe with a slot cut along its length. The slot width can be varied by means of a spreading mechanism shown in Figure 14. The testing consisted of flow visualization tests on both the roof-mounted and machine-mounted concepts and also smoke purge time tests on the machine-mounted concepts.

5.1 Flow Visualization Tests without Machine Mock-Up

Flow visualization and airflow restriction tests were conducted on the roof-mounted configuration. A mining machine mock-up was not used for these tests; consequently, the "throw" required of the air curtain was approximately six feet. The tests indicated that an airflow of 1,000 cfm and a slot width of 1/8 in. provide a viable barrier between the intake and return sides. The ventilation air velocity at the intake side was measured to be a nominal value of 250 ft/min. Highly visible white smoke was used to observe the airflow through the chamber. It was observed that with the air curtain off, smoke generated at the face end of the chamber remained stagnant. However, when the air curtain was turned on, this smoke was quickly flushed to the return side.

Airflow restriction tests were performed on the air curtain with a 15.7 ft long x 1/8 in. wide slot. At 1,000 cfm, the restriction or jet pressure was 1.5 in. wg. Figure 15 presents a plot of airflow versus restriction. Theory indicates that 58.4 cfm per linear

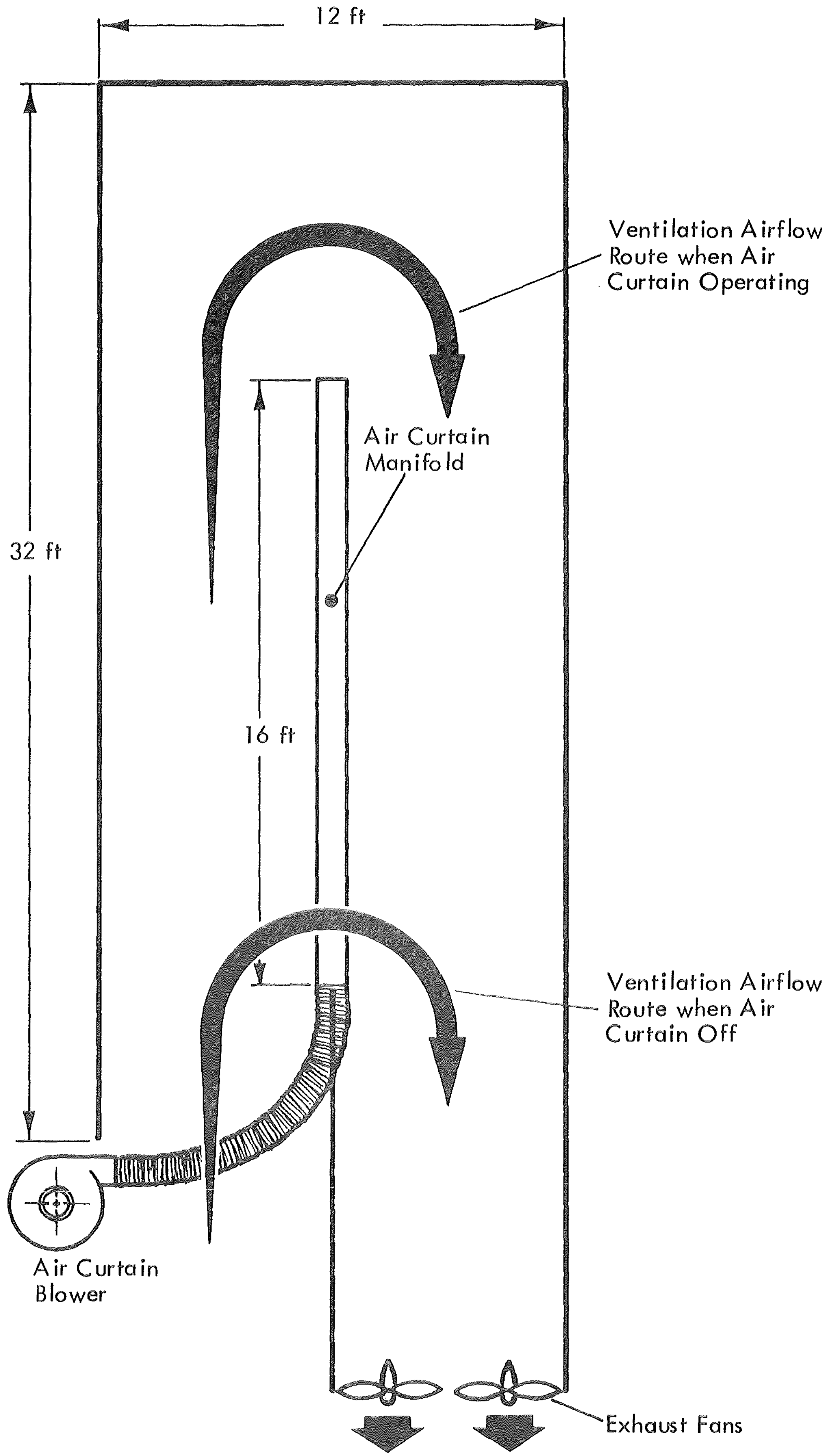


Figure 13. Full Scale Chamber

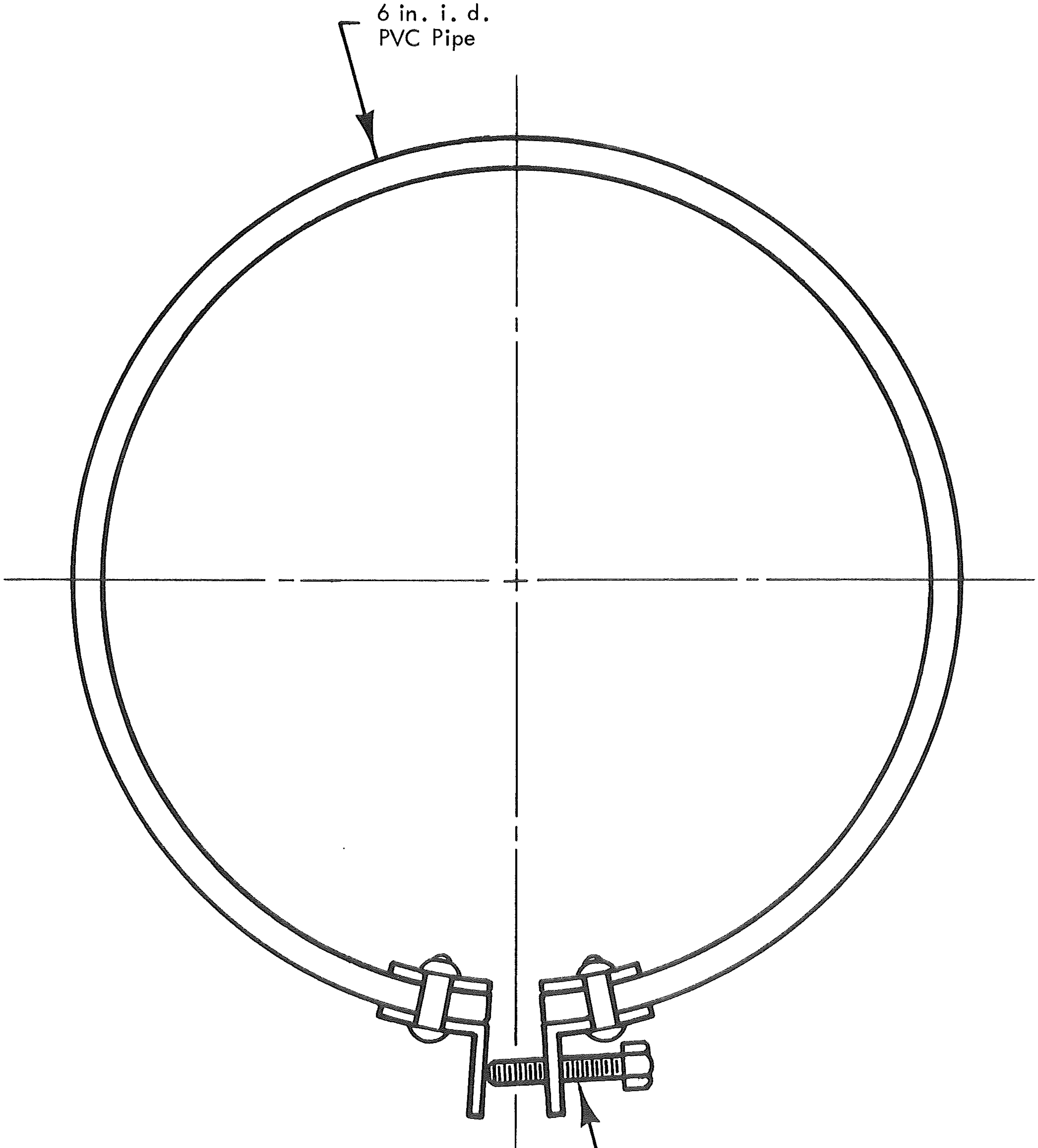


Figure 14. Air Curtain Manifold - End View

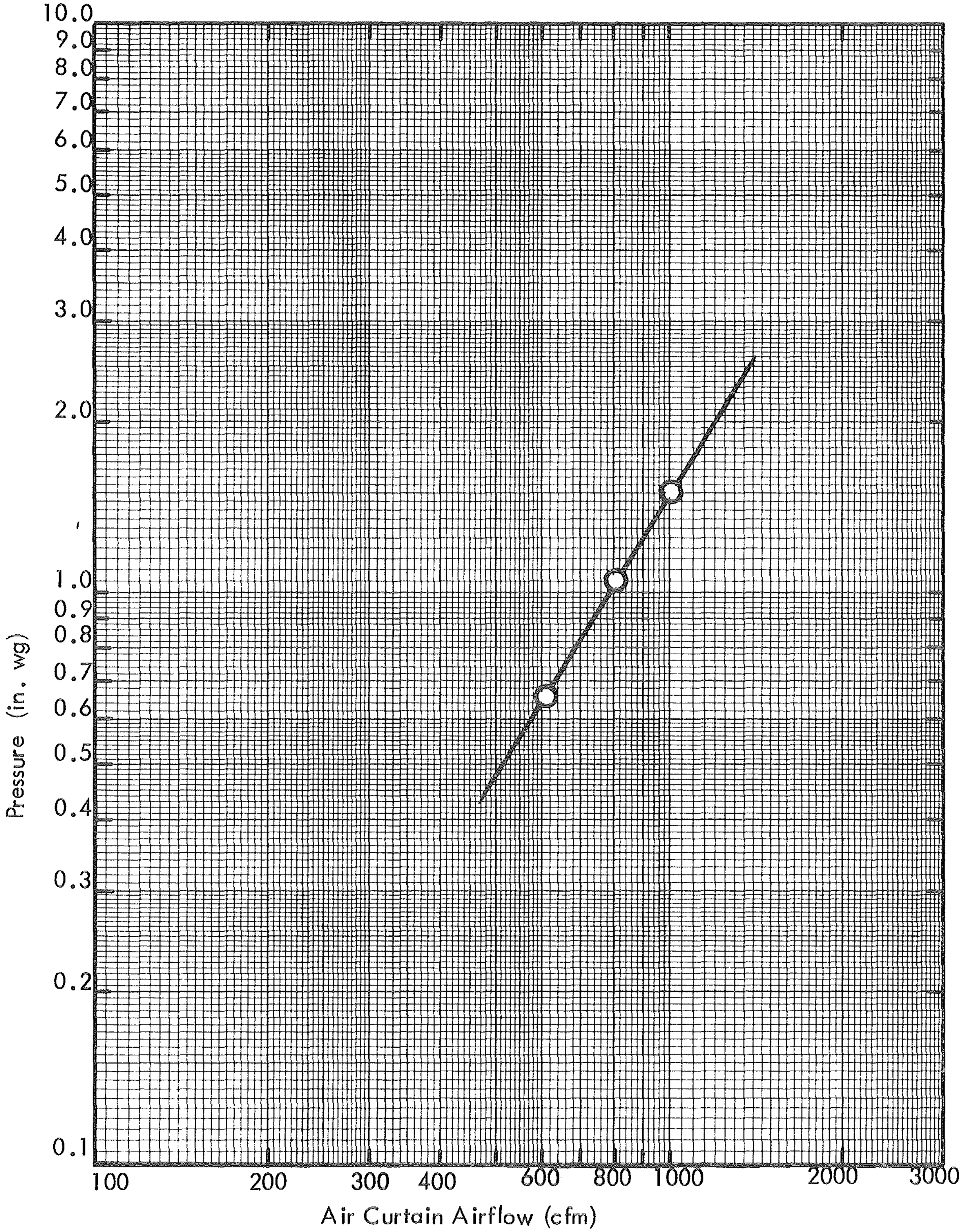


Figure 15. Air Curtain Pressure – (1/8 in. slot x 15.7 ft long)

foot at 2.0 in. wg would be needed for the air curtain. For a 15.7 foot air curtain, the total theoretical airflow would be 920 cfm at 2.0 in. wg. This is close to the 1,000 cfm indicated from flow visualization tests.

5.2 Flow Visualization Tests with Machine Mock-Up

Flow visualization tests were conducted on the roof-mounted concept with the mining machine mock-up in place. The slot width, airflows, and slot angle were varied while smoke was injected into both the air curtain airflow and the ventilation airflow in order to observe airflow patterns. The face ventilation velocity was also measured in order to indicate how much of the inlet airflow was reaching the face rather than shorting to the return side. Ventilation airflow volume was maintained at approximately 9,000 cfm and the rib distance for the brattice was 6 feet (centered). Air curtain airflows from 100 cfm up to 900 cfm were used. The slot angles tested were from 30 degrees from horizontal directed toward the intake side of the chamber to 70 degrees from horizontal directed toward the return side. A sketch of the test set-up for these tests is shown on Figure 16.

The best jet angle appeared to be vertical or 90 degrees for this configuration. When the jet was angled toward the intake side, the jet airflow impacted on the machine and spilled the dirty air into the intake side. When the jet was angled to the return side, the ventilation airflow "leaked" under the air curtain to the return side and did not reach the face as desired. These three conditions are shown on Figures 17, 18 and 19. Smoke purge time tests later indicated that the spillage into the intake side does not necessarily degrade performance.

The slot widths tested were 0.040 inch and 0.062 inch. The 0.040 inch slot provided a more uniform airflow along the length of the slot and subsequently a more effective air curtain. The restriction of these two slot widths are shown on Figure 20.

Air curtain airflows of 100 cfm to 900 cfm were evaluated. The airflow which appeared to provide the least amount of spillage and still allow for good ventilation to the face was from 525 to 550 cfm.

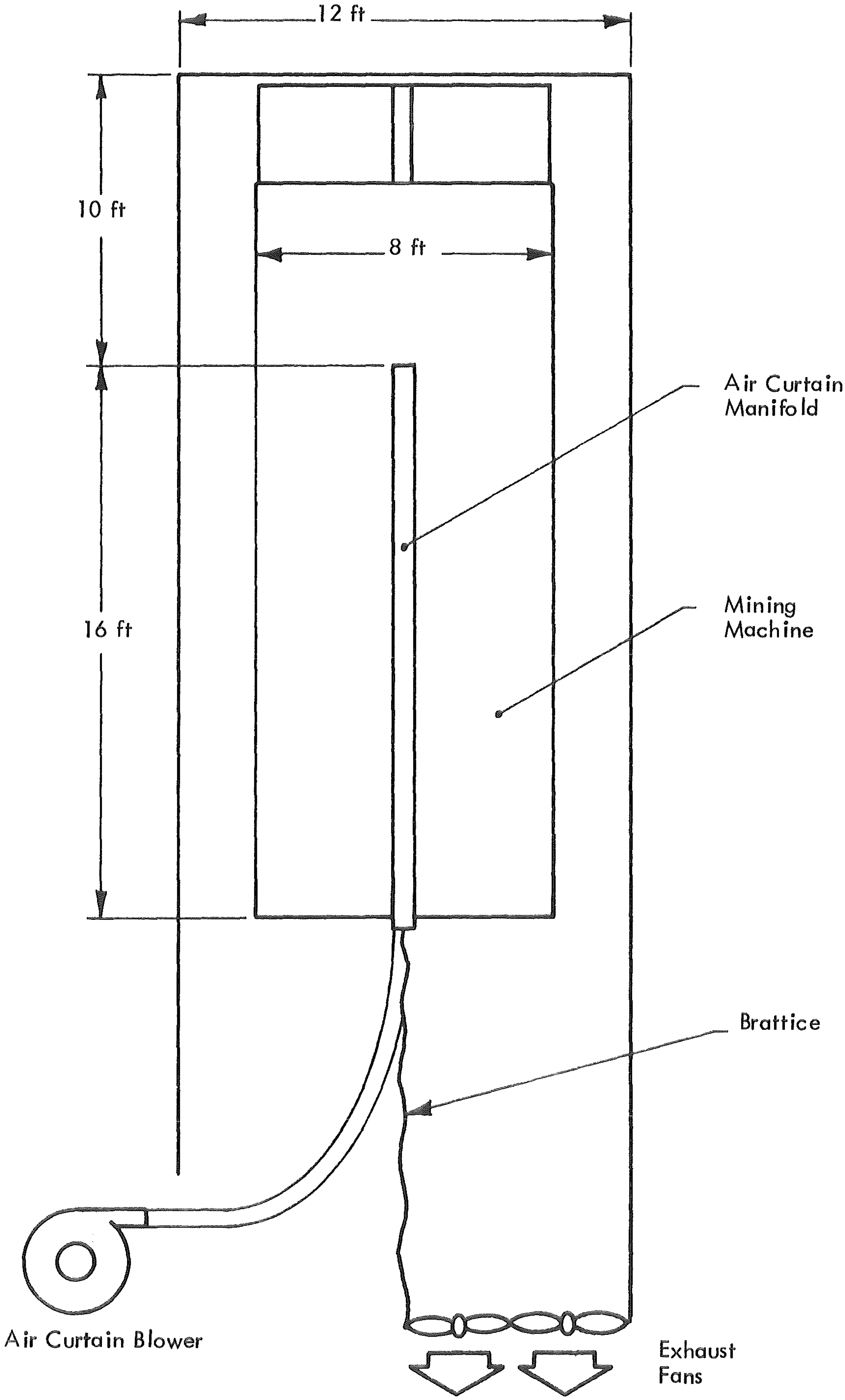


Figure 16. Flow Visualization Tests with Machine Mock-Up

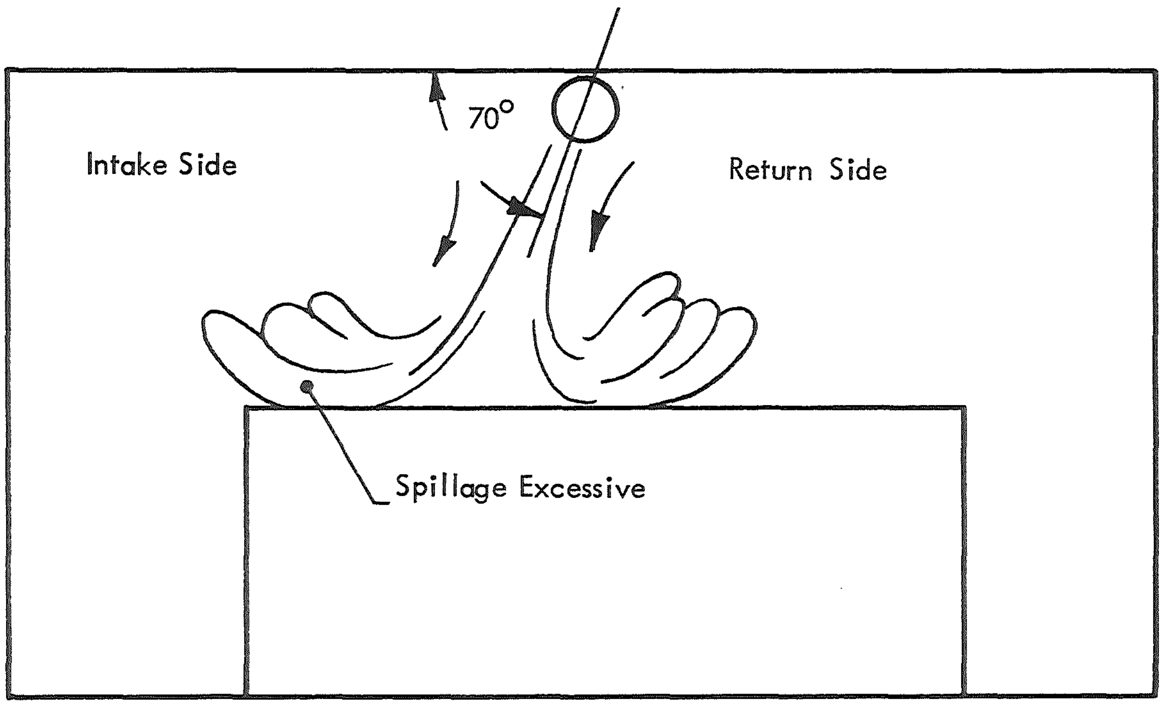


Figure 17. Jet Angled Toward Intake Side - Spillage Excessive

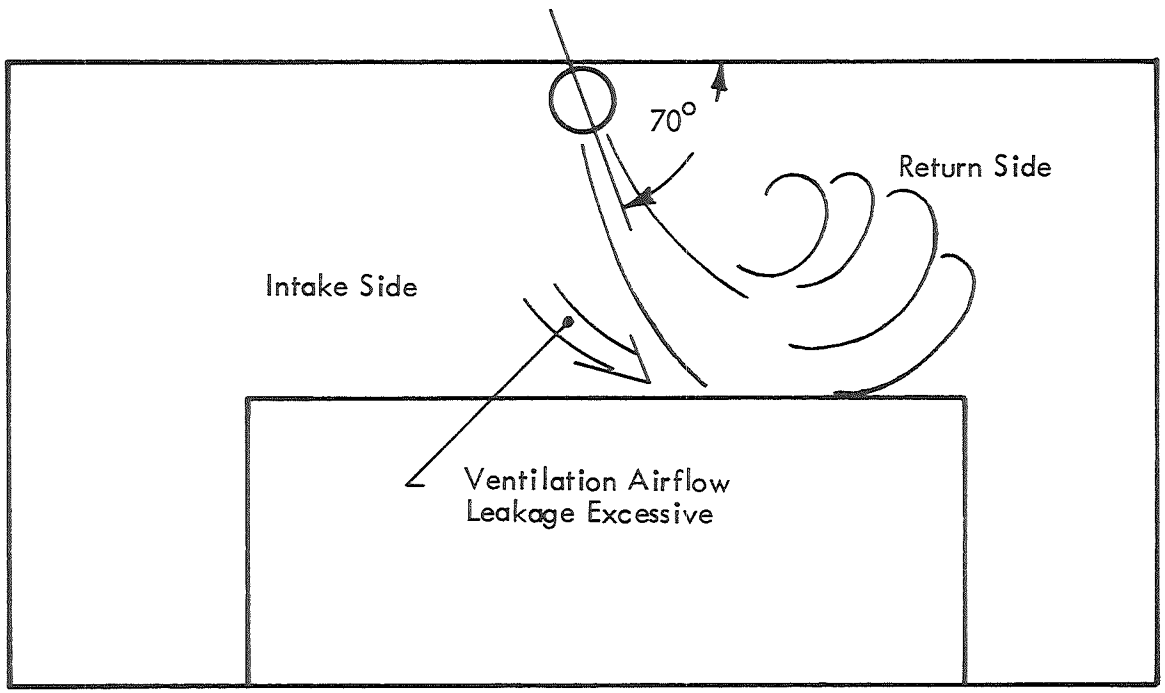


Figure 18. Jet Angled Toward Return Side - Leakage Excessive

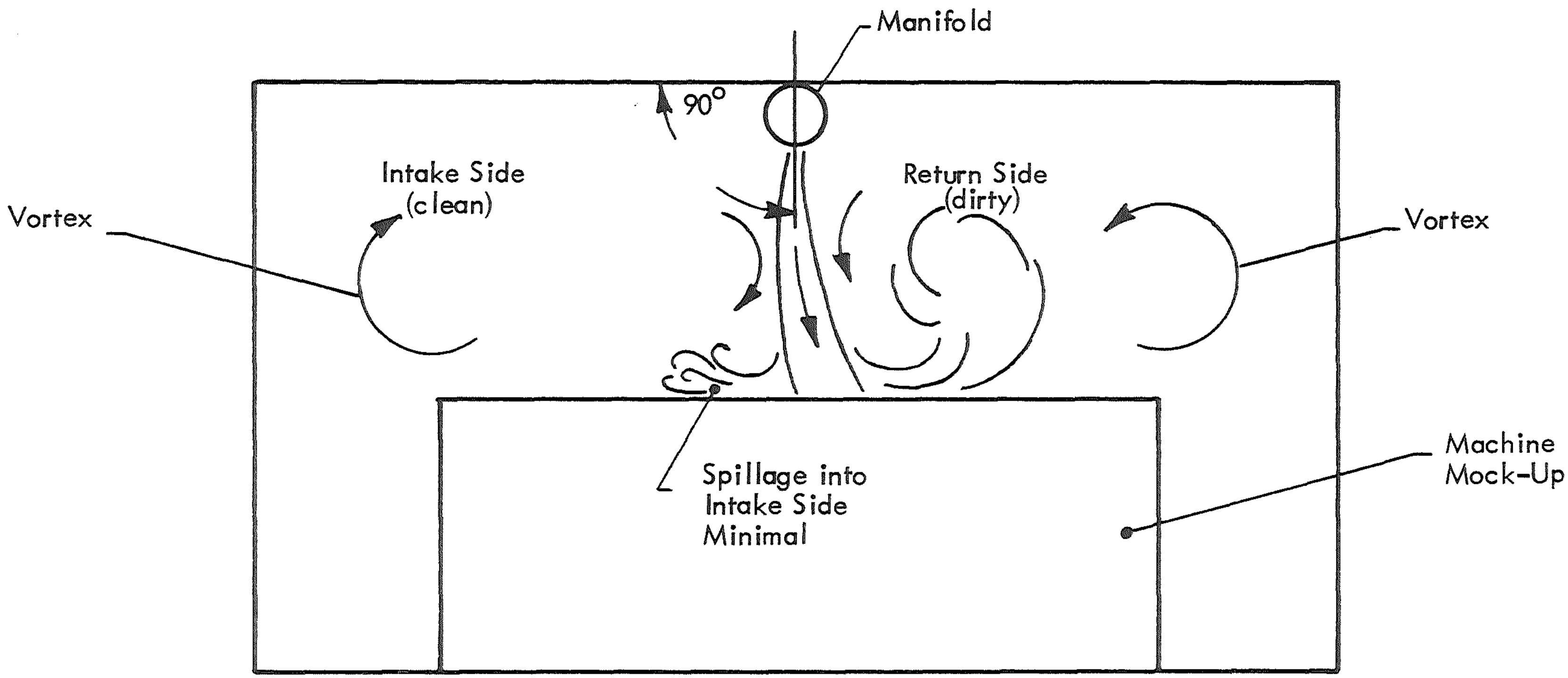


Figure 19. Jet Vertical - Minimum Spillage

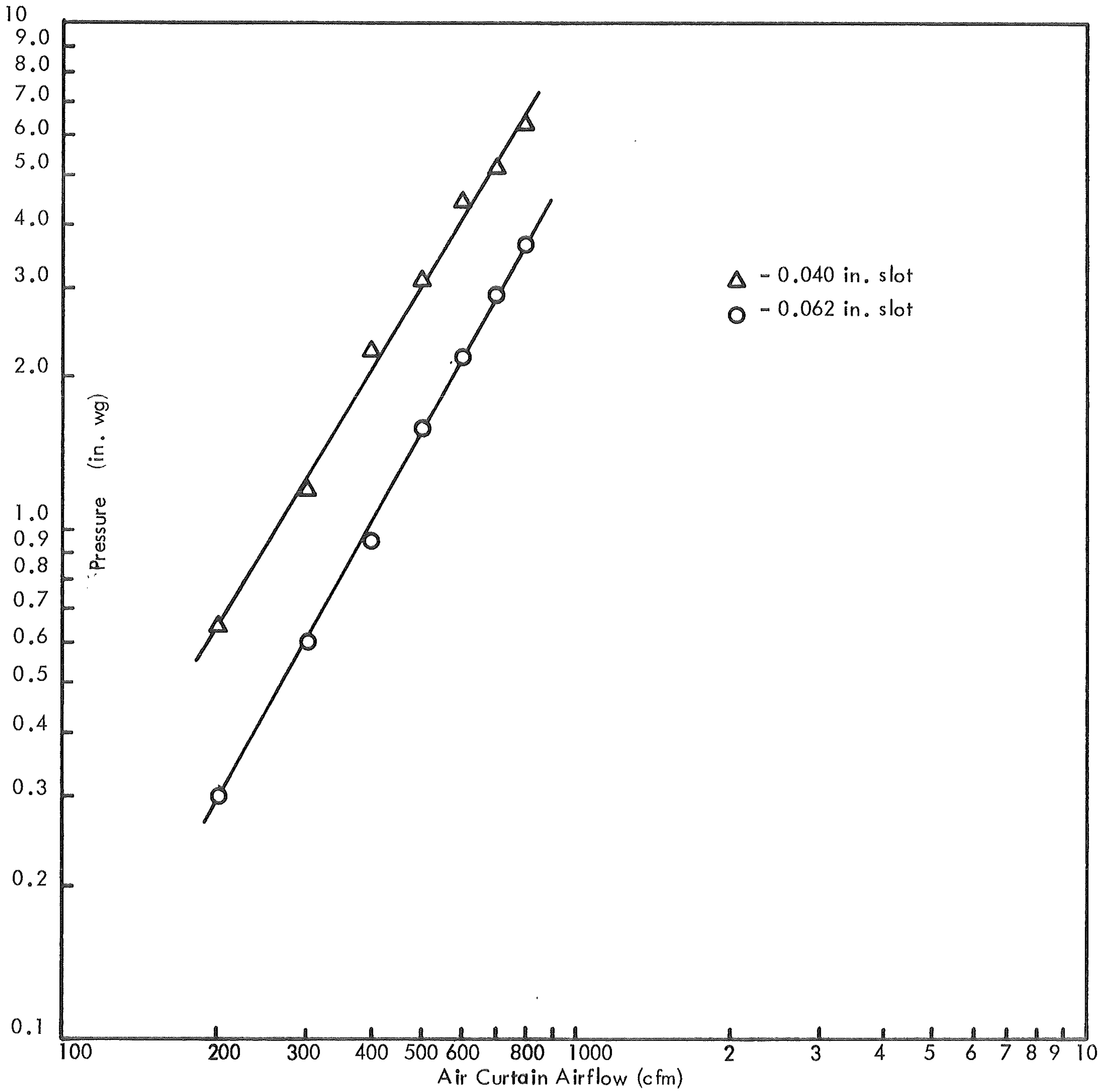


Figure 20. Air Curtain Pressure (15.7 ft long slot)

5.3 Smoke Purge Time Tests

The machine-mounted concept was tested with a brattice rib distance of 2 feet. This rib distance is more realistic than 6 feet because of mining machine mobility requirements. The test set-up is shown in Figure 21. The tests consisted of measuring the amount of time required to purge the face of smoke. The purge time should be low for an efficient system.

The smoke concentration was measured in the return airway at eight different points simultaneously. The test equipment consisted of a light scattering chamber coupled to a penetrometer. Baseline measurements of the ventilation effectiveness without the air curtain were taken initially. Measurements were taken with the brattice set ten feet from the face and then 22 feet from the face. The ventilation airflow was maintained at approximately 6,000 cfm during these tests. The procedure consisted of building up a smoke concentration at the face until 100 percent was observed on the penetrometer in the return airway. The smoke generator was then stopped and the time to purge down to 1.0 percent was recorded. The data is presented on Table 5.

Two different machine-mounted configurations were tested on an L-shaped manifold and a straight manifold. The following parameters were varied for each configuration: Airflow, slot angle, slot width, and orientation.

The L-shaped manifold configuration consisted of a 12 foot long section of 6-inch diameter pipe running the length of the machine to the right of center. In addition, there was a 30 inch long section running perpendicular to the 12 foot length starting four feet from the end of the machine in order to accomodate the operator's compartment. This configuration is illustrated on Figure 21.

The straight manifold was constructed of the same six inch pipe except without the 30 in. long section. This configuration resulted in low smoke purge times when oriented parallel to and along the outside edge of the mining machine, with a jet angle of 40 degrees from horizontal toward the intake side. The airflow requirement for this configuration is 575 cfm

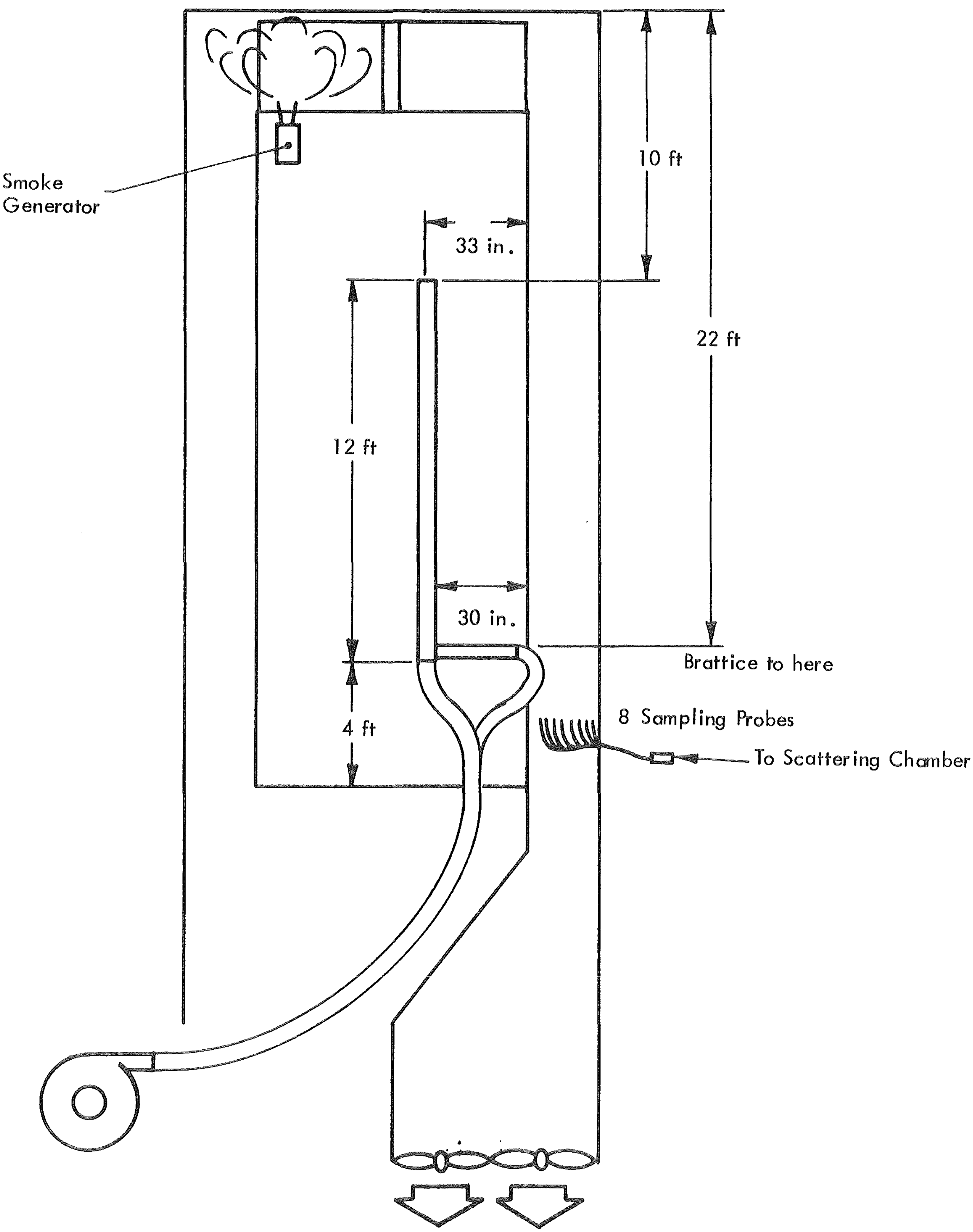


Figure 21. Machine-Mounted Concept Tests

Table 5. Smoke Purge Tests

Manifold Configuration	Orientation	Slot Width	Slot Angle	Airflow (cfm)	Average Purge Time (minutes)
Air Curtain off (brattice 10 ft to face)	-	-	-	-	4.23
Air Curtain off (brattice 22 ft to face)	-	-	-	-	14.17
L-Shaped Air Curtain (brattice 10 ft to face)	parallel	.040/.062	both @ 90°	730	0.28
L-Shaped Air Curtain (brattice 22 ft to face)	parallel	.040/.062	both @ 90°	700	4.83
				750	4.61
				775	1.64
				800	1.50
				900	1.47
L-Shaped Air Curtain (brattice 22 ft to face)	skewed	.050/.062	both @ 90°	400	9.84
				600	6.19
				800	6.63
				1000	5.62
L-Shaped Air Curtain (brattice 22 ft to face)	skewed	.050/.062	both @ 70°	500	3.16
				600	3.41
				700	3.25
				800	2.96
				1000	2.68
L-Shaped Air Curtain (brattice 22 ft to face)	skewed	.050/.062	both @ 50°	500	1.09
				550	.93
				600	.89
				650	.90
				700	.92
				800	1.12

Table 5. Smoke Purge Tests (continued)

Manifold Configuration	Orientation	Slot Width	Slot Angle	Airflow (cfm)	Average Purge Time (minutes)
L-Shaped Air Curtain (brattice 22 ft to face)	skewed	.050/.062	both @ 40°	500	1.30
				600	1.02
				650	1.18
				700	1.20
L-Shaped Air Curtain (brattice 22 ft to face)	skewed	.050/.062	both @ 30°	500	1.73
				600	1.39
				650	1.50
				700	1.33
				800	1.61
Straight Air Curtain (brattice 22 ft to face)	skewed	.040	90°	300	5.95
				400	4.51
				500	3.81
				550	2.95
				600	3.80
Straight Air Curtain (brattice 22 ft to face)	parallel	.050	90°	400	6.45
				500	5.76
				600	6.00
				700	5.13
				800	5.49
				900	5.16
Straight Air Curtain (brattice 22 ft to face)	parallel	.050	70°	700	2.63
				750	1.90
				800	2.00
				850	2.02
				900	2.15

Table 5. Smoke Purge Tests (continued)

Manifold Configuration	Orientation	Slot Width	Slot Angle	Airflow (cfm)	Average Purge Time (minutes)
Straight Air Curtain (brattice 22 ft to face)	parallel	.050	50°	650	1.25
				750	1.19
				800	1.07
				850	1.16
				900	1.57
Straight Air Curtain (brattice 22 ft to face)	parallel	.050	40°	500	1.60
				550	0.94
				575	0.93*
				600	0.94
				650	1.04
Straight Air Curtain (brattice 22 ft to face)	parallel	.050	35°	400	1.48
				450	1.35
				500	1.09
				550	1.03
				600	1.07
				700	1.39
				800	1.80
Straight Air Curtain (brattice 22 ft to face)	parallel	.050	20°	400	1.97
				500	1.81
				550	1.62
				600	2.64
				700	2.45

*Optimum Design

at 5.9 in. wg. Figure 22 depicts this configuration. This configuration is considered optimum because of its low airflow requirements, good efficiency, and simplicity of design.

The orientation of both the L-shaped and straight manifold was varied in order to determine its effect on performance. The L-shaped manifold was oriented parallel to the centerline of the machine as shown on Figure 21. This manifold was also located in a skewed line as shown on Figure 23. It was found that this skewed orientation aided the ventilation airflow because the airflow spillage off the roof is in the same direction.

The L-shaped manifold when oriented as shown on Figure 23 resulted in the lowest purge times. However, the margin is slight between this configuration and the straight manifold shown on Figure 22. In addition, the straight manifold requires less space on the mining machine and is less complex. Consequently, the straight manifold configuration was recommended for Phase IV testing.

The angle of the straight manifold configuration proved to have a great effect on efficiency. The test data shown in Table 5 indicates that the optimum slot angle is 40 degrees from horizontal toward the intake side. There are two probable reasons for this: (1) The spillage of air curtain airflow into the intake side sets up a scouring vortex to the coal mine face, or (2) the angled air jet enlarges the open area between the jet and the rib on the return side which presents less resistance to airflow.

The straight manifold configuration was also tested when oriented in a skewed line as shown on Figure 24. The testing indicated poor efficiency when compared to the same configuration oriented parallel with the brattice cloth. In this case, the airflow spillage off the roof acts as a resistance to the ventilation airflow direction.

The slot width was increased from 0.040 in. to 0.050 in. on both air curtain configurations. This change resulted in lower head requirements for the air mover without degrading performance. In addition, the wider slot allows for more liberal tolerancing in manufacture and less plugging problems from debris. The pressure versus airflow for the 0.050 in. wide slot by 12 ft long is presented on Figure 25.

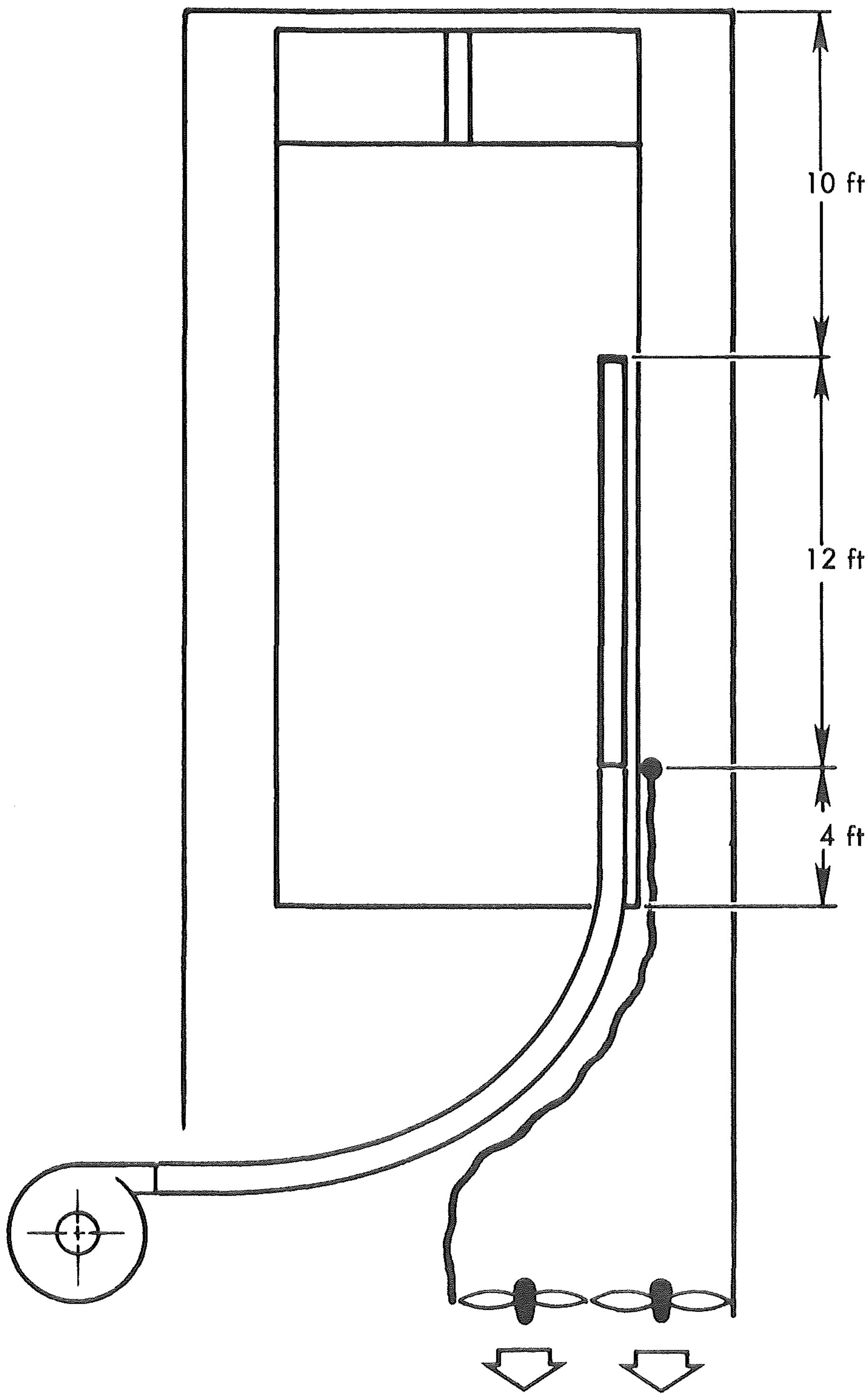


Figure 22. Straight Manifold Parallel to Brattice Cloth

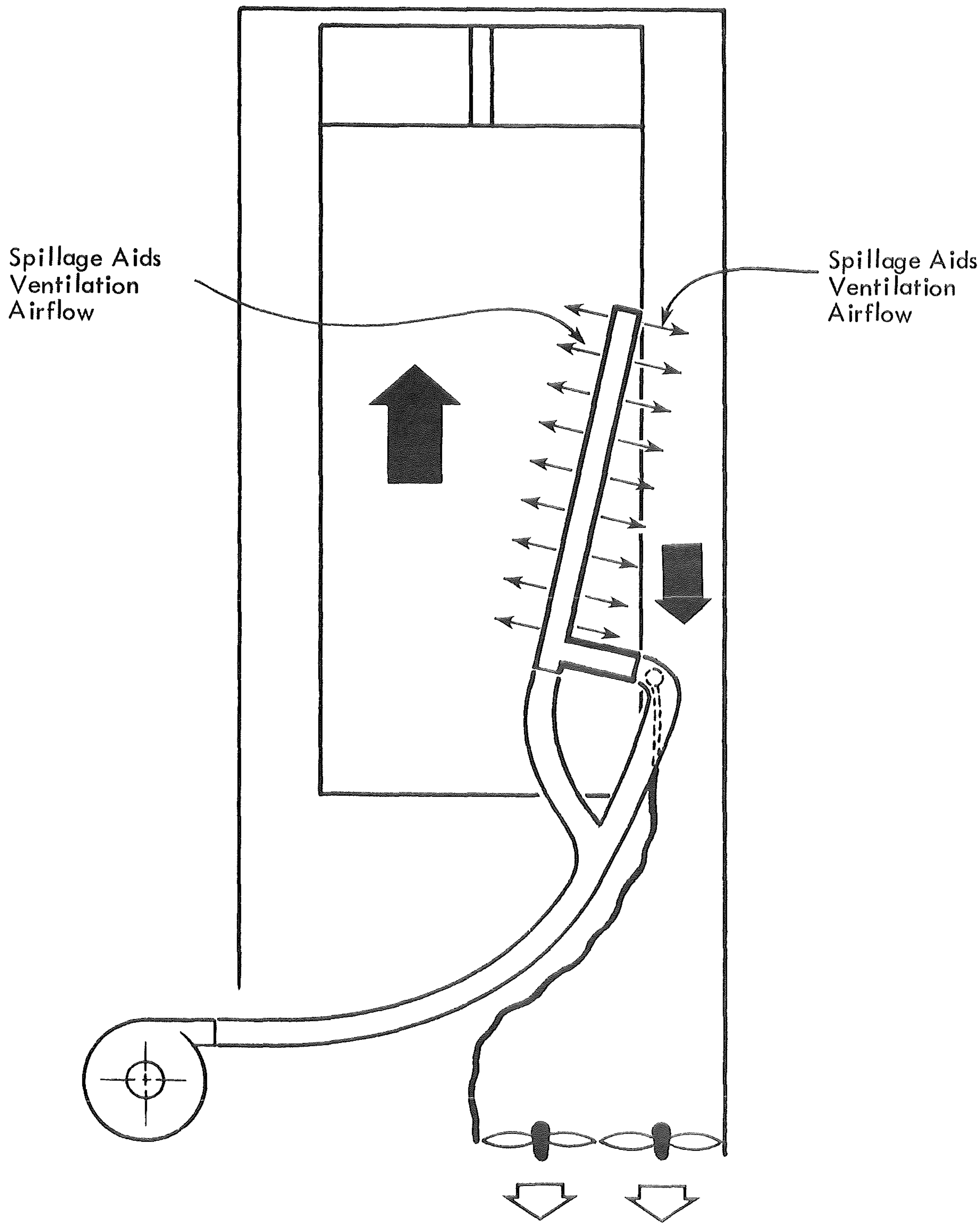


Figure 23. L-Shaped Manifold - Skewed Orientation

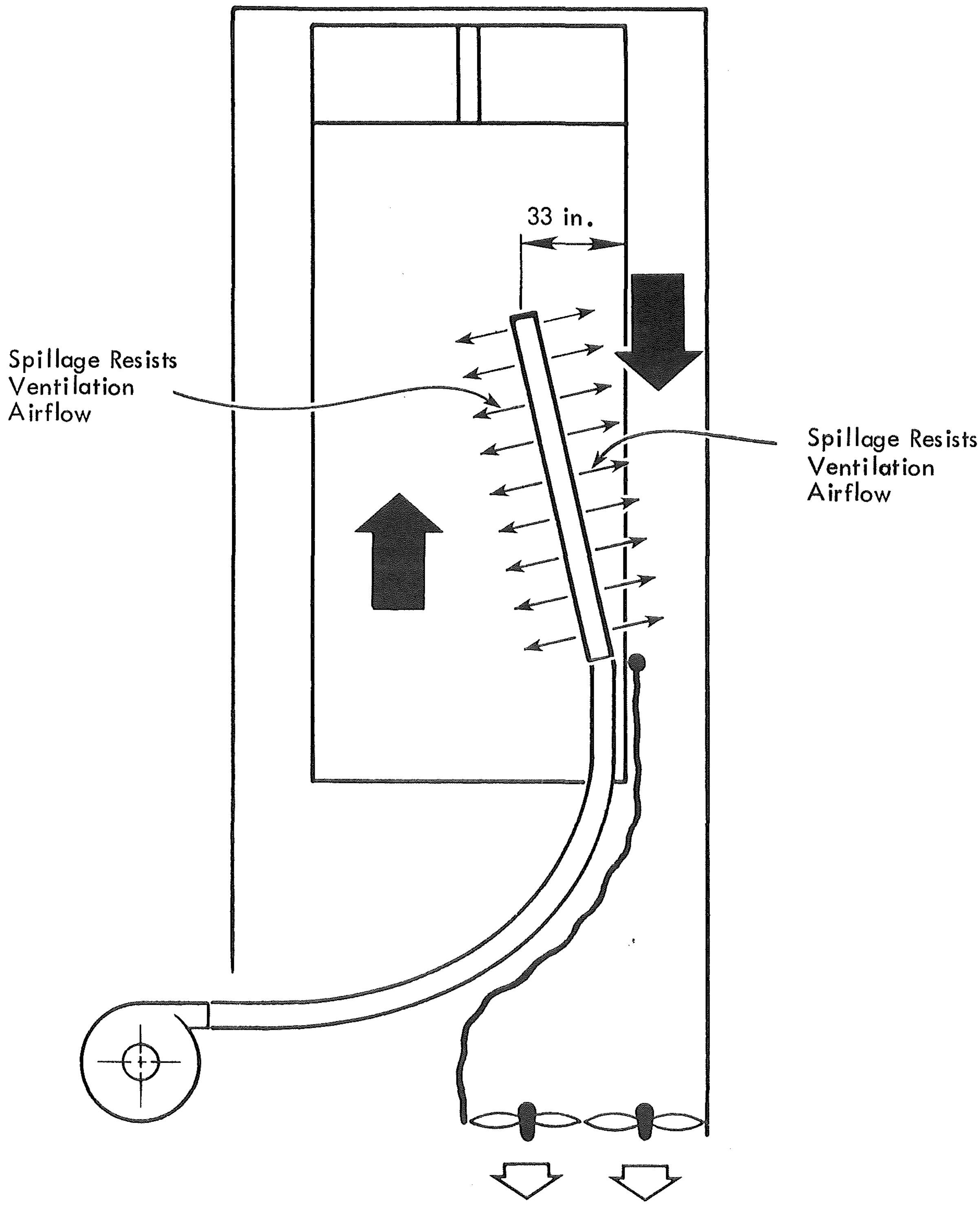


Figure 24. Straight Manifold - Skewed Orientation

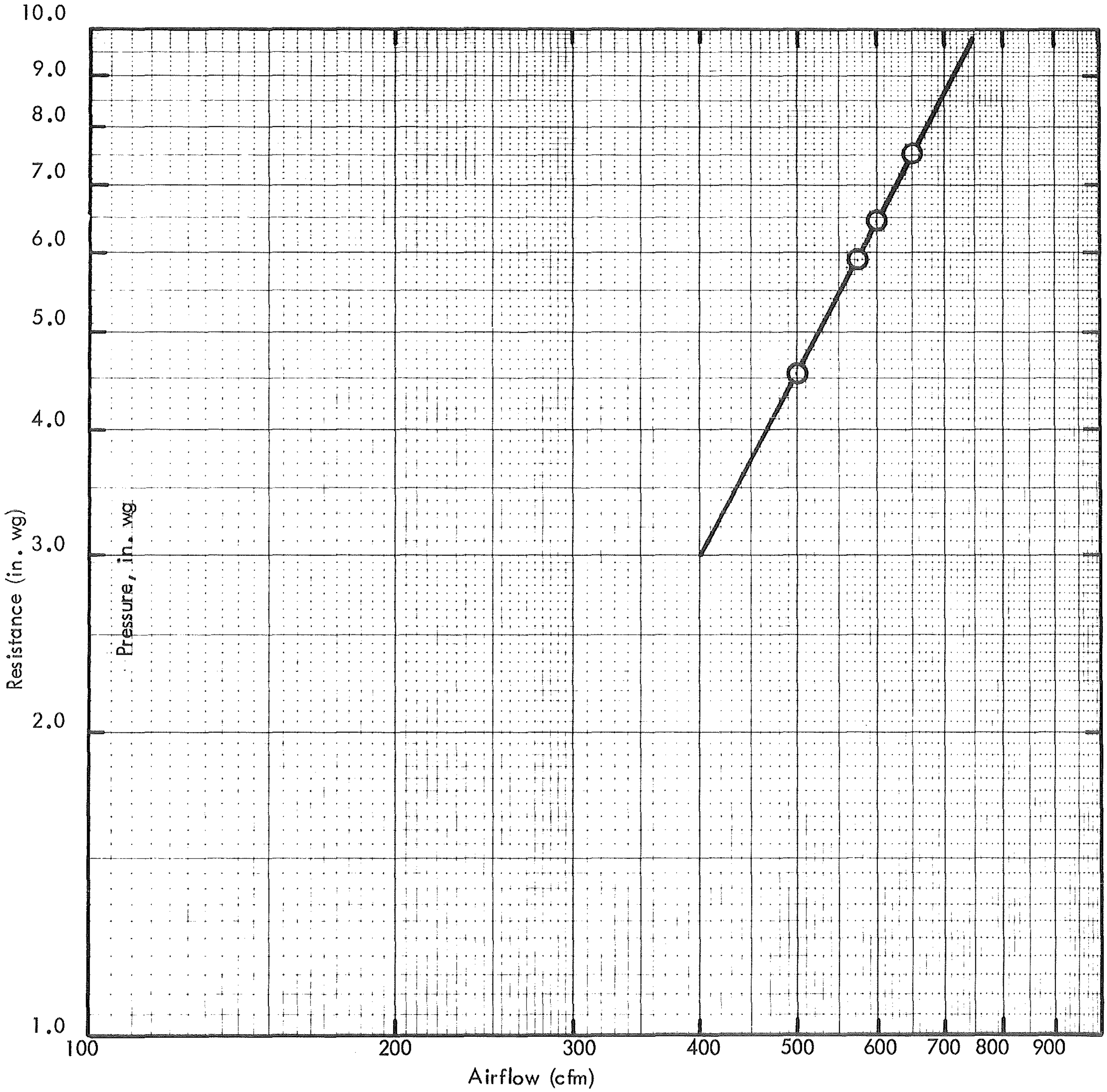


Figure 25. Airflow Resistance (.050 in. slot by 12 ft long)

5.4 Tests Using Blowing Ventilation System

The tests during the last portion of Phase III were aimed at determining the effectiveness of the air curtain when used with a blowing ventilation system. All previous tests were conducted with an exhausting ventilation system. Figure 26 illustrates the full-scale test chamber when configured as a blowing system. Table 6 presents data taken with the air curtain off and line brattice distances of 10 and 20 feet. This data provides baseline information to compare the air curtain to an ideal line brattice system. Note that when the air curtain was off and the brattice distance was 10 feet, the purge times averaged 1.07 minutes. When the air curtain was used and the brattice was set at 20 feet from the face, the purge times averaged 0.96 minutes at 875 cfm. The purge times increased only slightly to 1.02 minutes when 600 cfm was used. The airflow of 600 cfm also proved effective when used with an exhausting ventilation system. Consequently, the blower specifications apply to both an exhausting and blowing ventilation system. The only difference between the air curtains used in either ventilation system would be the slot angle. The Phase IV curtain was designed such that the slot angle can be easily converted.

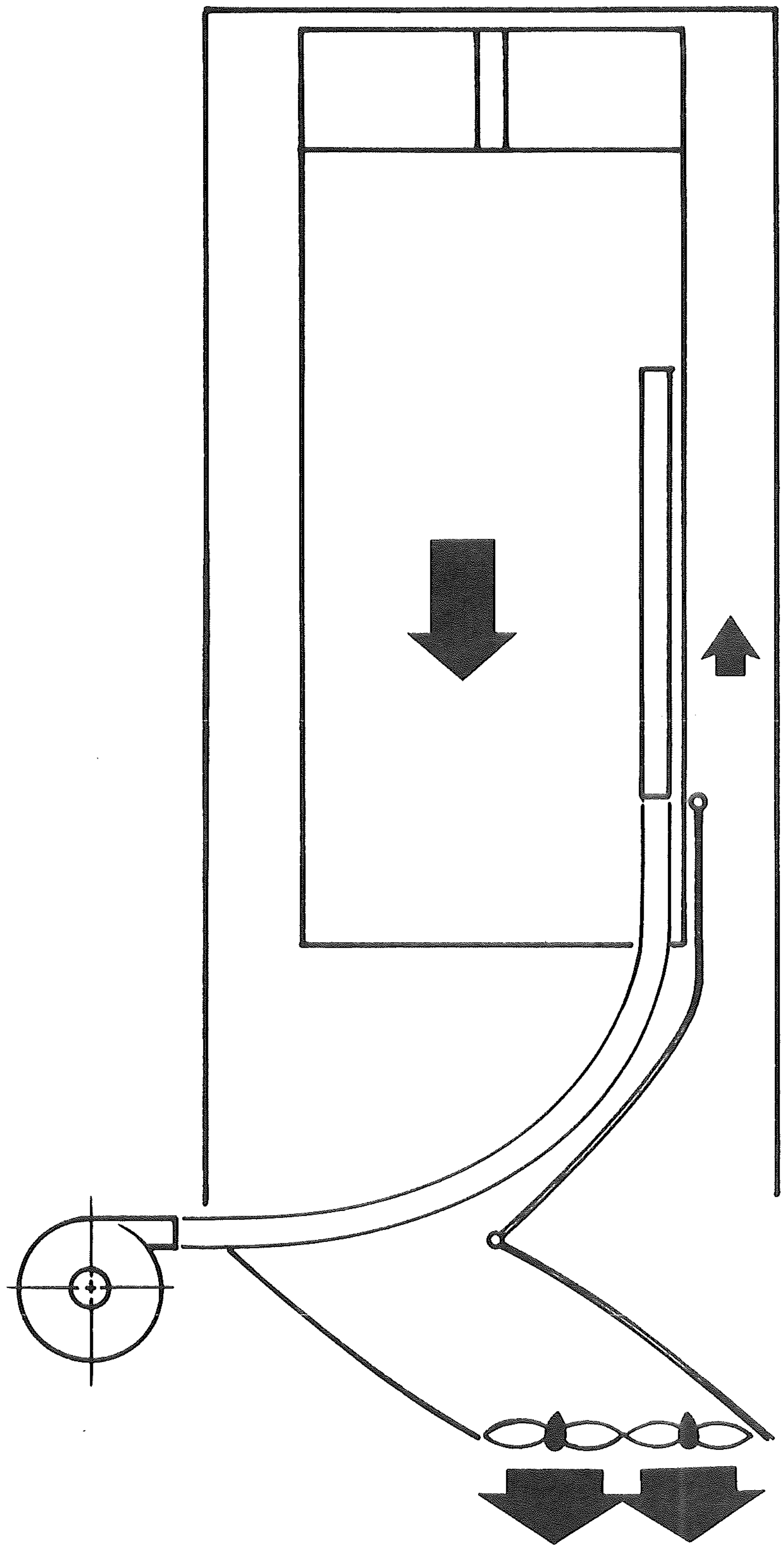


Figure 26. Blowing Ventilation Configuration with Straight Air Curtain Manifold

Table 6. Smoke Purge Tests - Blowing Ventilation System

Manifold Configuration	Orientation	Slot Width	Slot Angle	Airflow (cfm)	Average Purge Time (minutes)
Air Curtain Off (brattice 10 ft to face)	-	-	-	-	1.07
Air Curtain Off (brattice 20 ft to face)	-	-	-	-	2.38
Straight Air Curtain (brattice 10 ft to face)	parallel	0.050	90°	575	0.92
Straight Air Curtain (brattice 20 ft to face)	parallel	0.050	90°	400 600 800 875 1000	1.32 1.02 .98 .96 1.18

6 PHASE IV

Phase IV of this program was devoted to the design, fabrication, and testing of a production model air curtain. This model was designed for underground coal mine use. It was suitably protected from possible rock falls and was powered with a hydraulic motor in order to avoid permissibility problems. The length of the device was such that it could be mounted on top of or along side of a typical continuous mining machine. The air curtain manifold tube was 12 feet long. The test program consisted of: check-out tests at the Donaldson Company, facility; coal dust tests at the Bureau of Mines mine simulator in Building 19 at Bruceton; further optimization tests at the Donaldson Company facility aimed at improving the performance at low ventilation airflows; and, methane sampling tests at the Bureau's Safety Research Coal Mine at Bruceton, PA.

6.1 Check-Out Tests

Both noise tests and smoke purge time tests were conducted on the Phase IV hardware prior to shipment to the Bureau of Mines in Bruceton, PA.

The noise level readings were taken while the air curtain was operating with all rock shields in place and the hydraulically driven blower delivering 575 cfm to the air curtain. A B & K sound level meter and microphone were used to take the measurements. The microphone was positioned behind the air curtain blower package where it is anticipated that the mining machine operator would be located. Initial measurements were taken with no provisions for noise abatement. A reading of 95 dB(A) was noted. After various noise reduction measures were employed, the noise level was reduced to 82 dB(A). This is below the permissible eight hour day noise exposure of 90 dB(A).

In order to reduce the noise to an acceptable level, three different measures were taken in the following configurations: (1) Added sound attenuation material to the inside surface of the blower rock shield, (2) added rubber stand-off washer between the hydraulic motor and the motor mount, and (3) blocked-off air intake to the blower which is closest to the machine operator's position. These measures are relatively inexpensive to incorporate into the design and were included into the Phase IV hardware which was tested at the Bureau of Mines facility at Bruceton, PA.

The smoke purge time tests indicated that the Phase IV air curtain is more effective than the Phase III prototype model. The Phase IV unit averaged 0.90 minutes when using 575 cfm. The Phase III unit averaged 0.93 minutes under the same conditions. The Phase IV was subsequently shipped to the Bureau of Mines mine simulator in Bruceton, PA, for tests.

6.2 Dust Tests at the Bureau of Mines Simulator

The Phase IV air curtain was tested at the Bureau of Mines simulator located in Building 19 in Bruceton, PA. These tests consisted of steady state coal dust tests. Air curtain effectiveness was determined by comparing gravimetric dust samples at the operator's station with and without the air curtain in operation.

Coal dust was fed to the face of the mine simulator through sixteen 4-in. diameter pipes. A total of 687 cfm was used to transport the dust into the simulator. The main ventilation to the face was varied during tests - 3,000 cfm, 6,000 cfm, and 8,500 cfm. The brattice rib distance was three feet. The air curtain airflow was set at 575 cfm and the slot angle was set at approximately 50 degrees from horizontal away from the return side. See Figure 27 for an illustration of the test set-up.

The test results are included on Table 7. The results show poor effectiveness when the ventilation airflow is at 3,000 cfm. The air curtain works as well as the brattice when the ventilation airflow is 8,500 cfm. At the low airflow of 3,000 cfm, it is felt that the dust feed airflow of 687 cfm tends to have an adverse effect on the performance. This is not representative of an actual coal mine. Note that the ventilation airflow was measured in the return side of the entry. Consequently, the incoming ventilation airflow is actually 3,000 cfm less 687 cfm, or about 2,300 cfm. The resulting air velocity on the intake side is about 40 ft/min for 3,000 cfm and 30 ft/min for 2,300 cfm. Dust concentrations were sampled using MSA personal samplers. The sampler locations were at the operator's position, in the return airway and forward of the operator on the left side of the machine. Three samplers were run concurrently at both the operator's position and in the return. The tests were run in pairs - with the brattice up to ten feet from the face and then with the brattice back to 20 feet and the air curtain on. This procedure minimized effects on the ambient dust concentration. Sampling times were in

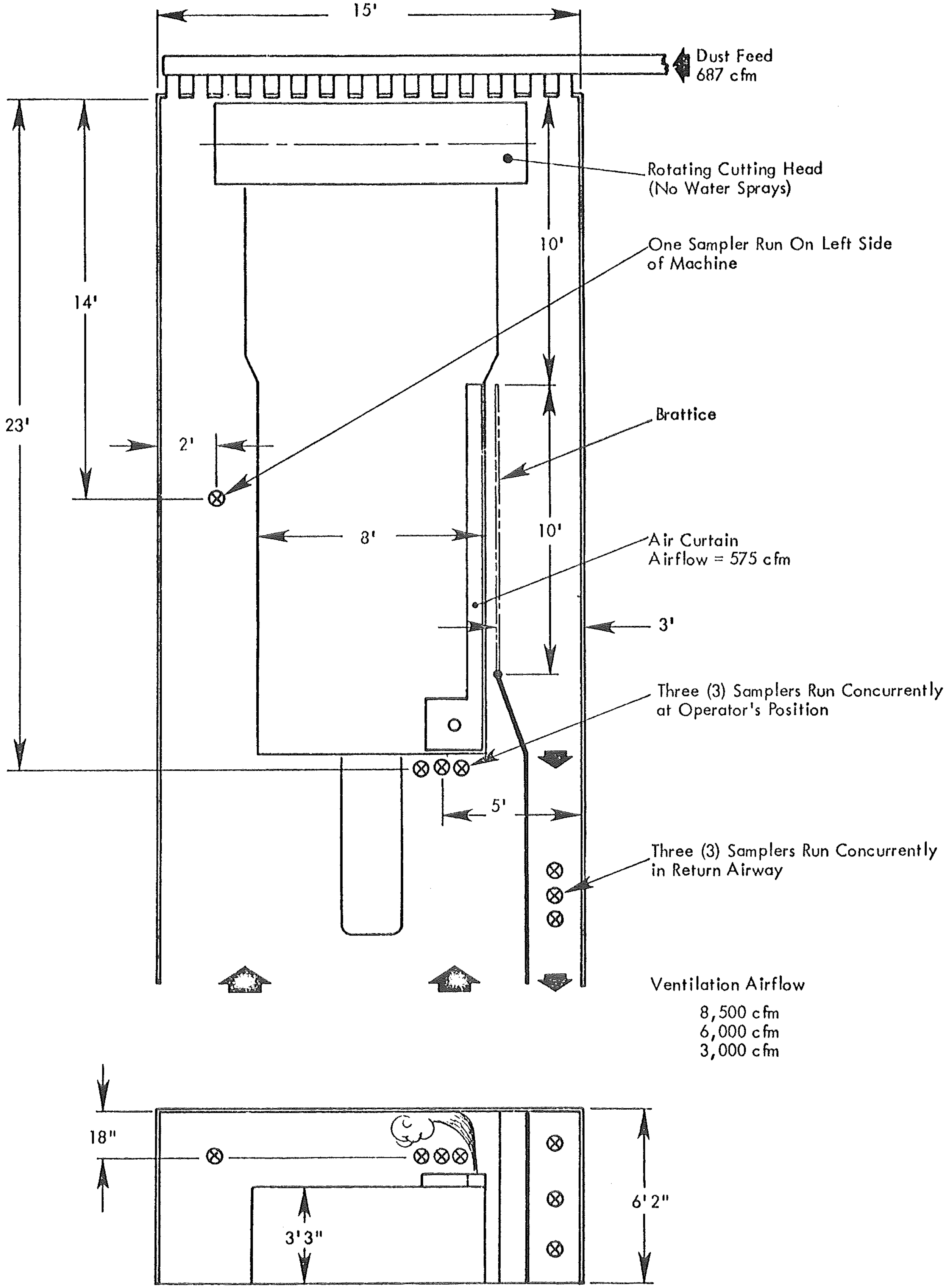


Figure 27. Test Set-Up - Bruceton Mine Simulator

Table 7. Dust Test Results - Bruceton Mine Simulator

	Dust Concentrations (mg/m^3)			
	* α	Return (ave)	Operator (ave)	Left Side of Machine
8500 cfm:				
Air Curtain Off (brattice 10 ft to face)	.0064 .009	20.3 15.88	0.13 0.15	0.28 0.15
Air Curtain On (brattice 20 ft to face)	.0063 .007	11.2 24.89	0.07 0.17	2.18 5.44
6000 cfm:				
Air Curtain Off (brattice 10 ft to face)	.017 .000	28.18 27.72	0.49 0.00	0.55 2.07
Air Curtain On (brattice 20 ft to face)	.054 .018	14.38 53.13	0.78 0.98	3.15 10.12
3000 cfm:				
Air Curtain Off (brattice 10 ft to face)	.0085	31.2	0.266	-
Air Curtain On (brattice 20 ft to face)	0.171	40.0	6.84	-

$$* \alpha = \frac{\text{Operator Concentration}}{\text{Return Concentration}}$$

most cases 60 minutes except in the return which has very heavy dust loading. Here the sampling time was only 30 minutes.

It was anticipated that improved effectiveness of the air curtain could be obtained at lower ventilation airflows by adjusting the slot angle and the airflow. This type of work was not feasible at the Bruceton mine simulator facility using only personal samplers for instrumentation because of the time consuming procedure. Tests were conducted again at Donaldson Company's facility using smoke in order to optimize the slot angle at low ventilation airflows. Tests were then conducted at the Bureau's Safety Research Coal Mine at Bruceton, PA, using methane as a tracer.

There is a basic difference between the smoke purge time tests performed at Donaldson Company and the tests at Bruceton. The smoke tests were unsteady state - smoke shut off at 100 percent and time measured to purge. The dust tests were steady state - dust continually fed at concentrations measured at the operator's station and compared to ambient. An actual coal mine working face is probably somewhere between steady state and unsteady state. The unsteady state condition cannot be performed using personal samplers and coal dust monitoring. However, with methane and methane monitors and/or a hydrocarbon analyzer, this can be done. Consequently, further testing was deemed necessary before final conclusions could be reached.

6.3 Optimization Tests for Low Ventilation Airflows

The test results obtained at the Bureau's mine simulator described in the previous paragraphs indicated poor air curtain effectiveness at ventilation airflows of 3,000 cfm when tested under steady state conditions. Consequently, further testing was conducted at Donaldson Company's facility to improve the effectiveness at lower ventilation airflows. In addition, steady state smoke sampling was conducted along with unsteady state or purge time tests. The steady state tests consisted of generating smoke continuously at the face and sampling at both the operator's station and opposite the operator and forward (see Figure 28).

A light scattering chamber and penetrometer were used to monitor the smoke concentrations. Purge time tests were also conducted because it was observed that even though a rather smoke-free area could be obtained at the operator's station, the smoke at the face was stagnant.

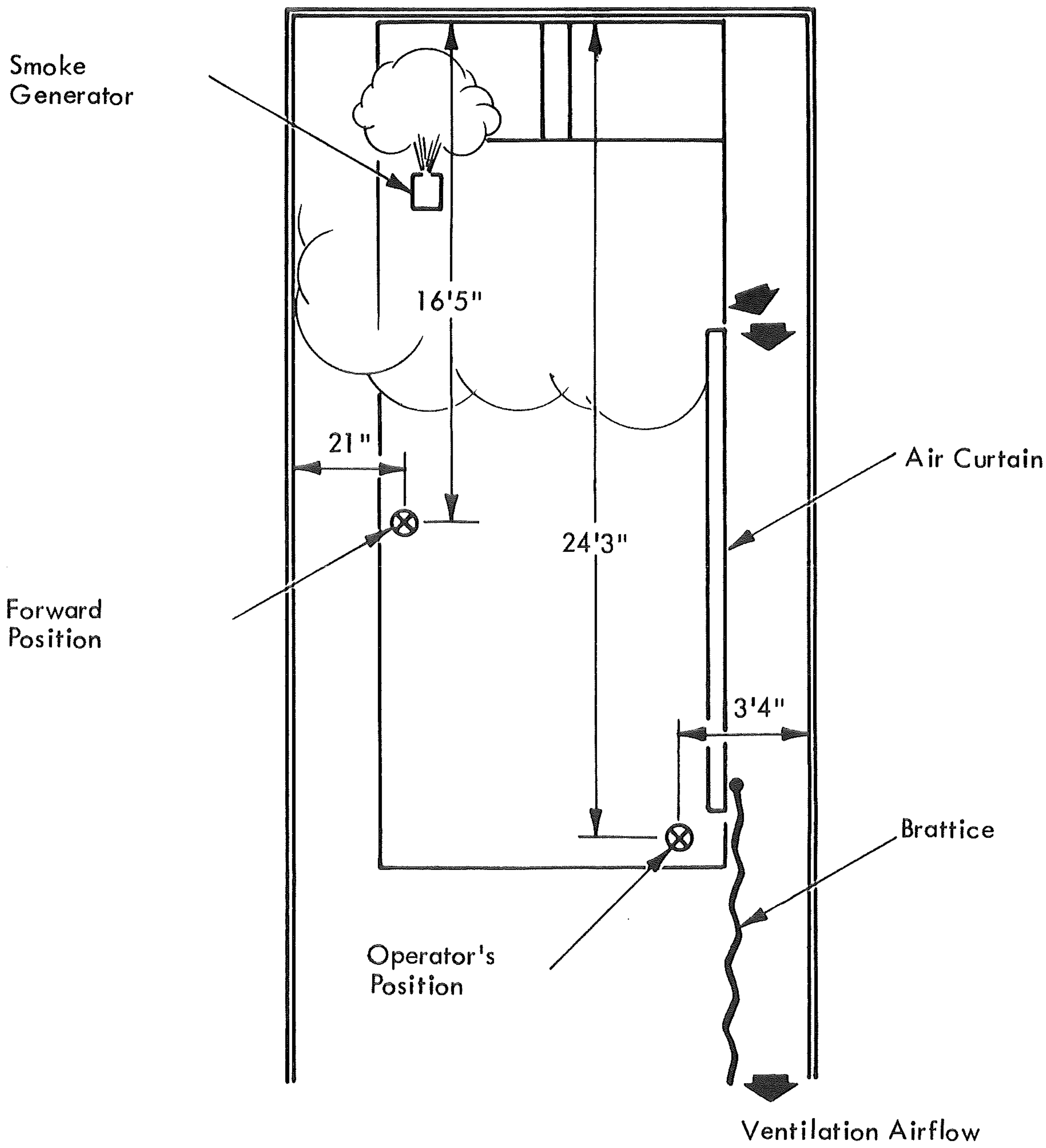


Figure 28. Smoke Sampling Locations

It was found during visual observations of the smoke patterns, that when the air curtain is oriented with its inlet closest to the face and the slot angle near vertical, the performance is greatly improved for low ventilation airflows. The reason for the improvement is attributed to the fact that the airflow emanates from the slot at an angle. Also, the air curtain is strongest toward the closed end of the tube. This directional characteristic together with a near vertical slot angle tends to give the ventilation airflow some assistance into the return side (see Figure 29). This was found to be true when the ventilation airflow was around 3,000 cfm. However, when the ventilation airflow was increased to 5,200 cfm, it was found that the slot angle had to be set at about 60 degrees from horizontal toward the intake side.

In summary, when the ventilation airflow is on the order of 3,000 cfm, the slot angle should be between 80 and 90 degrees from horizontal toward the return side. When higher ventilation airflows are encountered, the slot angle should be 60 degrees from horizontal toward the intake side. In both cases, the air curtain inlet must be at the face end of the machine and the air curtain airflow can be between 500 cfm and 600 cfm. The data is presented on Table 8. Note that the brattice was set at ten feet with the air curtain off to provide a baseline purge time when using 3,000 cfm ventilation airflow.

6.4 Testing at Bureau's Safety Research Coal Mine

Underground tests were performed on the air curtain at the Bureau's Safety Research Coal Mine at Bruceton, PA. These tests consisted of releasing methane at the face and sampling the intake and return sides of the entry. A hydro-carbon analyzer and chart recorder were used to obtain the measurements. In addition to steady state concentration readings, purge time tests or unsteady state tests were run. Two ventilation airflows were used - 3000 cfm and 7200 cfm. Baseline tests were run with the air curtain off and the brattice set at 10 ft and at 20 ft, to provide comparative data. Test data indicates that only a small amount of methane reaches the area of the operator (see location #5 on Figure 30) when the air curtain is operating. Baseline tests indicated no methane at these locations. Purge time tests indicated better efficiency by the air curtain than a brattice system at 20 ft from the face and slightly higher times than tests with thebrattice system at 10 ft. One definite improvement was observed when using the air curtain; the highest value concentrations were lower than with the brattice system at 20 ft and did not vary as much.

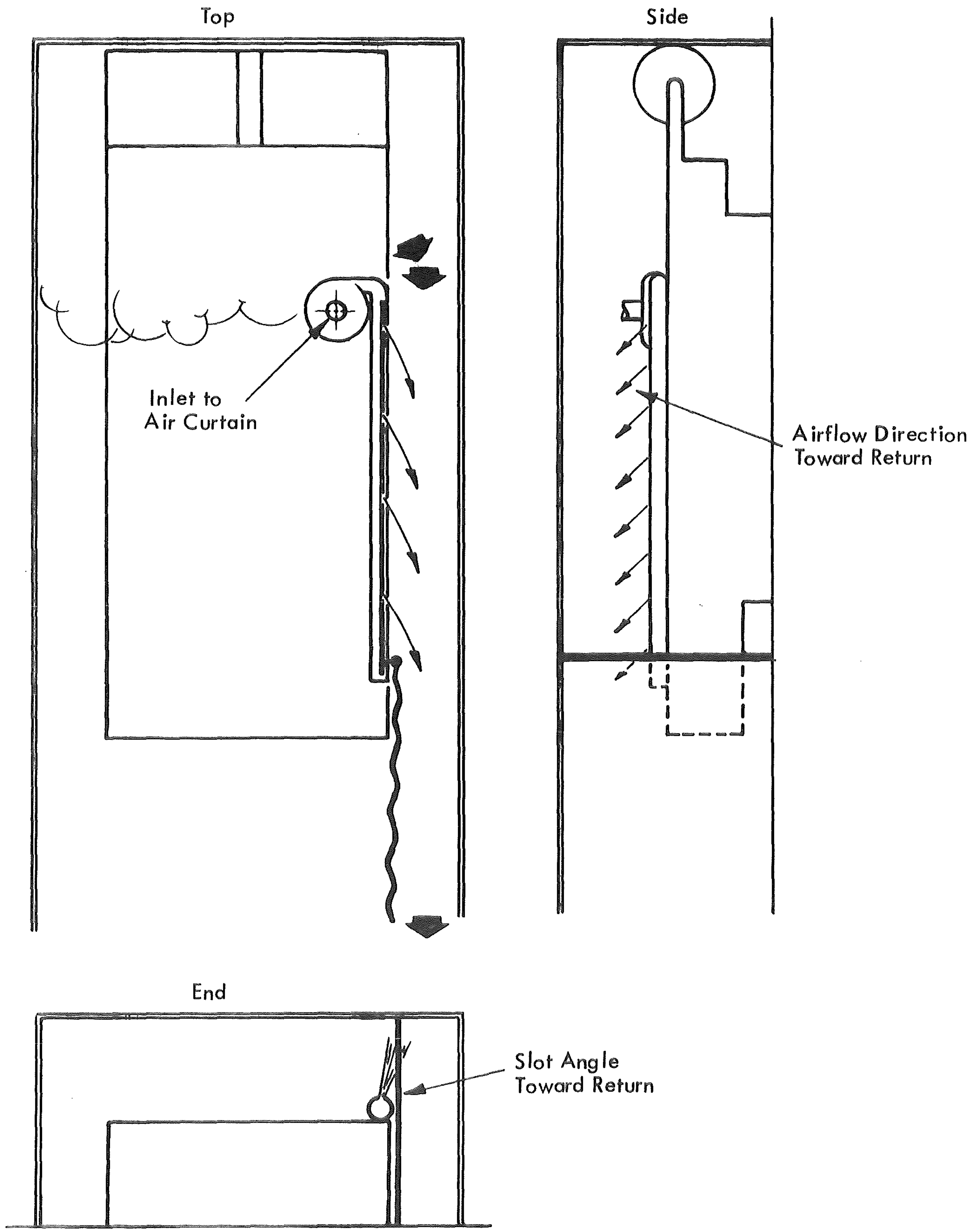
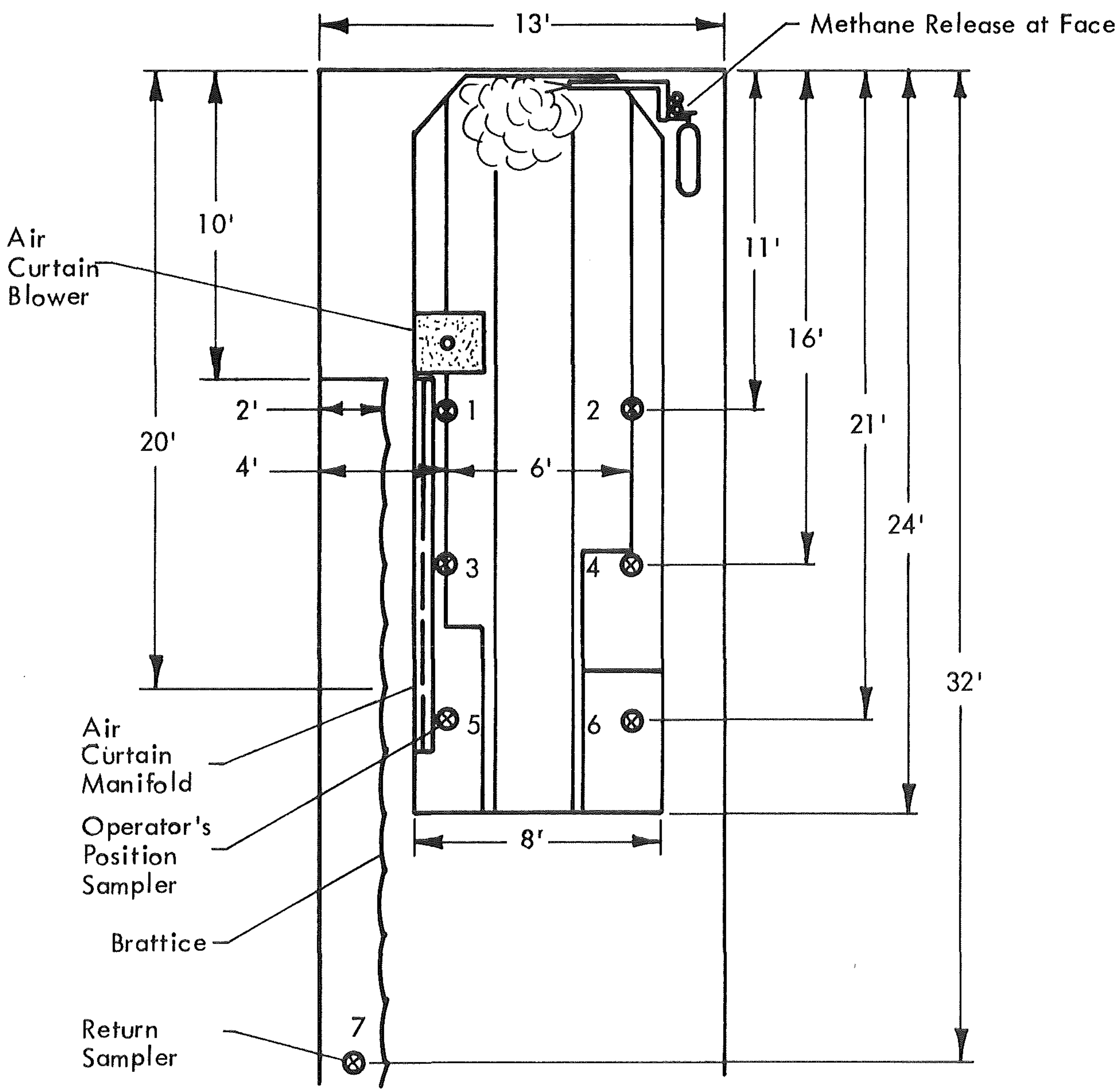


Figure 29. **Optimum Orientation for Low Ventilation Airflow (~ 3,000 cfm)**

Table 8. Air Curtain Smoke Tests

Orientation	Ventilation (cfm)	Air Curtain (cfm)	Concentration (%)		
			Forward	Operator	Purge Time (min)
Brattice 10 ft to face	3,300	0	0.044	0.040	6.05
Inlet @ Operator End (55° toward intake)	3,300	575	-	-	3.93
Inlet @ Face End (90° vertical)	3,200	350	0.22-0.60	0.33-0.50	5.53
""	2,900	400	0.38-3.00	0.16-0.46	3.66
""	3,400	400	0.20-45.00	0.20-0.42	2.82
""	3,400	450	2.00-24.00	0.20-0.50	2.91
""	3,400	500	2.00-32.00	0.22-0.32	1.79
""	2,900	500	44.00-54.00	0.20-0.40	2.78
""	2,900	500	-	-	2.05
""	2,900	500	15.00-30.00	-	2.66
""	2,900	500	6.00-40.00	0.30-0.68	2.63
""	2,900	575	16.00-34.00	0.40-1.00	2.65
""	3,200	575	20.00-30.00	0.50-0.70	3.07
""	3,400	575	15.00-30.00	0.40-0.95	2.83
Inlet @ Face End (80° toward return)	2,900	400	0.08-0.20	0.24-0.34	7.26
""	2,900	500	2.00-9.00	0.20-0.60	3.44
""	2,900	600	2.00-34.00	1.00-1.50	4.70
Inlet @ Face End (70° toward return)	2,900	400	-	0.50-0.90	7.36
""	2,900	500	-	2.00-3.00	5.18
""	2,900	600	-	1.00-2.00	6.29
Inlet @ Face End (90° vertical)	5,200	500	-	1.00-2.00	9.02
""	5,200	575	-	1.00-2.00	6.36
(75° toward intake)	5,200	400	-	0.50-2.00	7.63
""	5,200	500	-	1.50-2.50	3.59
""	5,200	575	-	1.00-1.50	3.37
(60° toward intake)	5,200	400	-	1.00-2.00	3.61
""	5,200	500	-	1.00-2.00	3.44
""	5,200	575	-	-	2.01
""	5,200	575	-	1.00-1.50	2.80



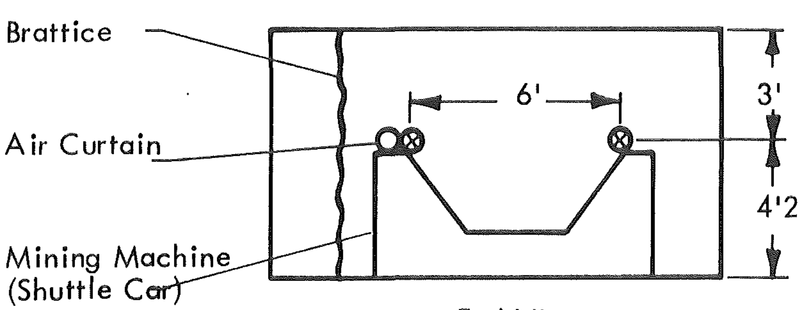


Figure 30. Sampler Locations

In other words, the air curtain does a better job of mixing and, consequently, tends to scour the face area of methane pockets.

6.4.1 Test Setup

Ventilation airflows were measured in the return airway using a handheld anemometer. The ventilation test configuration is shown on Figure 31. The entry was 54 ft long by 13 ft wide. A shuttle car was used to represent the mining machine at the face. The brattice was set at 10 ft and at 20 ft from the face, for ventilation airflows of 3000 cfm and 7200 cfm.

The brattice system was sealed better than is normally attainable in a working mine. The brattice construction consisted of a wood framework covered with impermeable plastic sheeting. Care was taken to minimize leakage at the interface with the roof and floor of the mine. This brattice construction was extended the full length of the entry to within 10 ft of the face. In actual practice, line brattice systems, using common jute fabric, have efficiencies on the order of 50 percent or less. (See studies reported in R. I. 6725, Face Ventilation in Underground Bituminous Coal Mines.)

Note: Figure 30 shows no physical connection between the air curtain device and the line brattice. This allows a portion of the clean ventilation airflow to short circuit before it reached the face. It is felt that the amount of short circuited airflow does not have a significant effect on the air curtain effectiveness.

The air curtain configuration was set for the most efficient angle, inlet orientation, and airflow, as determined from laboratory tests at Donaldson Company. At 3000 cfm ventilation airflow, the air curtain was angled 80 degrees from horizontal toward the return. At 7200 cfm airflow, the air curtain was angled 60 degrees from horizontal toward the intake side. In both cases, the air inlet for the air curtain was closest to the face (see Figure 30) and the air curtain airflow was 575 cfm.

6.4.2 Test Procedure

The test procedure consisted of introducing methane at the face and then sampling at several locations in the intake side and also in the return. A flowmeter was used to

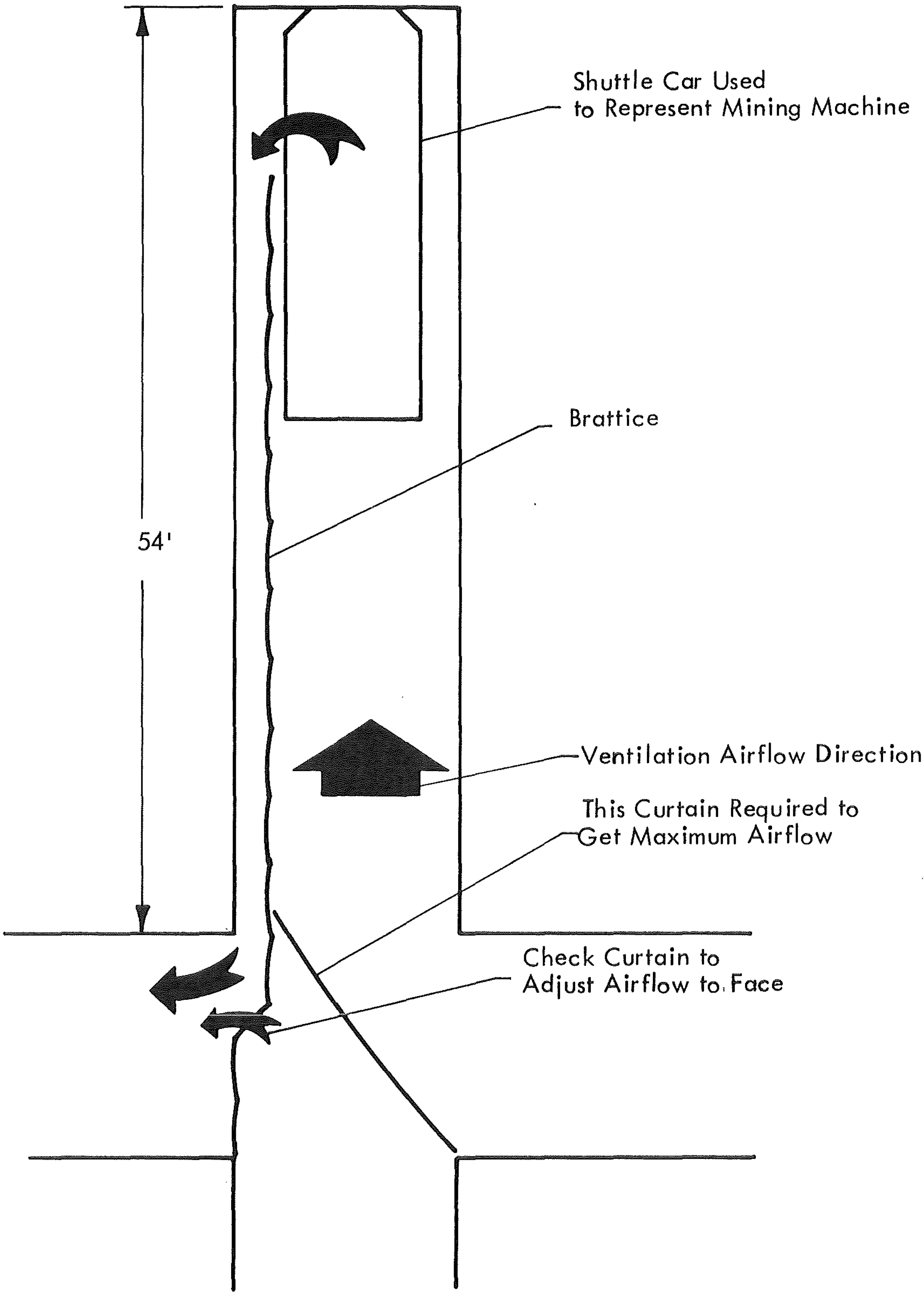


Figure 31. Ventilation Test Configuration

monitor the flow of methane. This flow was held constant and was checked periodically during the tests. A hydrocarbon analyzer and chart recorder were used to measure methane concentrations in parts per million (ppm). The sampling locations are shown on Figure 30. Location #5 represents the operator's position. However, location #6 could also be the operator's position depending on the machine being used. Purge time tests were also run. These tests consisted of allowing the return side concentration to stabilize while feeding methane at the face. The methane was then shut off and the time noted for the return concentration to reach 40 ppm.

Ventilation airflows used for these tests were 3000 and 7200 cfm. Originally, it was desired to attain 9000 cfm, but this was not possible because of the extensive sealing of outby locations required. Note, in Table 9, that 7200 cfm was not attainable when the air curtain was operating, and a rate of only 6400 cfm was achieved. Although this must be compared to a baseline test at 7200 cfm, the air curtain performs well.

6.4.3 Test Results

The test data was originally recorded on a strip chart. For convenience, this data was compiled, and tabulated, and is presented in Table 9. The data in parentheses represents the range of methane concentrations encountered at the indicated locations. There was a wide range of concentrations associated with the "air curtain off" configuration and with the brattice located 20 ft from the face. This indicates that ventilation air was not reaching the face efficiently and there were some rolling eddy currents and probably "dead" spots. This is also indicated by the high purge time. When the air curtain was turned on, the variance in concentrations was reduced, and the higher values were also reduced. However, when the air curtain is off and the brattice is located 10 ft from the face, concentrations at locations 1 through 6 were essentially zero. This was the case for both 3000 cfm and 7200 cfm ventilation airflow. Purge times were also lowest at these test conditions. As previously stated, the brattice system was sealed better than is attainable in working mines. Consequently, it was felt that the air curtain should compare favorably with the brattice systems used in production coal mines.

In conclusion, the air curtain performance was definitely better than a brattice system located 20 ft from the face and approaches the effectiveness of an "ideal" brattice system

Table 9. Test Results – Methane Sampling at Bureau's Safety Research Coal Mine

Configuration	Ventilation Airflow (cfm)	Concentration of Methane (ppm) Location (see Fig. 1)							Purge Time to 40ppm (min)	Initial Conc. (ppm)
		1	2	3	4	*5	*6	7		
Air Curtain Off Brattice 10 ft to face	3000	0	0	0	0	0	0	890 (870–930)	2.1	840
Air Curtain Off Brattice 20 ft to face	3050	– (300–1550)	– (100–1100)	– (50–365)	– (50–900)	– (0–10)	0	760 (690–810)	4.6	970
Air Curtain On Brattice 20 ft to face	3100	1350 (1300–1400)	660 (610–710)	290 (260–325)	575 (550–585)	75 (70–80)	120 steady	715 (680–725)	3.5	730
Air Curtain On Brattice 20 ft to face	3050	970 (930–1000)	520 (510–530)	330 (330–335)	365 (360–370)	100 steady	330 (325–335)	730 (720–745)	4.4	760
Air Curtain Off Brattice 10 ft to face	7200	0	0	0	0	0	0	265 (240–280)	1.4	250
Air Curtain Off Brattice 20 ft to face	7200	(0–900)	0	0	0	0	0	350 (310–380)	2.3	410
Air Curtain On Brattice 20 ft to face	6400	425 (390–465)	210 (190–225)	45 steady	95 steady	25 steady	20 steady	305 (290–315)	2.0	310

* 5 – operator's position

located 10 ft from the face. Also, it is apparent from the rather steady readings throughout the intake side that the air curtain is mixing the air well, which tends to scour the face area.

7 PHASE V

This phase was devoted to the underground testing of the air curtain device at two working underground coal mines. One mine company desired to remain anonymous and will be designated Mine A. The other mine site was the Florence Mining Company, Florence No. 1 Mine, Robinson Portal, near Armagh, Pennsylvania. The mining machine used for test at Mine A was a JOY 12CM. The mining machine under test at the Florence No. 1 Mine was a JOY 11CM. Both mine sites were mining in about a 6-foot-high coal seam and both used exhausting ventilation systems with line brattice on the left side of the mining machine.

Approval for the tests at Mine A were obtained from the state inspector and the district MESA office.

The testing performed at the Florence No. 1 mine was approved by the Pennsylvania Office of Deep Mine Safety and the District #2 MESA office.

The test program consisted of dust sampling at the machine operator's position using personal samplers. The sampling was conducted both with and without the air curtain operating in order to provide data to evaluate the effectiveness of the device against presently used line brattice systems. The program was originally scheduled to sample five shifts with the air curtain and five shifts without the air curtain. In most cases, three samplers were run concurrently at the operator's position and one sampler in the intake airway upstream of the working face. Records were kept of total tonnage during each shift, total sampling time, total time at each heading, quantity of ventilation airflow at each heading, and miscellaneous information such as equipment breakdowns and resulting lost time.

7.1 Tests at Mine A

The data obtained from Mine A indicate that the air curtain performs as well as the existing line brattice system. The average dust concentration for four shifts with the air curtain on was 4.16 mg/m^3. The average of five shifts with the air curtain off was 4.23 mg/m^3 for a reduction in operator exposure of 0.07 mg/m^3 (1.7 percent reduction). Table 10 presents the data obtained at Mine A. Figures 32 through 40 show the

Table 10. Summary Test Data from Mine A

Date	Shift	Air Curtain	Tonnage (no. buggies)	Total Sampling Time (hrs)	Ventilation Airflow (cfm)	Time at Heading (hrs)	Type of Cut	Respirable Concentration (mg/m^3)	Comments
9/28/76	1st	ON	54 (6 slate)	6.2	4180 5550 7760	2.83 0.78 0.75	crosscut crosscut crosscut	intake - 0.72 operator - 6.31 machine - 6.26 machine - 6.38 machine - 5.06 machine - 6.12 operator avg - 6.03	
	2nd	ON/OFF (on 23 minutes, off 4 hours)	62 (16 slate)	4.4	4000 3600 4500 3300	1.22 1.23 0.80 1.12	crosscut crosscut crosscut crosscut	intake - 0.18 operator - 3.68 machine - 10.68 machine - 7.14 machine - 7.46 operator avg - 7.24	
9/29/76	1st	OFF	65 (14 slate)	5.5	16500	----	heading	intake -0.12 operator - 1.15 machine - 1.55 machine - 1.52 machine - 1.51 machine - 1.40 operator avg - 1.43	This data eliminated
	2nd	ON	63 (21 slate)	4.8	18000 12125 23040 2550	0.42 0.67 0.72 1.17	heading heading heading heading	intake - 0.10 operator - 2.16 machine - 2.05 machine - 2.74 machine - 2.46 machine - 2.23 operator avg - 2.33	
9/30/76	1st	ON	52	6	12960 4600 5220 8370	0.17 1.33 1.50 0.75	heading heading crosscut heading	intake - 0.7 machine - 3.9 machine - 5.3 machine - 5.9 operator avg. - 5.03	
	2nd	OFF	58 (21 slate)	5.75	4210 4590 4315 ----	1.25 1.67 0.83 0.83	heading heading heading sump pit	intake - 0.1 operator - 3.4 machine - 2.3 machine - 2.7 operator avg. - 2.80	no brattice, return airway
10/1/76	1st	OFF	49 (23 slate)	4.75	18600 8346	2.25 2.33	heading heading	intake - 0.4 operator - 4.9 machine - 3.2 machine - 5.5 operator avg. - 4.53	seam height 12 to 14 ft rock fall, damaged air curtain
	2nd	ON	63 (16 slate)	6.50	28800 4698 4140 6225	1.00 1.17 1.42 2.25	heading heading heading heading	intake - 0.3 operator - 3.2 machine - 3.5 machine - 3.0 operator avg. - 3.23	no brattice, return airway
10/5/76	1st	OFF	63 (14 slate)	6.42	6330 3800 4608 6450 8136	0.82 0.92 0.53 0.42 1.50	heading heading heading heading heading	intake - 0.4 operator - 4.2 machine - 4.6 machine - 4.3 operator avg. - 4.37	
	2nd	OFF	44	5.50	7200 5000 4840 6000	1.08 1.75 1.25 0.08	heading crosscut crosscut crosscut	intake - 0.9 operator - 2.3 machine - 1.7 machine - 2.6 operator avg. - 2.20	

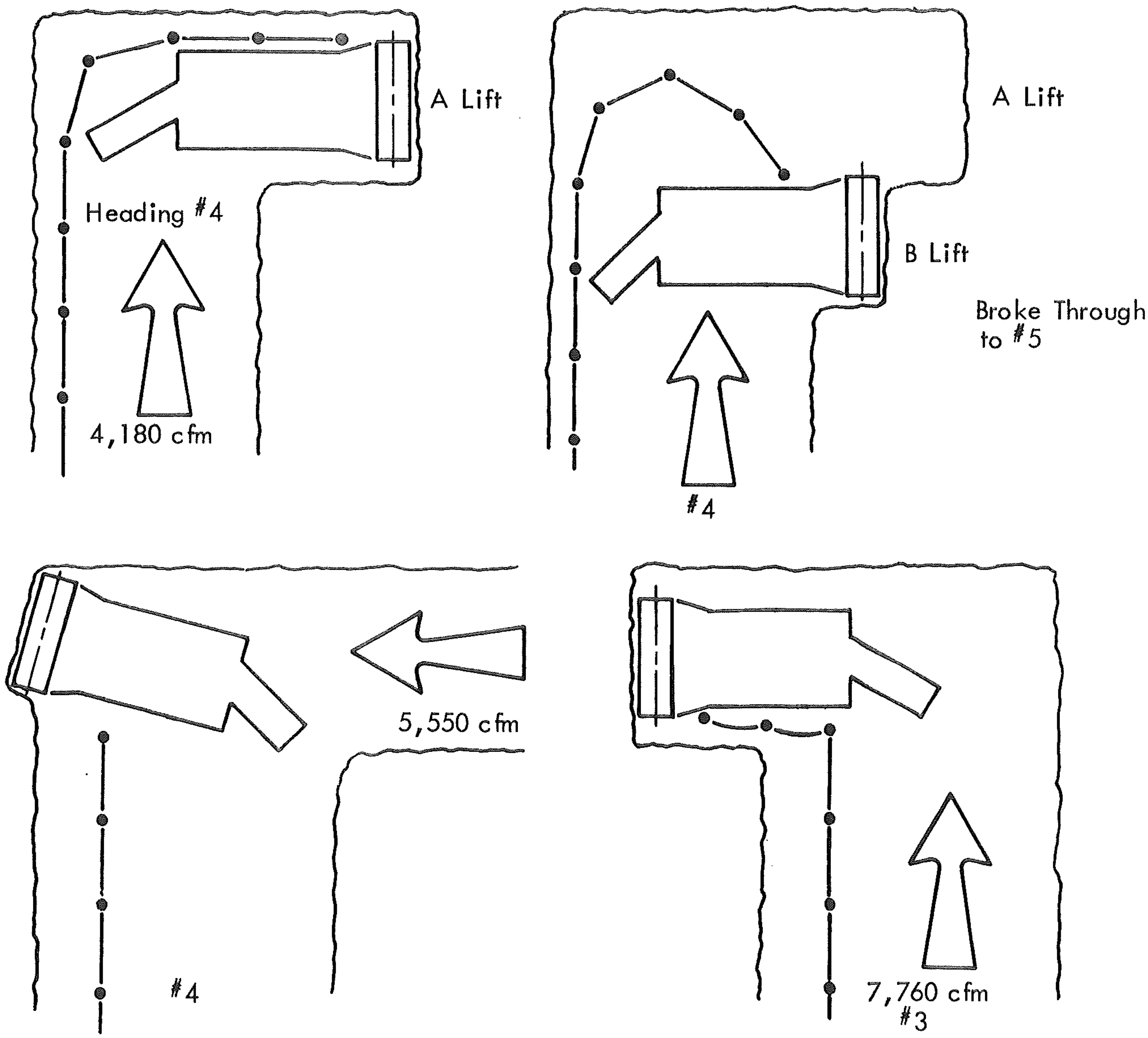


Figure 32. 9/28/76 (Tues) - a.m. shift - Air Curtain ON

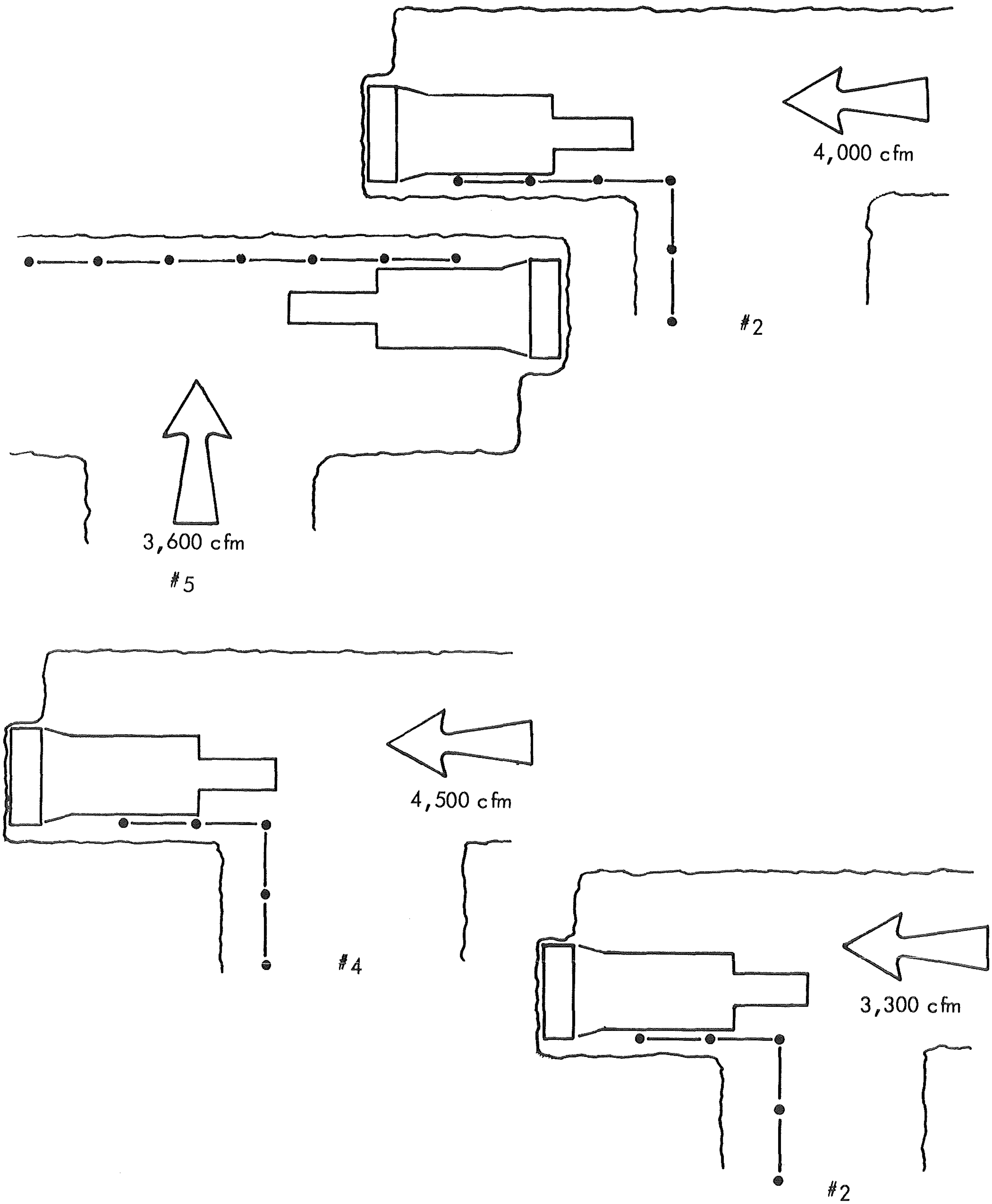
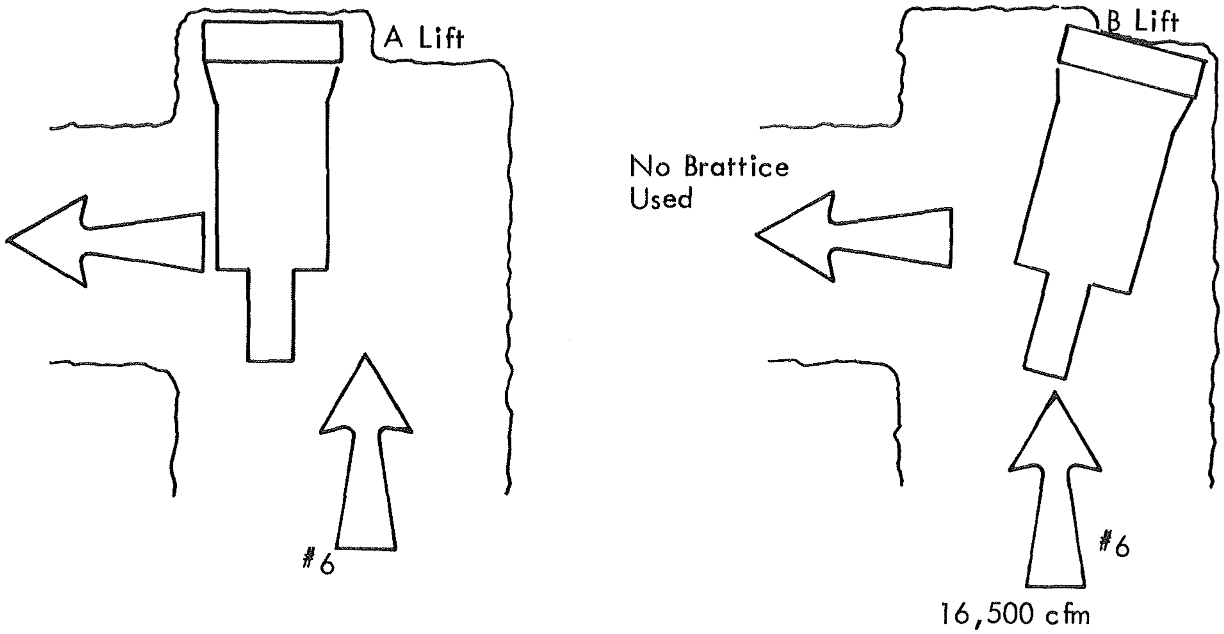


Figure 33. 9/28/76 (Tues) - p.m. shift - Air Curtain ON/OFF



9/29/76 (Wed) - a.m. shift - Air Curtain OFF

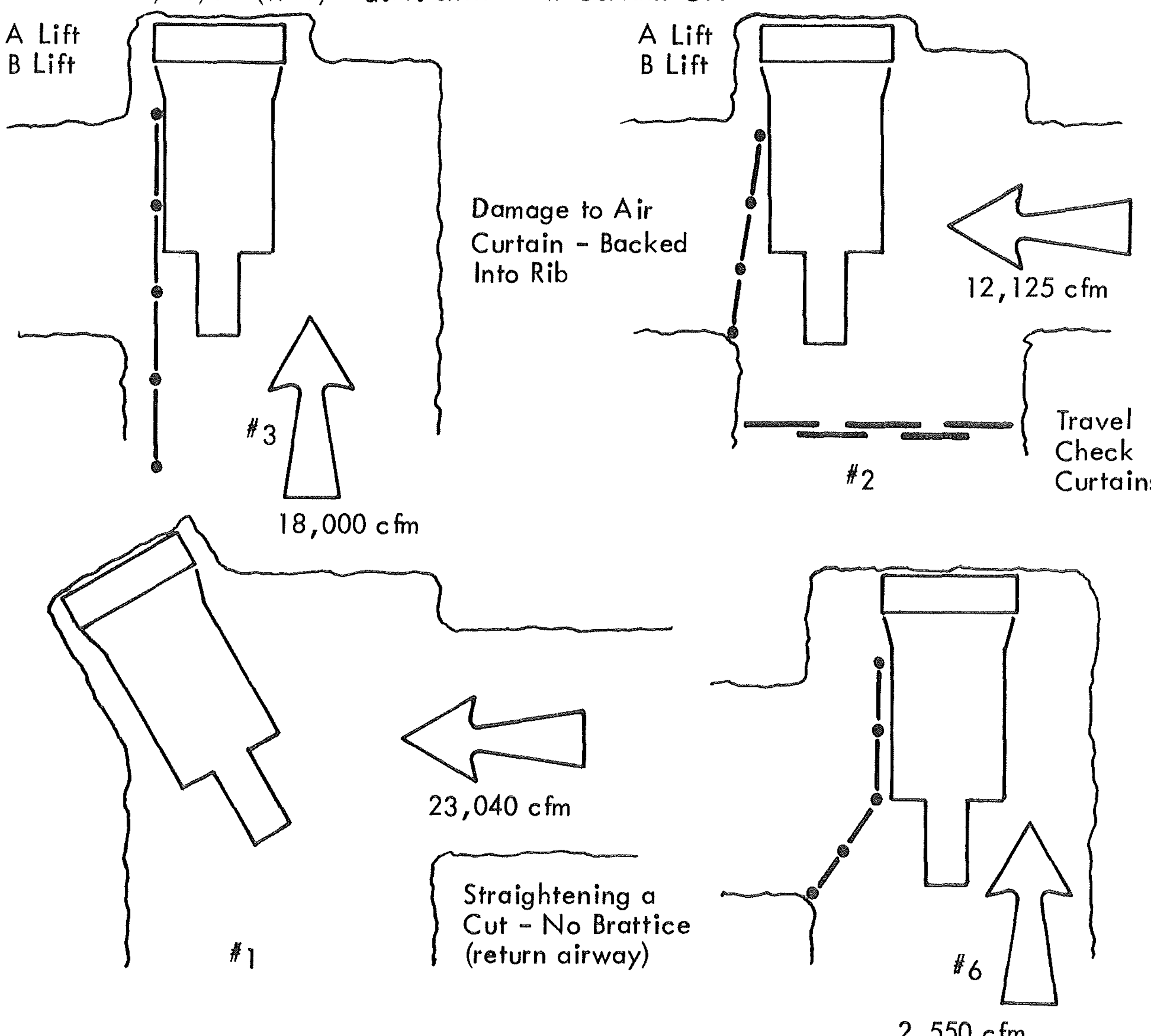


Figure 34. 9/29/76 (Wed) - p.m. shift - Air Curtain ON

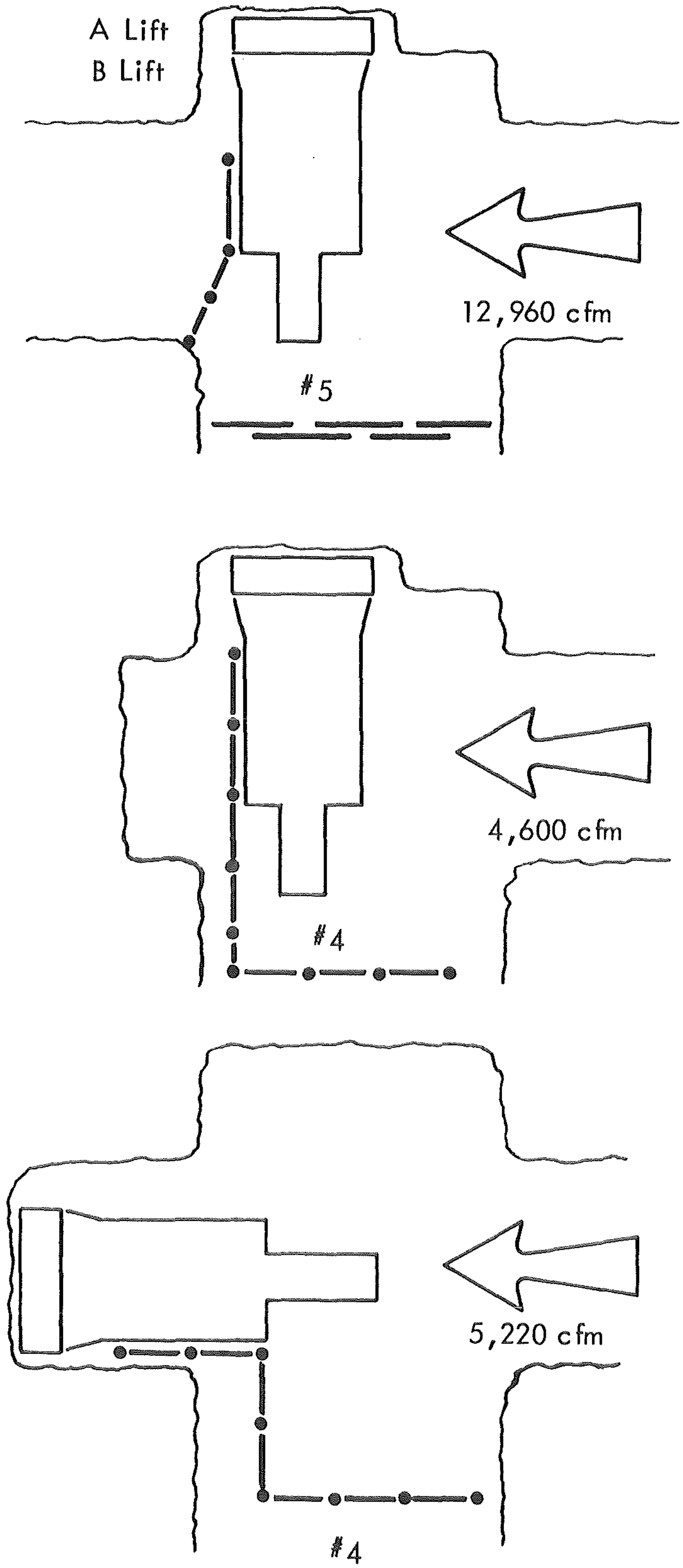
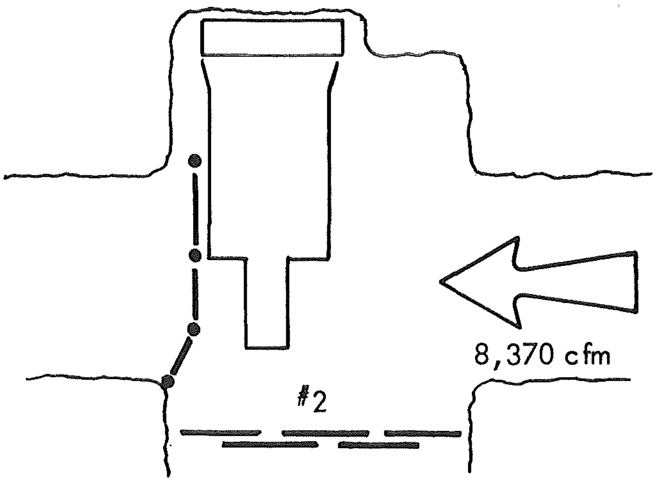


Figure 35. 9/30/76 (Thurs) - a.m. shift - Air Curtain ON



9/30/76 (Thurs) - a.m. shift - Air Curtain ON

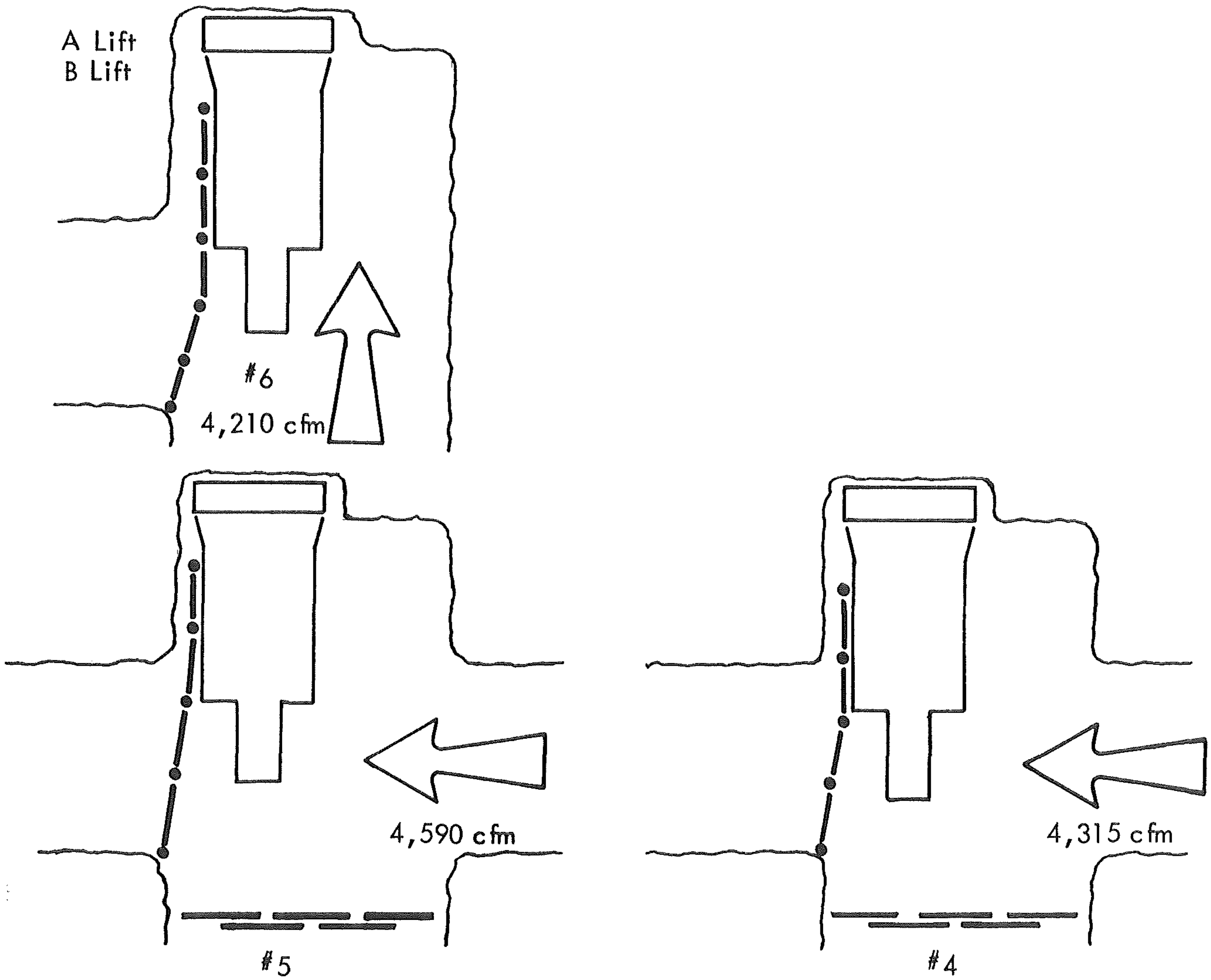
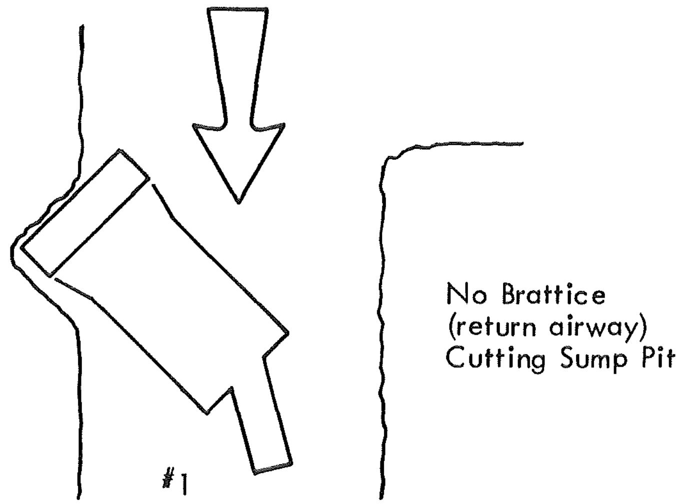
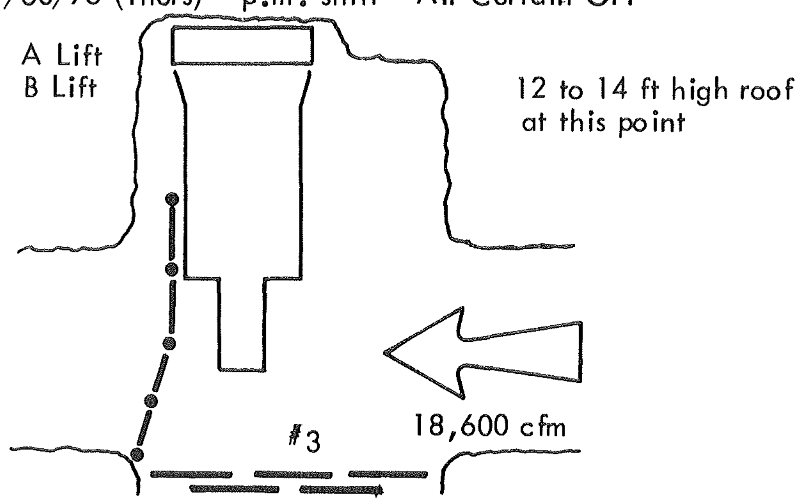


Figure 36. 9/30/76 (Thurs) - p.m. shift - Air Curtain OFF



9/30/76 (Thurs) - p.m. shift - Air Curtain OFF



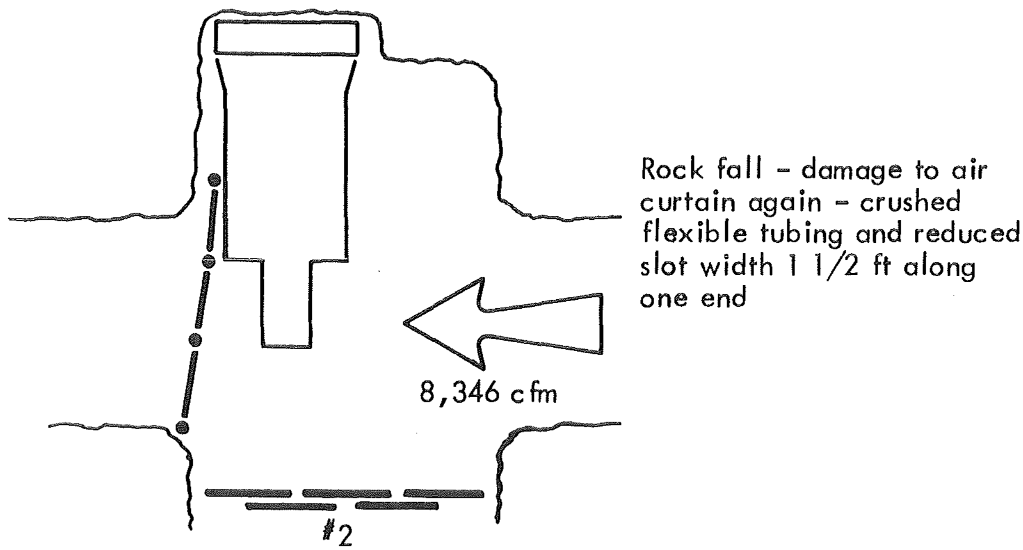


Figure 37. 10/1/76 (Fri) - a.m. shift - Air Curtain OFF

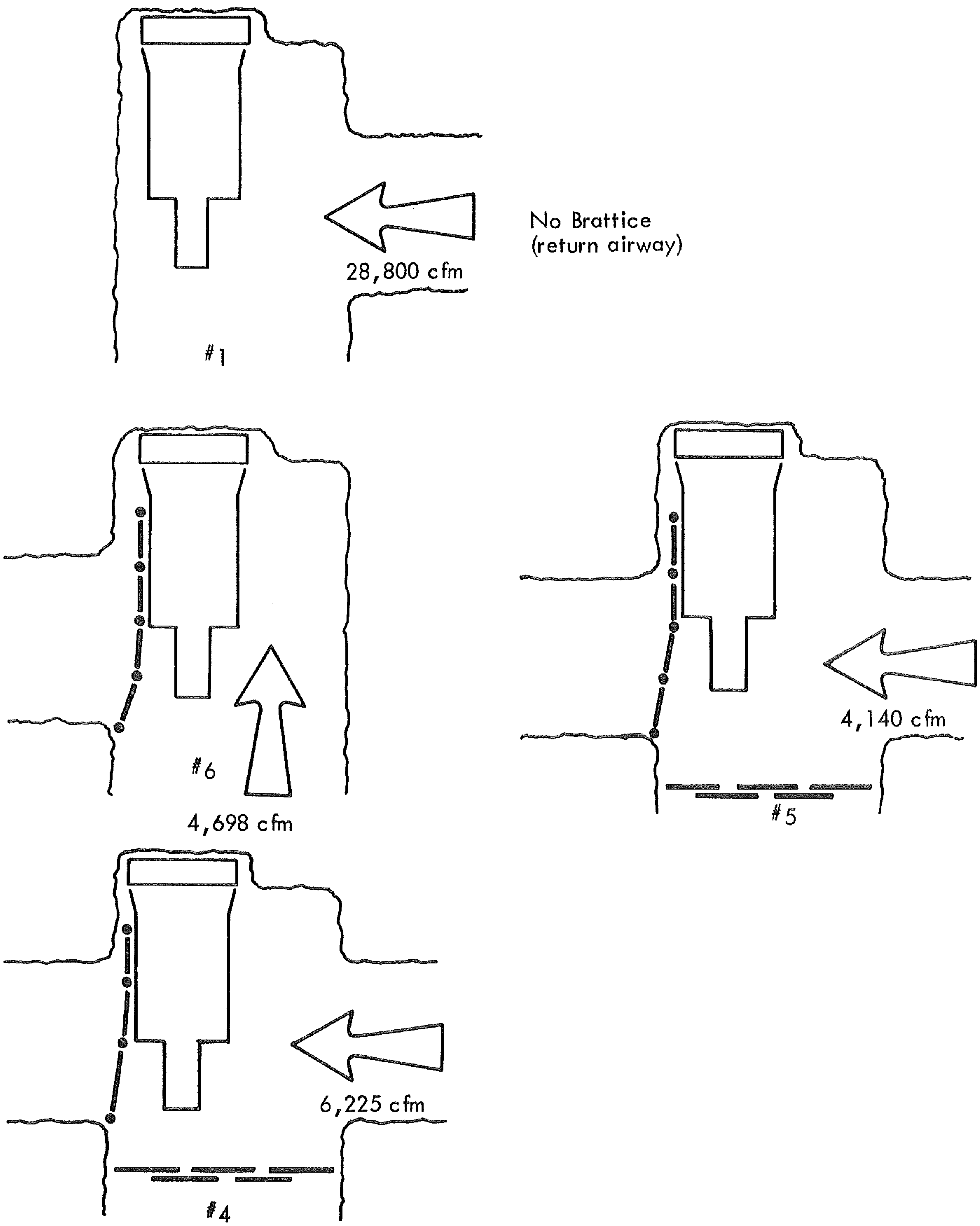


Figure 38. 10/1/76 (Fri) - p.m. shift - Air Curtain ON

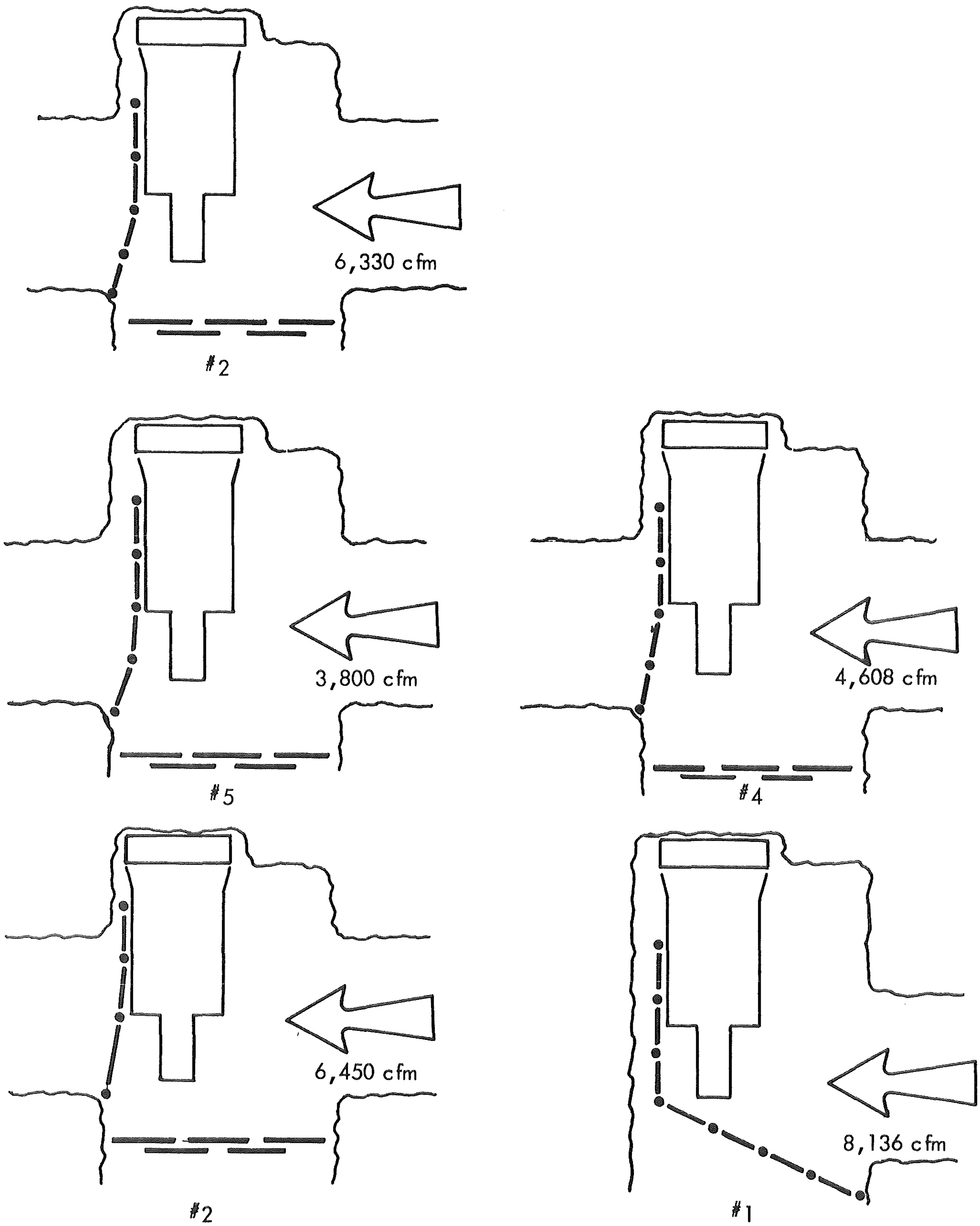


Figure 39. 10/5/76 (Tues) - a.m. shift - Air Curtain OFF

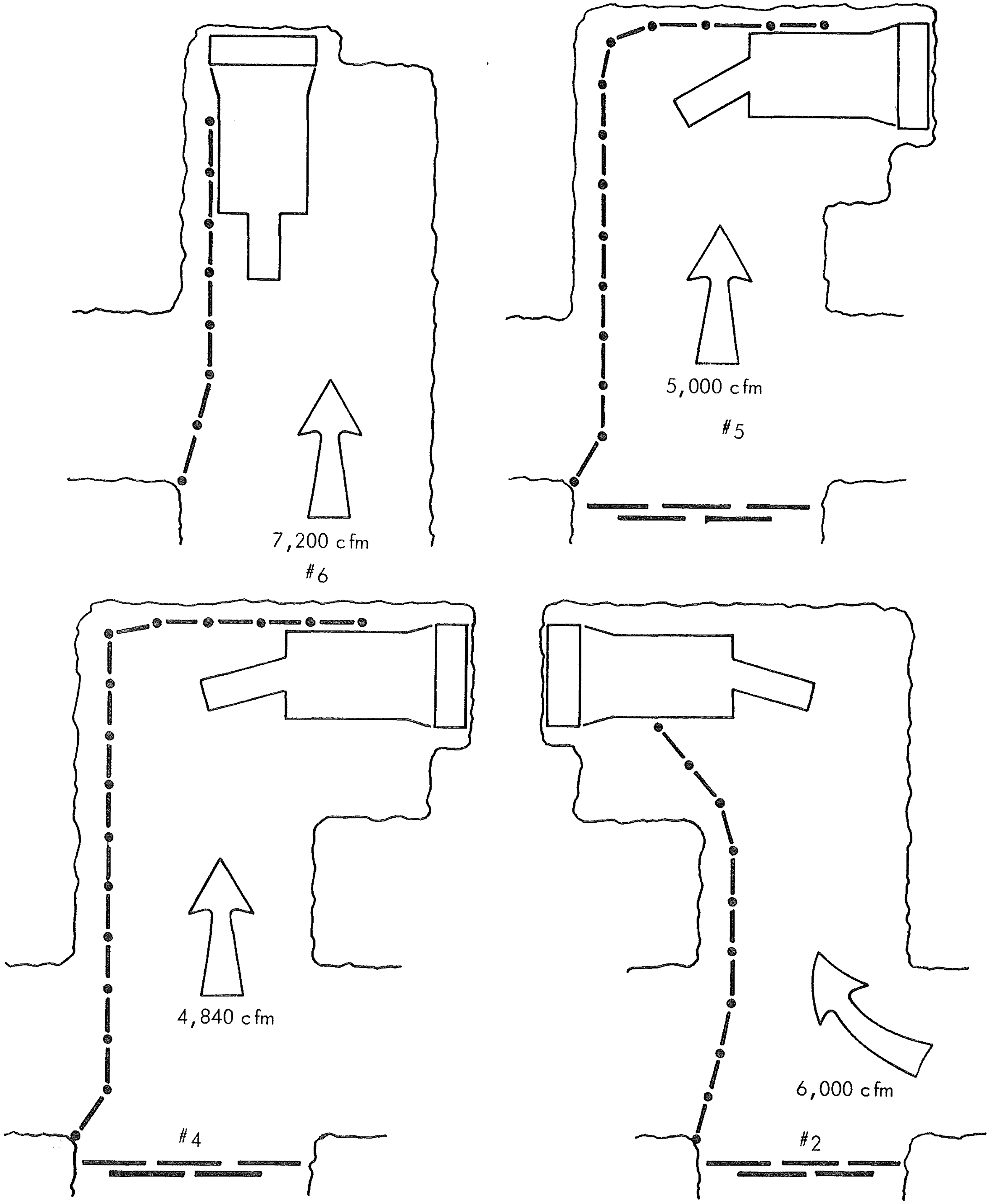


Figure 40. 10/5/76 (Tues) - p.m. shift - Air Curtain OFF

ventilation configuration at each heading. Note the data for 9/29/76, first shift, were eliminated. They were not considered representative because the machine was in the intake airway, no brattice was used, and the ventilation airflow was very high.

The air curtain manifold used at this site was 12 feet long (this turned out to be too long for the JOY 12CM). Consequently, about 1-1/2 feet of the manifold was allowed to hang over the back of the machine. This resulted in damage to the air curtain on at least two occasions (see Table 10 for 9/29/76 and 10/1/76). This damage was caused, for the most part, by contact with the rib.

As a result of the above problems, with the length of the air curtain at Mine A, the second unit was shortened to ten feet and the air curtain was recalibrated. As a result, the airflow was reduced from 575 cfm for the 12-foot long air curtain to 480 cfm for the 10-foot long air curtain. No damage was encountered at the Florence No. 1 Mine using the shorter air curtain.

7.2 Tests at Florence No. 1 Mine

The air curtain was installed and tested underground at the Florence No. 1 Mine near Armagh, Pennsylvania. The test program consisted of taking gravimetric dust samples at the operator's position and also in the intake airway. Tests were performed during five shifts with the air curtain in use and during four shifts of normal operating conditions without the air curtain. One shift was lost because of a wildcat strike on the last day of testing. In most cases, three personal samplers were run concurrently at the same location at the operator's position. One sampler was always used in the intake airway upstream of the working face. The personal samplers were monitored by Donaldson Company personnel at all times. The preweighed loaded filters were weighed by Bureau of Mines personnel. The test data presented on Table 11. Figures 42 through 49 show the ventilation configuration of each heading.

The test data indicates that the air curtain decreased significantly the respirable dust concentration at the operator's position, compared to the conventional line brattice. When all the dust samples collected were averaged for the five shifts, with the air curtain in use, the concentration was 1.04 mg/m^3; when data from the four shifts of normal operation

Table 11. Summary of Test Data From Florence No. 1 Mine

Date	Air Curtain	Tonnage (no buggies)	Total Sampling Time (hrs)	Ventilation Airflow (cfm)	Time at Heading (hrs)	Type of Cut	Respirable Concentration (mg/m³)	Comments
2/7/77	ON	44	5.783	4284 8085 4998	2.500 1.600 0.383	heading crosscut heading	0.82 } machine 0.91 } 0.84 ave. 0.78 } 0.46 - intake	
2/8/77	ON	40	3.327	9800 9800	1.783 1.917	heading heading	1.20 } machine 0.90 } 1.08 ave. 1.13 } 1.08 - intake	cat drive breakdown - lost 58 minutes cat drive breakdown and rockfall - lost 30 minutes
2/9/77	ON	63	4.983	5954 7744 8560 5000	0.633 1.500 1.250 0.667	heading heading heading heading	1.20 } machine 1.56 } 1.25 ave. 1.00 } 0.37 - intake	long entry (60-70 ft) long entry (70 ft), cat drive lost 8 minutes
2/10/77	ON	45	4.133	5780 5700 11468	1.917 0.330 0.917	crosscut crosscut crosscut	0.65 } machine 0.81 } 0.77 ave. 0.85 } 0.30 - intake	buggy cable broke - lost 20 minutes broke into heading #2 - ventilation high broke hydraulic hose - lost 25 minutes
2/11/77	ON	68	4.167	10800 8400 10200	1.667 1.417 1.083	crosscut crosscut crosscut	1.26 } machine 1.30 } 1.24 ave. 1.16 } 1.44 - intake	buggy breakdown - lost 15 minutes also rock dusting and bolting upstream rock dusting and bolting upstream

Table 11. Summary of Test Data From Florence No. 1 Mine (continued)

Date	Air Curtain	Tonnage (no buggies)	Total Sampling Time (hrs)	Ventilation Airflow (cfm)	Time at Heading (hrs)	Type of Cut	Respirable Concentration (mg/m³)	Comments
2/14/77	OFF	70	4.000	10248 9614 10200 9660	1.367 1.333 0.817 0.483	heading heading heading heading	2.44, 1.73, 1.67 } machine 1.95 ave. 1.90 - intake	rock dusting and bolting upstream rock dusting and bolting upstream
2/15/77	OFF	83	5.150	9771 7647 10500 8880 8900	0.250 1.967 1.983 0.917 0.417	heading heading heading heading heading	1.46, 1.47, 1.68 } machine 1.54 ave. 1.21 - intake	belt down - lost 43 minutes
2/16/77	OFF	50	3.300	8400 8000 9000	1.000 1.850 0.417	crosscut crosscut crosscut	1.26, 0.96 } machine 1.11 ave. 0.33 - intake	miner broke down - lost 40 minutes
2/17/77	OFF	42	2.800	7650 6772	3.200 1.300	crosscut crosscut	1.49, 1.37 } machine 1.43 ave. 0.42 - intake	miner down - lost 1 hour 55 minutes

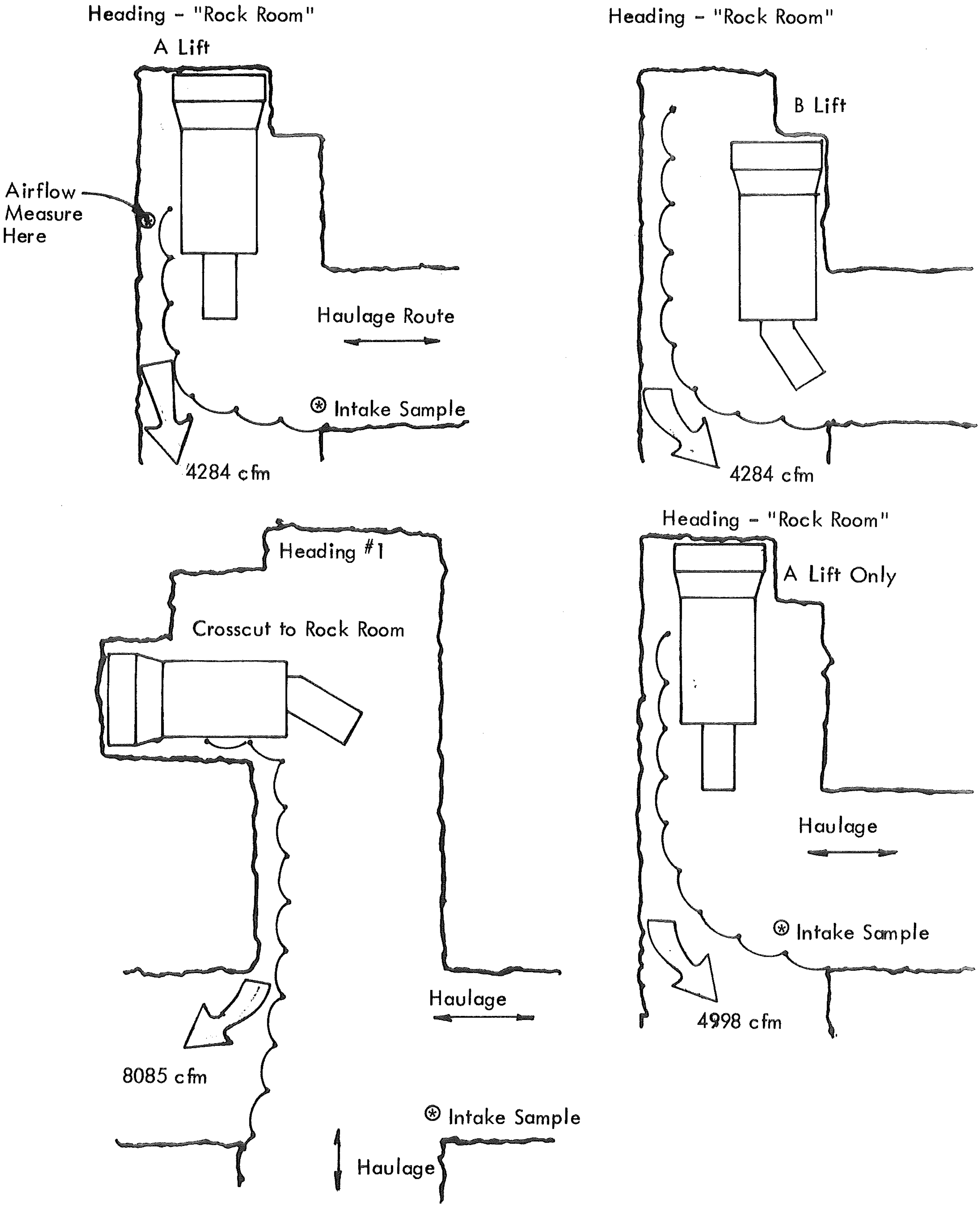


Figure 41. 2/7/77 (Mon.) - Air Curtain ON

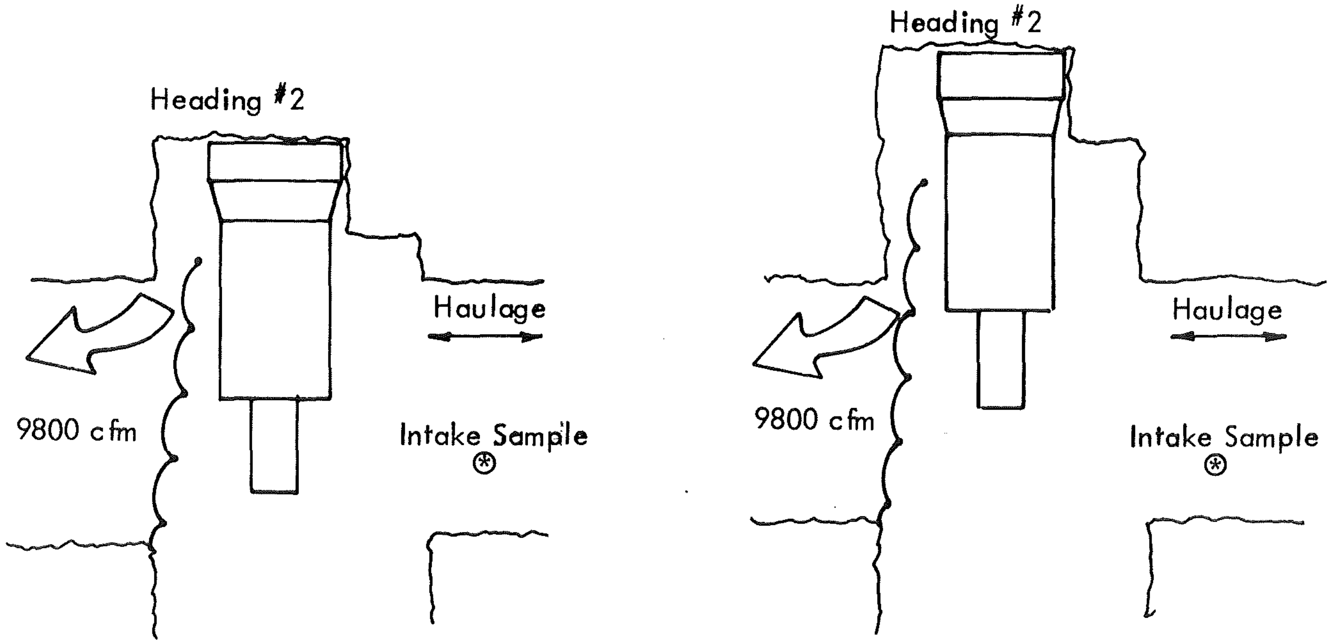


Figure 42. 2/8/77 (Tues.) - Air Curtain On

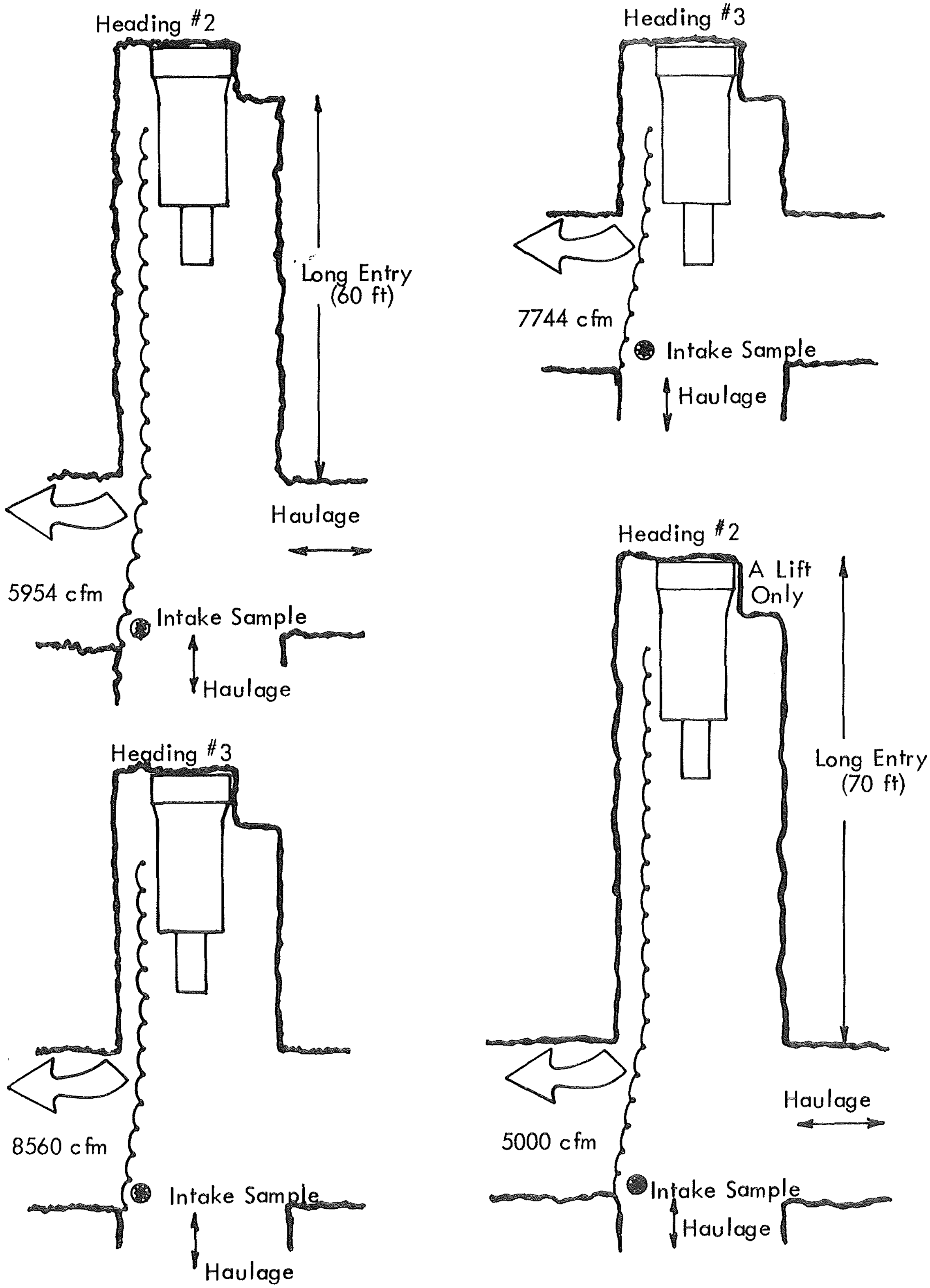


Figure 43. 2/9/77 (Wed.) - Air Curtain ON

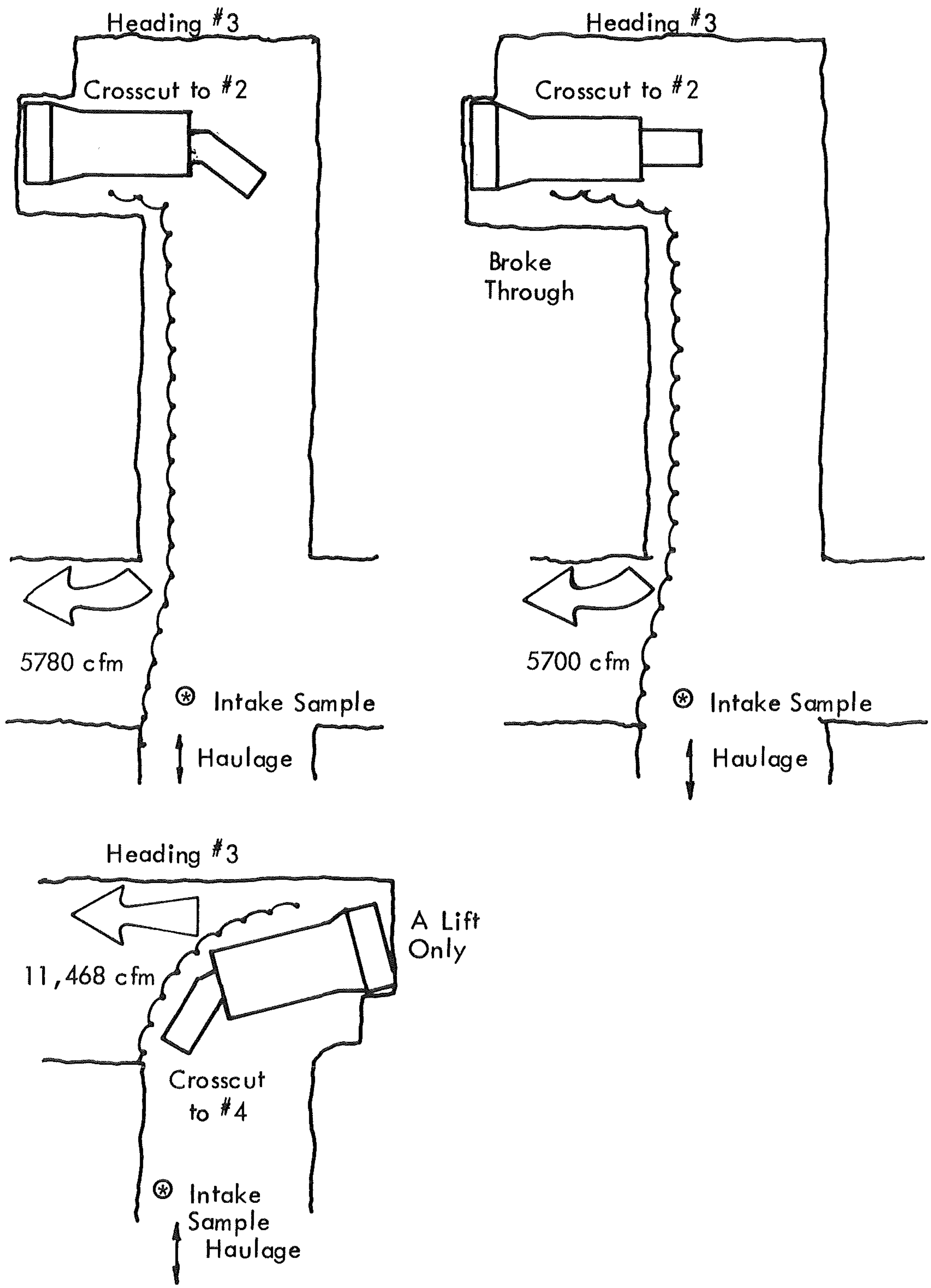


Figure 44. 2/10/77 (Thurs.) - Air Curtain ON

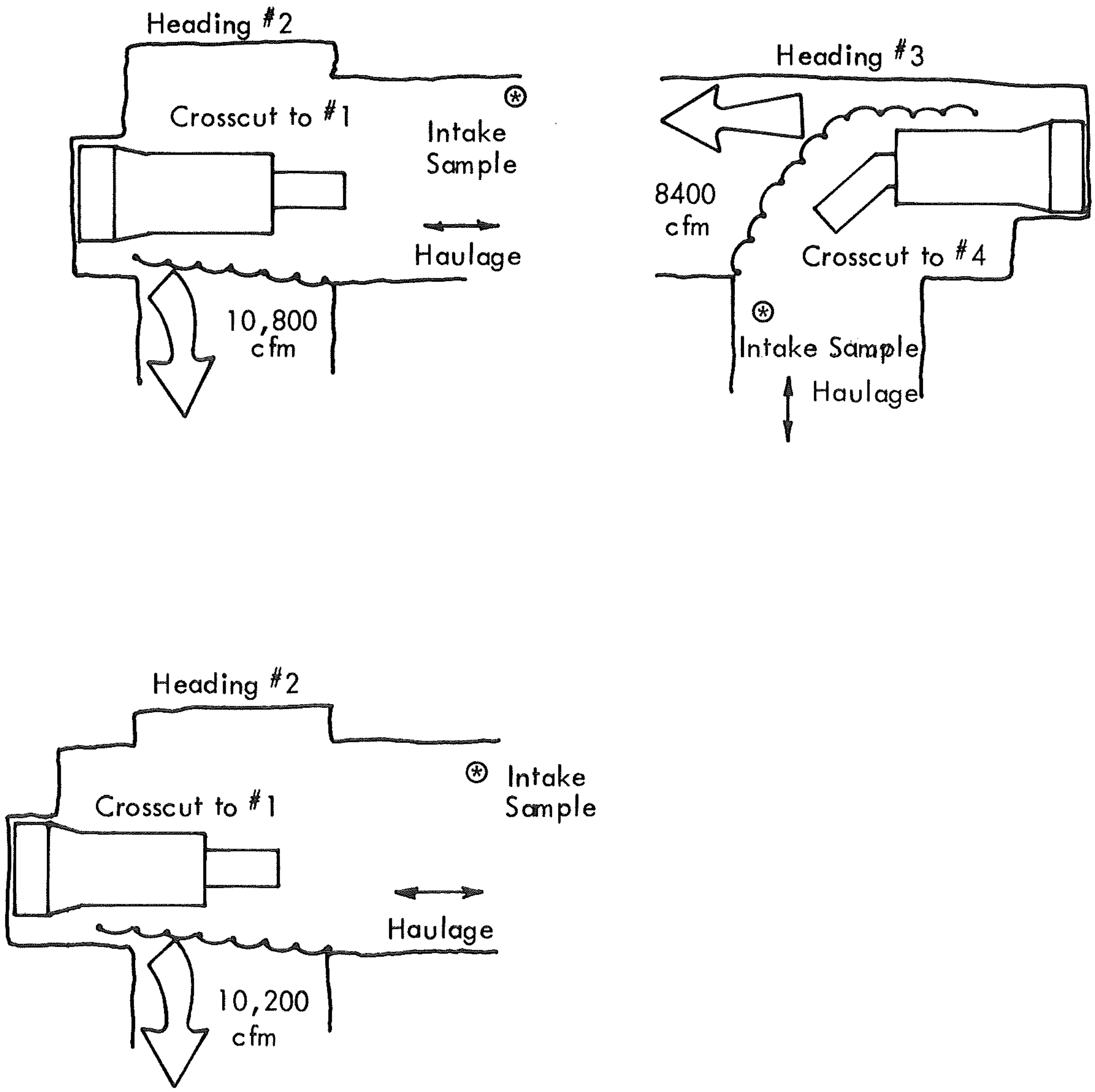


Figure 45. 2/11/77 (Fri.) - Air Curtain ON

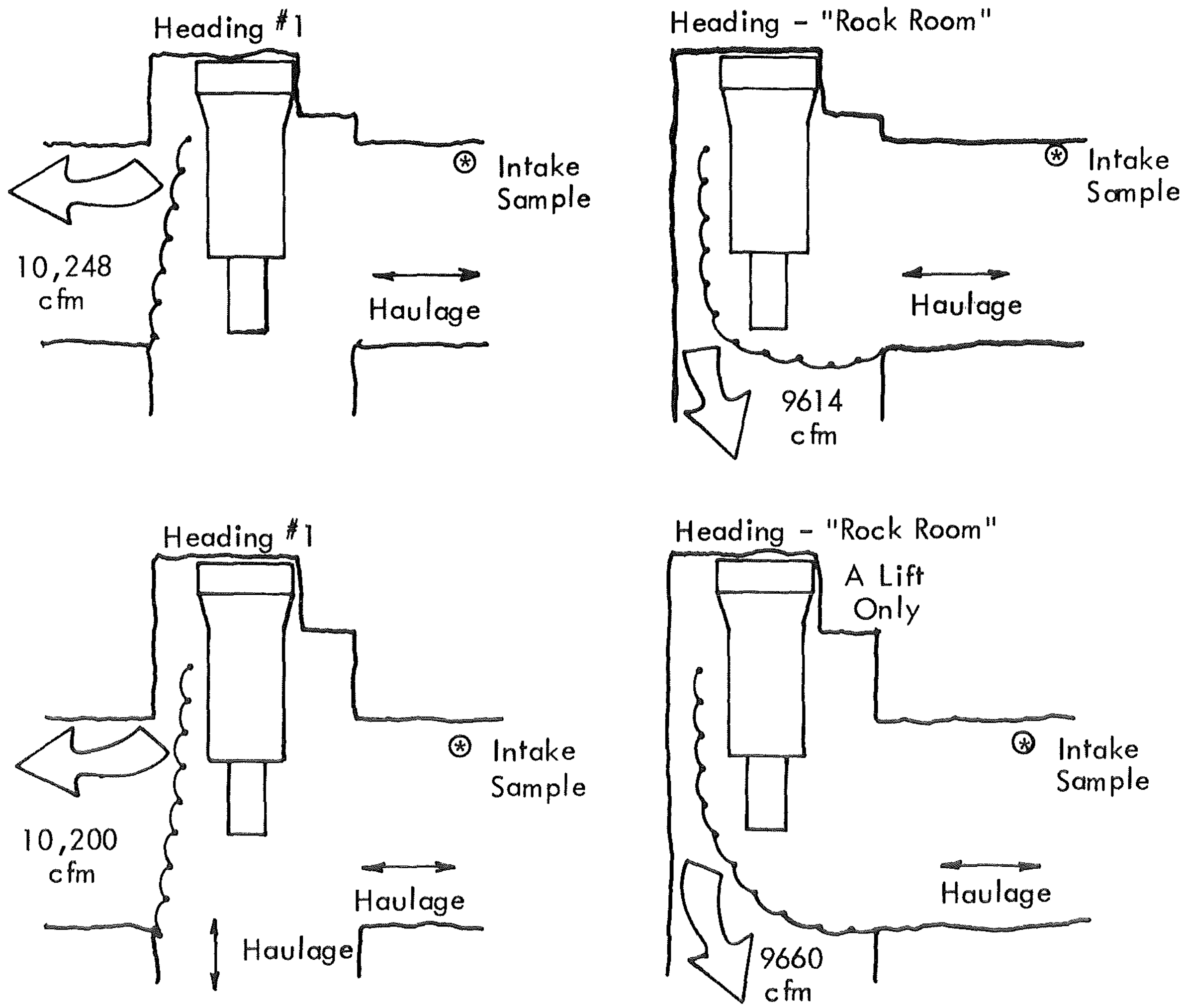


Figure 46. 2/14/77 (Mon.) - Air Curtain OFF

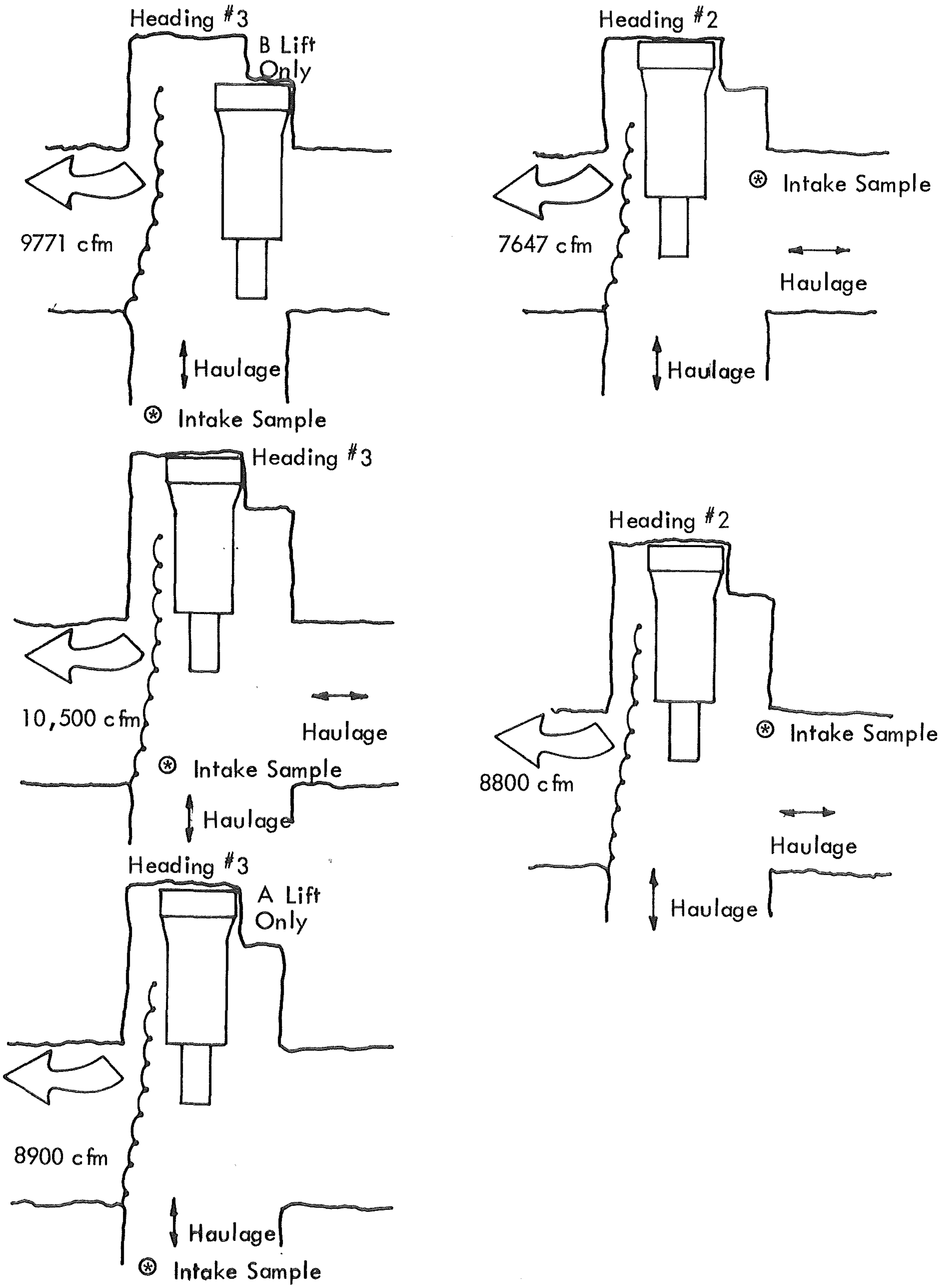


Figure 47. 2/15/77 (Tues.) - Air Curtain OFF

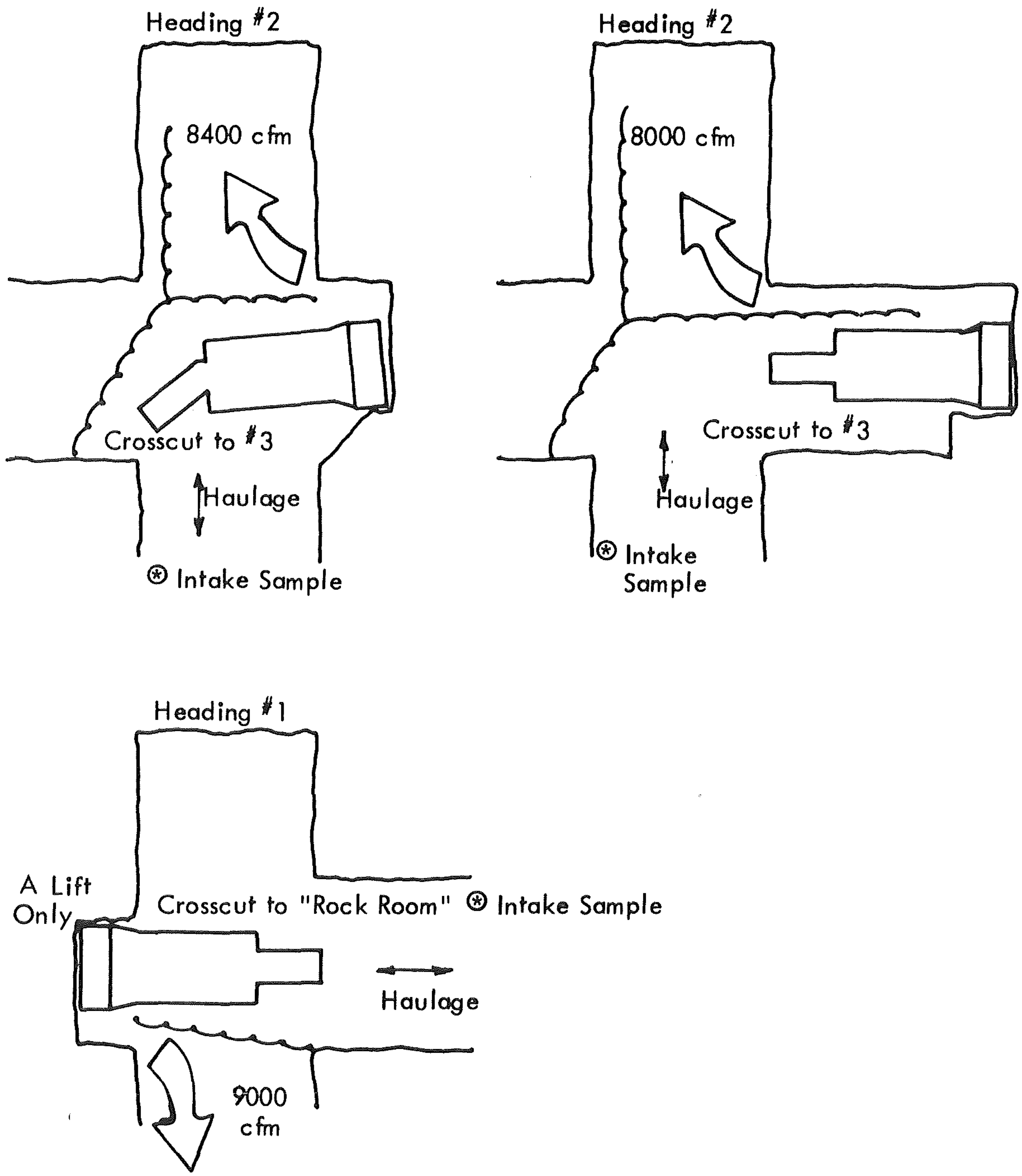


Figure 48. 2/16/77 (Wed.) - Air Curtain OFF

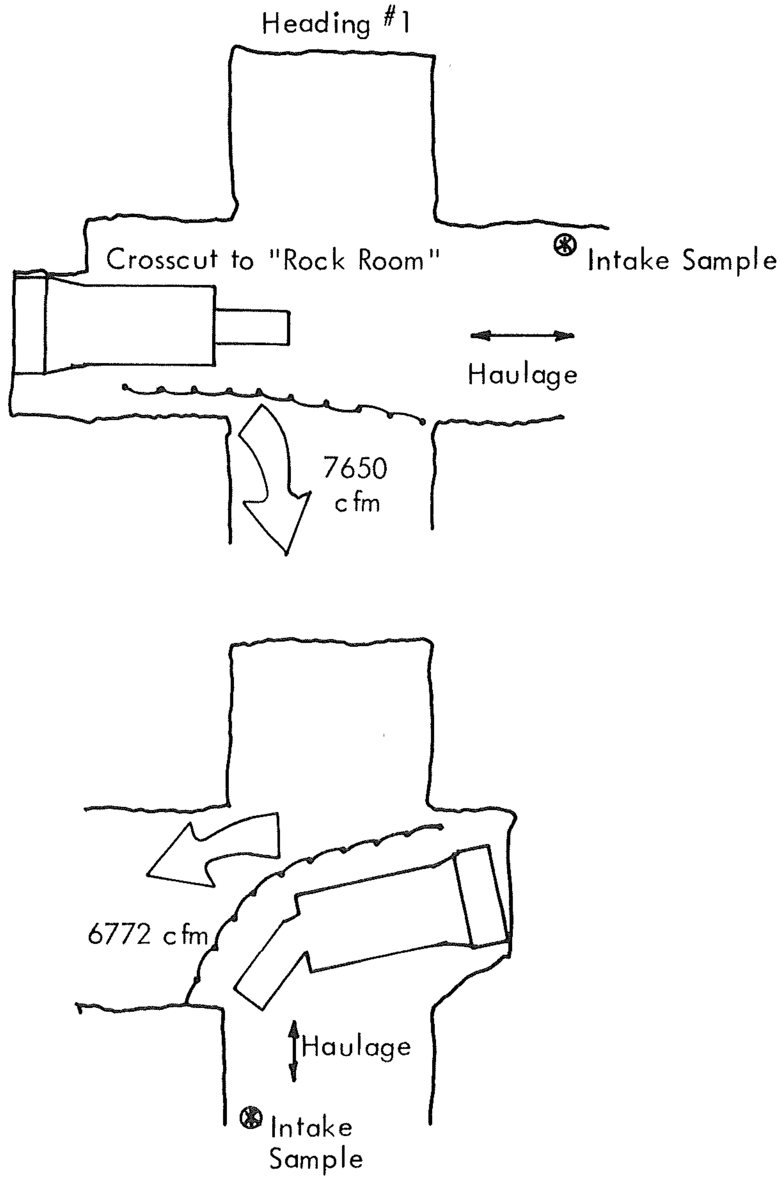


Figure 49. 2/17/77 (Thurs.) - Air Curtain OFF

using conventional line brattice was averaged, the concentration was 1.51 mg/m^3. Thus, the air curtain achieved a 0.47 mg/m^3 (31 percent) reduction in respirable dust concentration.

Note the high dust concentrations in the intake air for 2/11/77 and 2/14/77. These high concentrations were a result of roof bolting and rock dusting activities in an upstream heading.

This series of field tests concluded the technical effort on this contract.

8 INSTRUCTIONS FOR OPERATION AND MAINTENANCE

The operation of the line brattice air curtain is rather simple. In addition, the device requires no periodic maintenance. However, there are some initial set-up considerations. First, the physical size of the device requires that it be mounted on the top of the continuous mining machine on the side opposite the operator's position and along the outside leading edge (there is not enough space available on the operator's side). Also, it is necessary to stay behind the pivot point on the cutting-head boom because the air curtain manifold is a rigid member. Fortunately, the pivot point on most machines is close to ten feet from the face, which is the maximum legal limit that line brattice can be from the face. The prime purpose of the air curtain is to act as an <u>extension</u> of the conventional line brattice cloth. Consequently, the ventilation plan must be positioned, such that the line brattice and air curtain are both, on the same side of the machine. Figure 50 illustrates the air curtain mounted on a Jeffrey 120 Heliminer. Note that it is exhausting ventilation with the line brattice cloth on the left side.

The air curtain airflow must also be adjusted to the specific conditions extant underground. The slot angle can be easily adjusted by means of graduations on the end of the rock shield. The manifold is locked in place with two bolts after the necessary adjustments. The airflow is varied by setting the speed on the hydraulically-driven blower until a predetermined positive pressure is measured at the inlet of the air curtain manifold. This was easily accomplished during the underground testing of the air curtain by using a roll-up water manometer and a hydraulic flow control valve. It was found during the calibration of the two field test units that although both units were made to the same specifications, the inlet pressures were slightly different. This probably is the result of variances in the slot width. Consequently, each air curtain device must be calibrated with respect to inlet pressure versus airflow. For example, one unit was found to have an inlet pressure of 10.70 in. wg at 575 cfm. The other unit had an inlet pressure of 12.75 in. wg at 575 cfm. This unit was later shortened from 12 ft to 10 ft to accommodate the length of the machine under test at Florence No. 1. The airflow was then reduced to 480 cfm resulting in an inlet pressure of 10.00 in. wg.

Because the air curtain is powered with a hydraulic motor, the hydraulic oil flow and pressure available on the mining machine to be used must be considered. This power

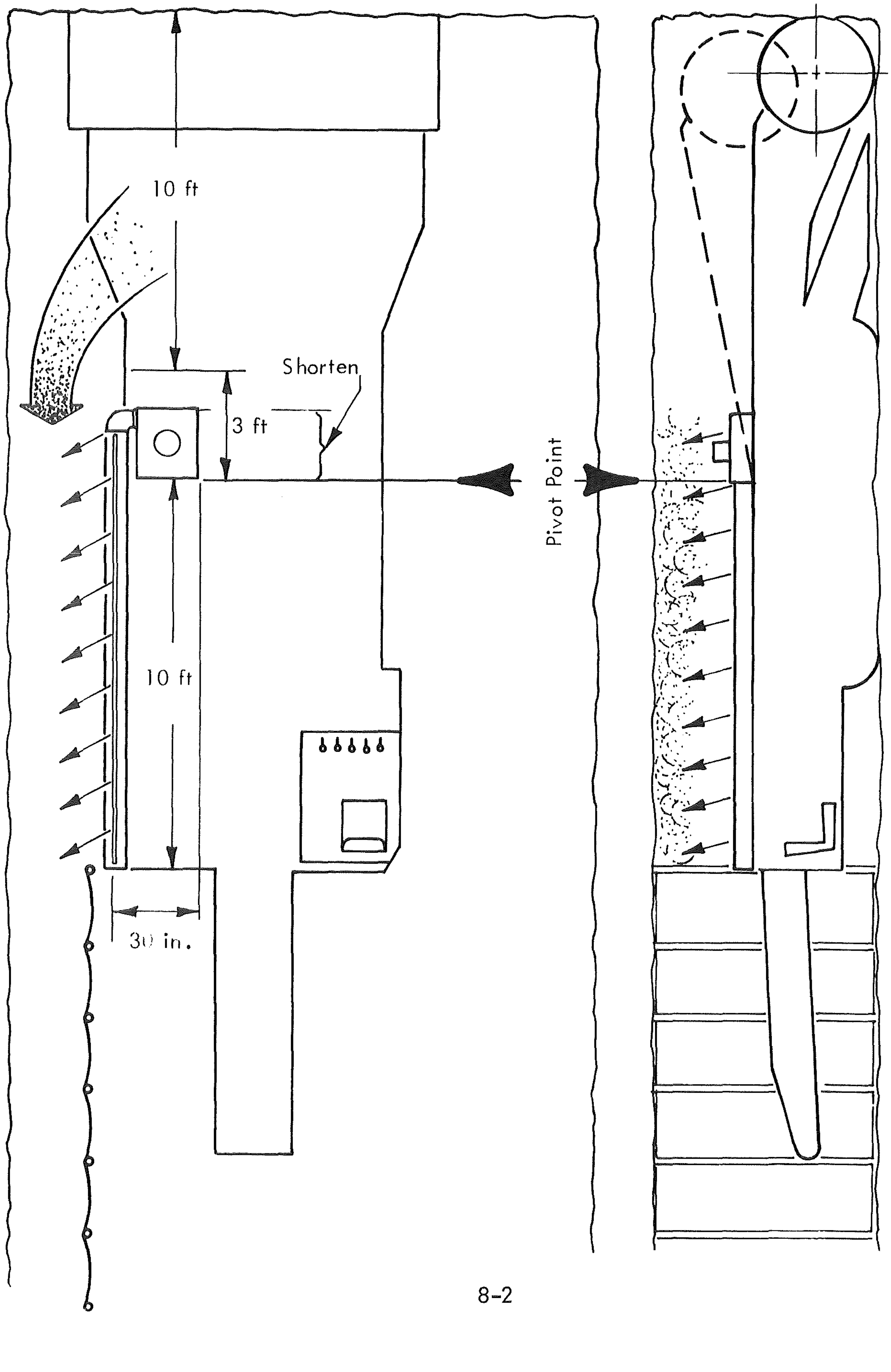


Figure 50. Line Brattice Air Curtain Adapted to Jeffrey 120 Heliminer

requirement also varies with individual air curtains. One unit required 5.5 gpm at 850 psi to get 575 cfm, while a second unit required 5.9 gpm at 1000 psi. The requirements for this second unit dropped to 5.3 gpm at 700 psi when it was shortened. During the under ground test, these power requirements were readily available on the mining machines. The JOY 11CM tested at the Florence No. 1 Mine required an extra stage be added to the main hydraulic pump. Both installations required no more than one shift to install the air curtain. These installations included some metal cutting and welding.

The hydraulic circuit used to power the blower is shown on Figure 51. The hydraulic flow control knob can be locked to avoid unwanted adjustments. The relief valve is included as a protection device for both the hydraulic motor and the pump on the mining machine. For example, at the Florence No. 1 Mine, only 5 gpm of the pumps 20 gpm capacity was needed. Consequently, 15 gpm was dumped back to the reservoir. The hydraulic motor is a gear-type motor and requires a 20 micron hydraulic filter. These hydraulic filters are usually in the circuit on the mining machine.

No periodic maintenance is required on the air curtain device. However, because the inlet of the blower is mounted in close proximity to the top of the mining machine, it was found that the blower tends to pick up accumulated pieces of coal and debris on initial start-up. It quickly scours the immediate area and further pieces are then only periodically picked up. This is not a problem for the blower but could, over a period of time, tend to accumulate in the opposite end of the manifold tube. Another possible problem, although not a problem during the underground tests, could be damage to the manifold slot from falls of coal and roof. This could alter the volume and distribution of the air current.

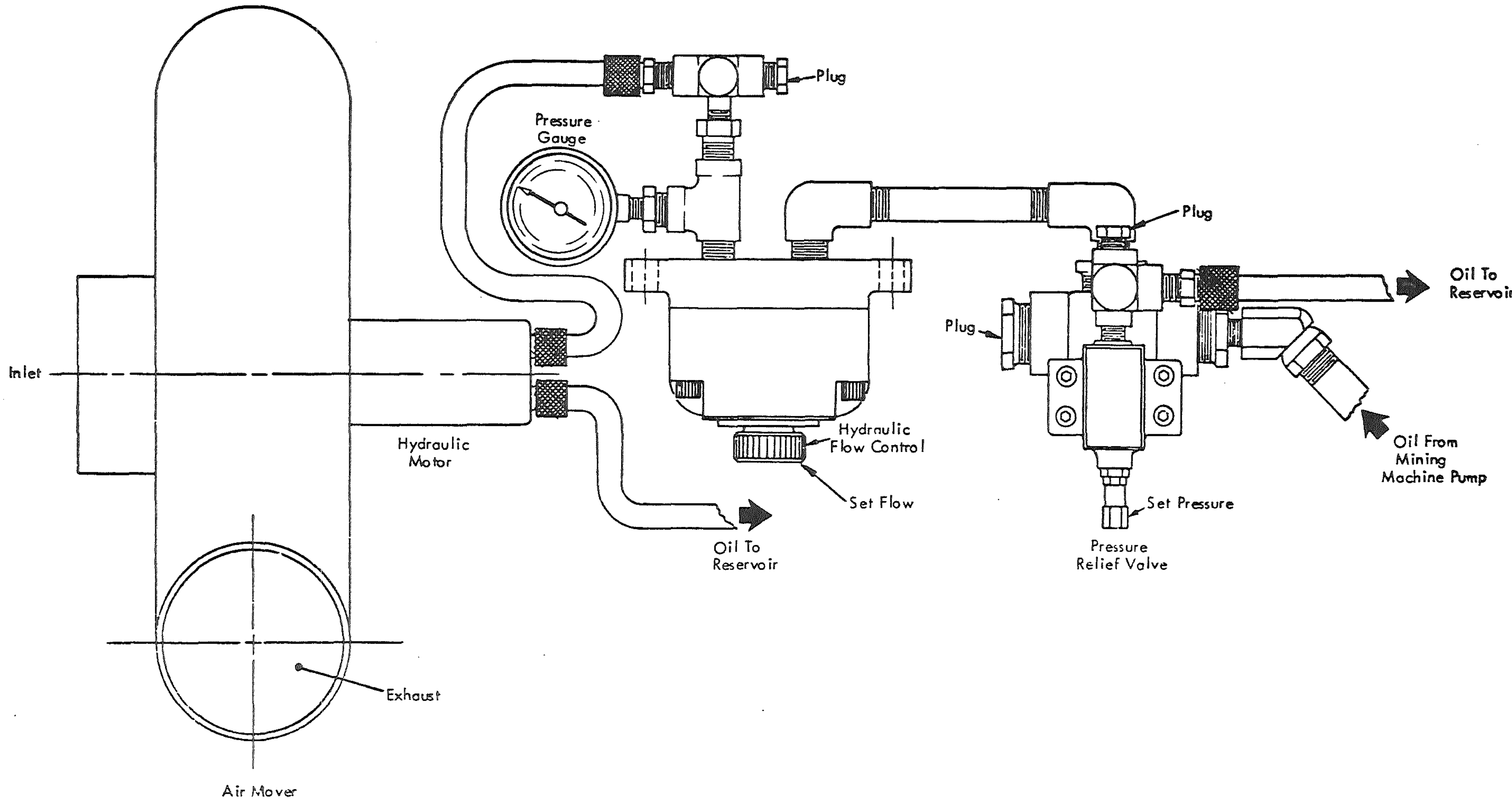


Figure 51. Hydraulic Circuit for Blower Package

9 RECOMMENDATIONS

The following recommendations should be considered on future production models:

- The use of a MESA-approved electric motor to power the blower to facilitate installation and increase running time (when using the hydraulic motor, the air curtain shuts down when machine shuts down)

- The possibility of integrating the air curtain into the mining machine to improve visibility

- The possible interference of the air curtain with the new lighting requirements on mining machines.

- The use of a inexpensive hydraulic motor, flow control and relief valve to reduce costs.

- Investigate the means of shielding the blower inlet from ingestion of debris

- The use of an air curtain on both sides of the mining machine in order to accommodate a ventilation plan where the line brattice can be used on either side

10 SUBJECT LIST OF INVENTIONS

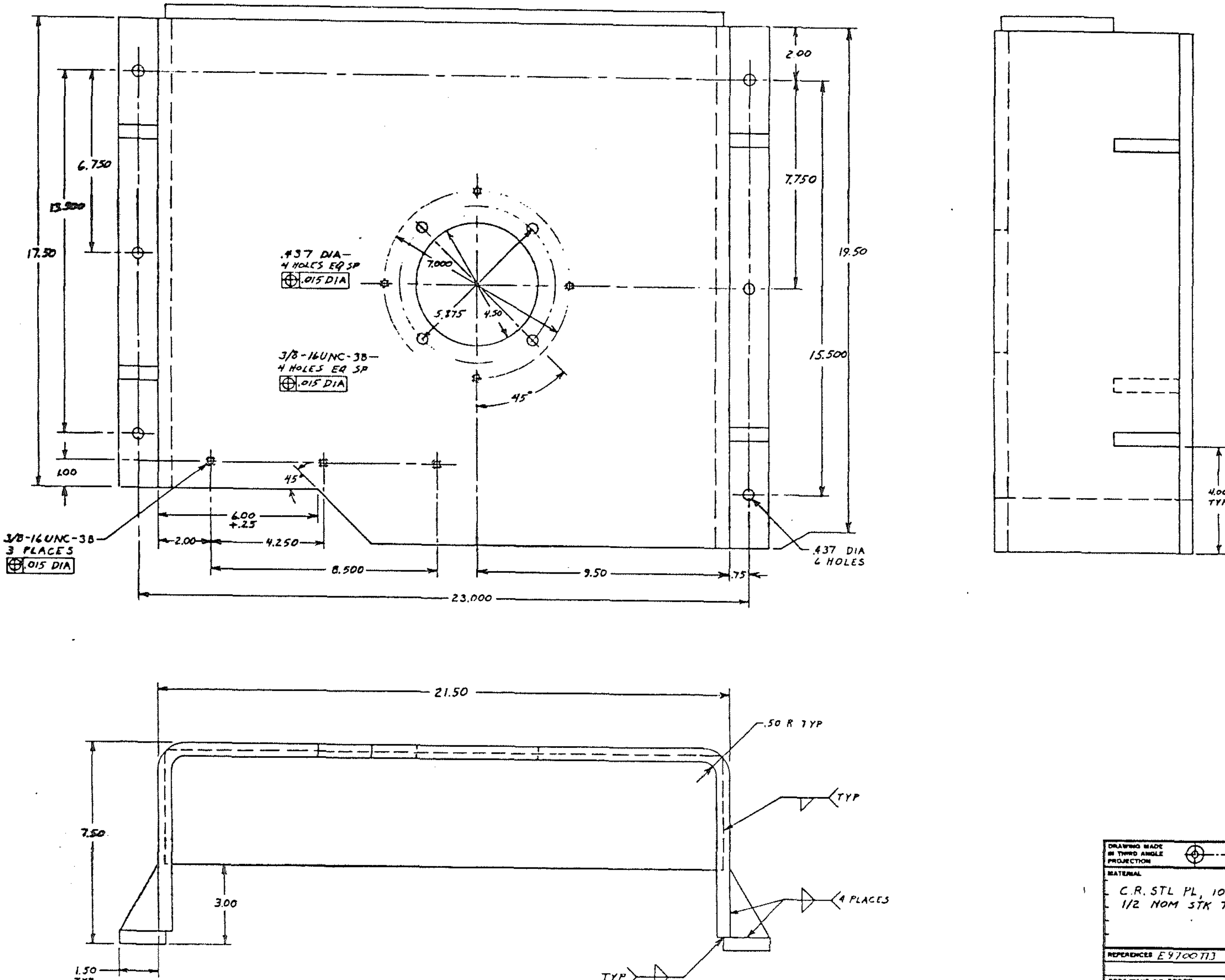
An Invention Disclosure, Form DI-1217, was filed with the Department of the Interior, 29 June 1976, titled "Line Brattice Air Curtain".

APPENDIX

ENGINEERING DRAWINGS

DWG NO.	D9700T4

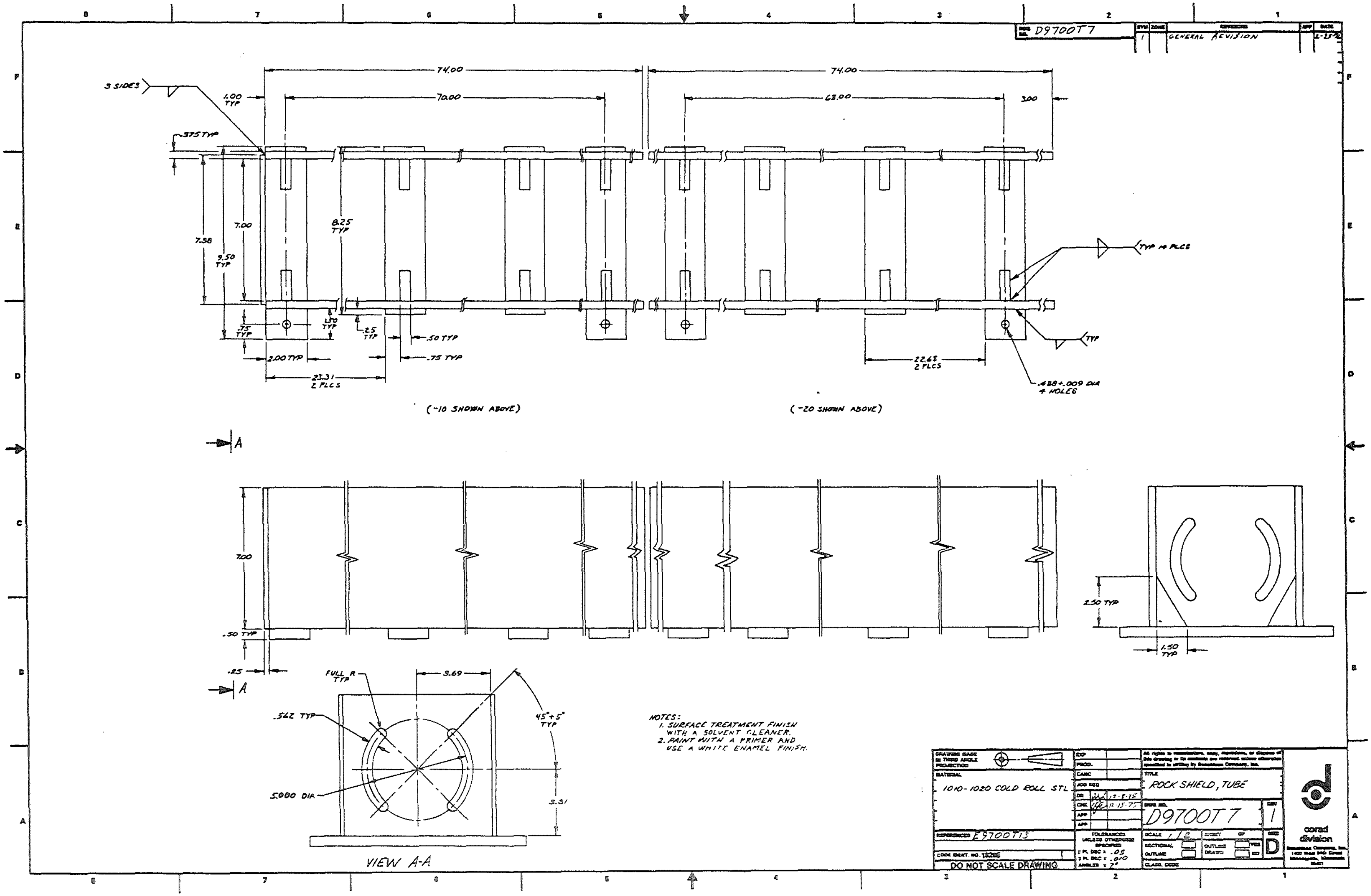
SYM	ZONE	REVISIONS	APP	DATE
1		GENERAL REVISION		2-24-76
2		CHANGE BOLT HOLE PATTERN		3-26-76



NOTES:
1. SURFACE TREATMENT FINISH WITH A SOLVENT CLEANER.
2. PAINT WITH A PRIMER AND USE A WHITE ENAMEL FINISH.

DRAWING MADE IN THIRD ANGLE PROJECTION	
MATERIAL	C.R. STL PL, 1020, 1/2 NOM STK THK
REFERENCES	E9700T13
CODE IDENT NO	18265
DO NOT SCALE DRAWING	
EXP	
PROD.	
CANC	
JOB REQ	
DR	12-10-75
CHK	
APP	
APP	
TOLERANCES UNLESS OTHERWISE SPECIFIED	2 PL DEC ± .06; 3 PL DEC ± .015; ANGLES ± 2°
TITLE	SHIELD, BLOWER
DWG NO.	D9700T4
REV	2
SCALE	1/2
SHEET	OF
SIZE	D
SECTIONAL OUTLINE	
OUTLINE DRAWN	YES / NO
CLASS CODE	

conrad division
Donaldson Company, Inc.
1400 West 94th Street
Minneapolis, Minnesota
55431



NOTES:
1. SURFACE TREATMENT FINISH WITH A SOLVENT CLEANER.
2. PAINT WITH A PRIMER AND USE A WHITE ENAMEL FINISH.

DRAWING MADE IN THIRD ANGLE PROJECTION	
MATERIAL	1010-1020 COLD ROLL STL
REFERENCES	E9700T13
CODE IDENT. NO.	18285
DO NOT SCALE DRAWING	
DR	12-8-75
CHK	12-15-75
TOLERANCES UNLESS OTHERWISE SPECIFIED	2 PL DEC ± .05; 3 PL DEC ± .010; ANGLES ± 2°
TITLE	ROCK SHIELD, TUBE
DWG NO.	D9700T7
REV	1
SCALE	1/12
SIZE	D

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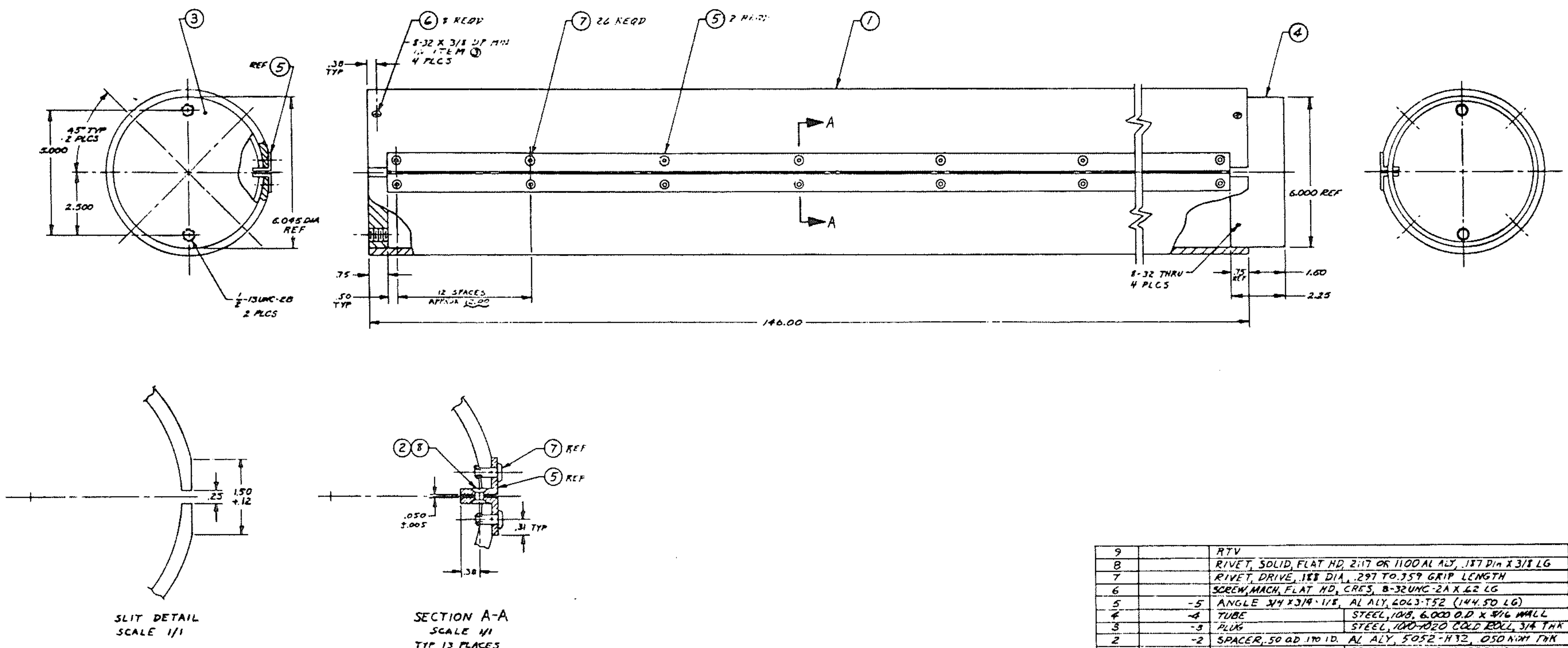
D9700T8

SYM	ZONE	REVISIONS	APP	DATE
1		GENERAL REVISION		3-3-76



NOTES:
1. ITEMS ③ AND ④ TO BE CAD. PLATED
2. MATCH DRILL ALL HOLES IN ITEMS ①,②,③ + ④.
3. APPLY ITEM ⑨ TO ITEMS ③ + ④ PRIOR TO ASSEMBLY TO ITEM ①.

ITEM	DWG NO.	NOMENCLATURE	MATERIAL	QTY
9		RTV		---
8		RIVET, SOLID, FLAT HD, 2117 OR 1100 AL ALY, .187 DIA X 3/8 LG		13
7		RIVET, DRIVE, .188 DIA, .297 TO .359 GRIP LENGTH		26
6		SCREW, MACH, FLAT HD, CRES, 8-32UNC-2A X .62 LG		8
5	-5	ANGLE 3/4 X 3/4 X 1/8, AL ALY, 6063-T52 (144.50 LG)		2
4	-4	TUBE	STEEL, 1018, 6.000 O.D. X 5/16 WALL	1
3	-3	PLUG	STEEL, 1010-1020 COLD ROLL, 3/4 THK	1
2	-2	SPACER, .50 O.D. .190 I.D.	AL ALY, 5052-H32, .050 NOM THK	13
1	-1	TUBE	CPVC, 6.625 O.D. X .280 WALL	1

PARTS LIST

DRAWING MADE IN THIRD ANGLE PROJECTION

MATERIAL

REFERENCES E9700T13

CODE IDENT NO 18265

DO NOT SCALE DRAWING

ENG | PROD. | CANC | JOB REQ | DR 12-11-75 | CHK 12-15-75 | APP | APP

TOLERANCES UNLESS OTHERWISE SPECIFIED
2 PL DEC ± .06
3 PL DEC ± .015
ANGLES ± 1°

TITLE TUBE, AIR CURTAIN

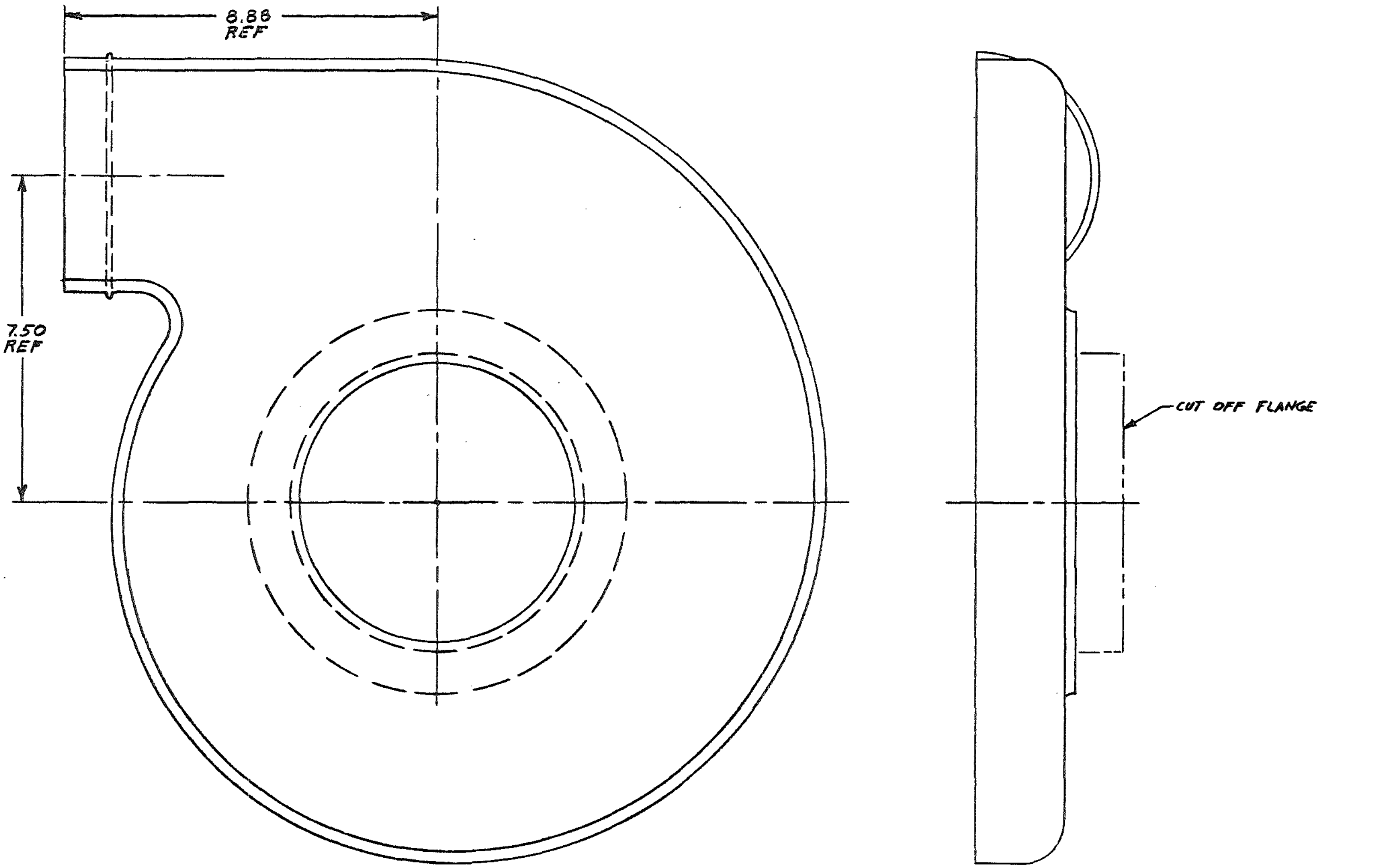
DWG NO. D9700T8 REV 1

SCALE 1/2 | SHEET OF | SIZE D

SECTIONAL | OUTLINE | OUTLINE DRAWN YES NO

CLASS. CODE

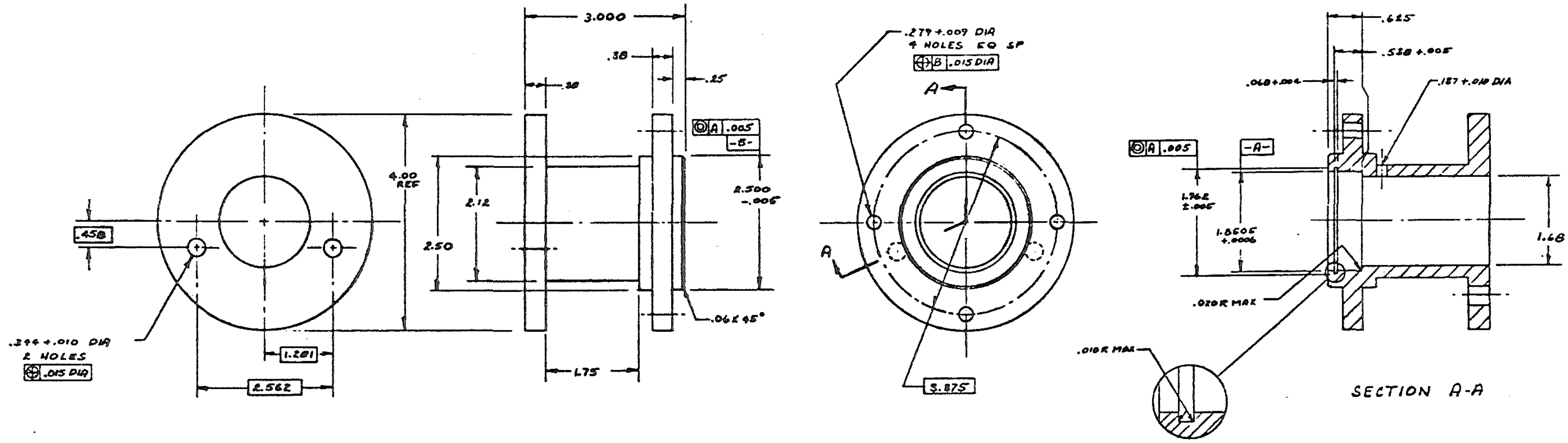
cored division
Donaldson Company, Inc.
1400 West 94th Street
Minneapolis, Minnesota
55431



DRAWING MADE IN THIRD ANGLE PROJECTION	EXP / PROD.	
MATERIAL: INLET HALF OF BLOWER, PB-12, CINCINNATI FAN & VENTILATOR CO., 6516 WIEHE ROAD, CINCINNATI, OHIO 45237	CANC / JOB REQ / DR / CHK / APP / APP	TITLE: FAN HOUSING MOD.
		DWG NO. C9700T9 — REV 1
REFERENCES E9700T23	TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL DEC = ; 3 PL DEC = ±.010 ; ANGLES =	SCALE 1/2 — SHEET OF — SIZE C
CODE IDENT NO 18265		SECTIONAL / OUTLINE — OUTLINE DRAWN YES / NO
DO NOT SCALE DRAWING		DATE CODE

corad division
Donaldson Company, Inc.
1400 West 94th Street
Minneapolis, Minnesota
55431

DWG NO D9700T10



NOTE
1. REMOVE ALL BURRS AND BREAK SHARP CORNERS

DRAWING MADE IN THIRD ANGLE PROJECTION

MATERIAL
ALUMINUM ALLOY 2024-T351 OR CARBON STEEL 4.00 DIA STK

REFERENCES

CODE IDENT NO 18265

DO NOT SCALE DRAWING

TOLERANCES UNLESS OTHERWISE SPECIFIED
2 PL DEC ±.03
3 PL DEC ±.010

TITLE
ADAPTOR, MOTOR TO BLOWER

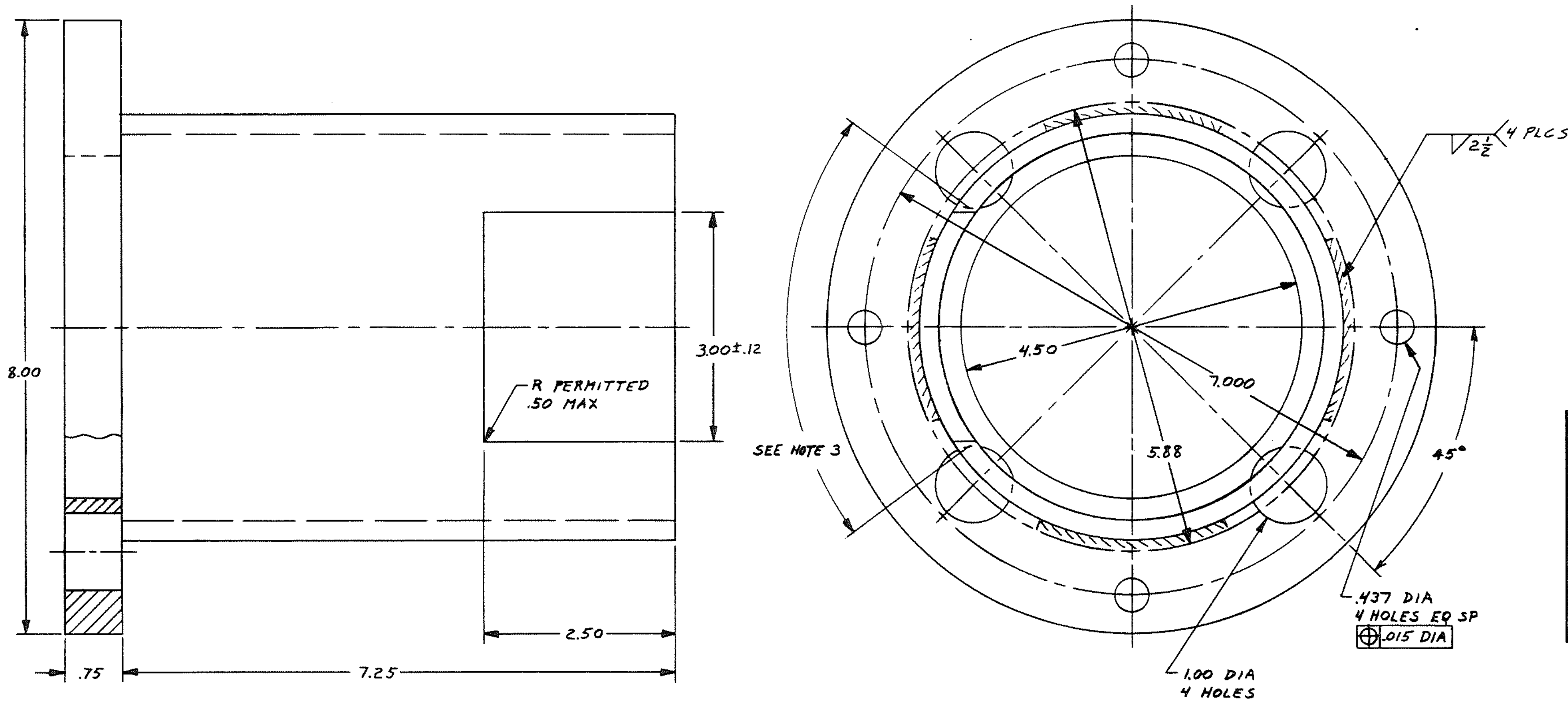
DWG NO. D9700T10 REV 1

SCALE 1/1

SIZE D

corad division

SYM	ZONE	REVISIONS	APP	DATE
1		RELOCATED HOLES	WJE	8-26-76



NOTES:

1. SURFACE TREATMENT FINISH USE A SOLVENT CLEANER.
2. PAINT WITH A PRIMER AND USE A WHITE ENAMEL FINISH.
3. RADIAL CUTS PERMITTED FOR SIDES OF NOTCH.

DRAWING MADE IN THIRD ANGLE PROJECTION

MATERIAL: STL PLATE 1020, 3/4 THK & BLACK PIPE, 5 IN. DIA, SCHEDULE 40, 5.05 I.D. X 5.62 O.D.

REFERENCES: E9700T13

CODE IDENT NO. 18265

DO NOT SCALE DRAWING

EXP	
PROD.	
CANC	
JOB REQ	
DR	WJE 2-26-76
CHK	
APP	
APP	

TOLERANCES UNLESS OTHERWISE SPECIFIED
2 PL DEC = .06
3 PL DEC = .015
ANGLES = 2°

TITLE: SHIELD, MOTOR

DWG NO. C9700T11 — REV 1

SCALE 1/1 — SHEET OF — SIZE C

SECTIONAL OUTLINE — OUTLINE DRAWN YES NO

CLASS. CODE

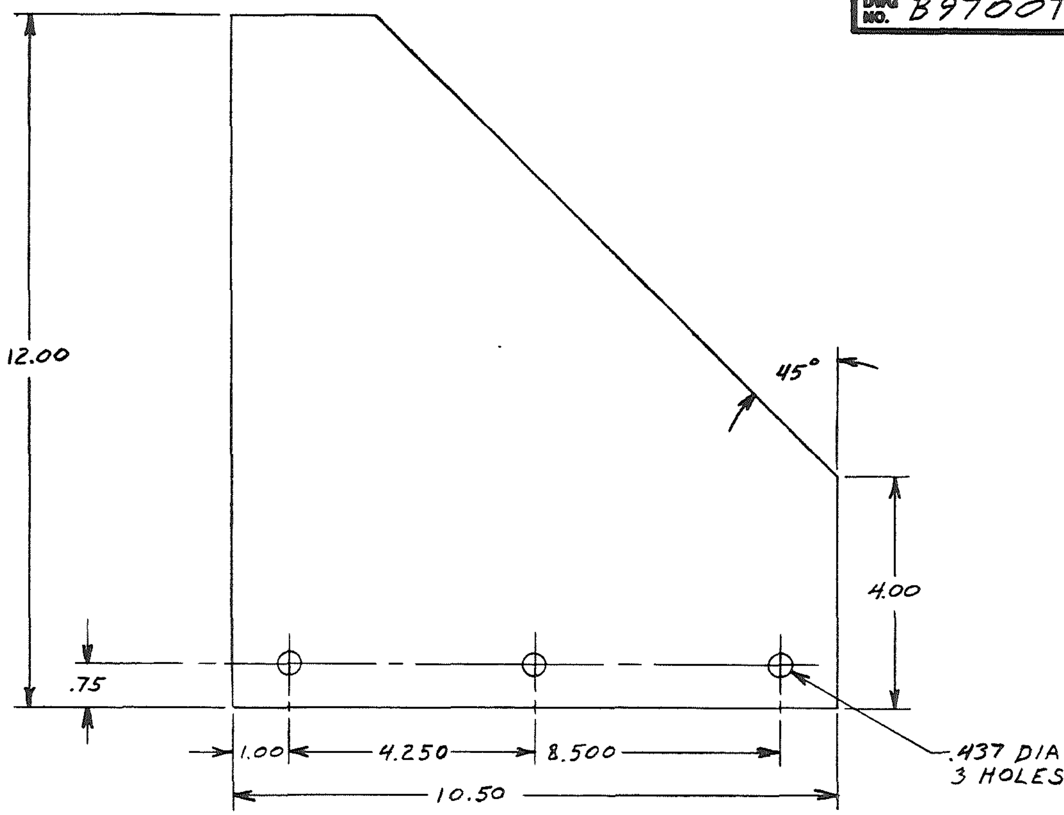
corad division

Donaldson Company, Inc.
1400 West 94th Street
Minneapolis, Minnesota
55431

DWG NO. C9700T11

DWG NO. B9700T12

SYM	ZONE	REVISIONS	APP	DATE



NOTES:

1. SURFACE TREATMENT FINISH USE A SOLVENT CLEANER.
2. PAINT WITH A PRIMER AND USE A WHITE ENAMEL FINISH.

DRAWING MADE IN THIRD ANGLE PROJECTION

MATERIAL
C.R. STL PL, 1020,
1/2 NOM STK THK

REFERENCES E9700T13

CODE IDENT. NO. 18265

DO NOT SCALE DRAWING

EXP		
PROD.		
CANC		
JOB REQ		
DR	DJE	2-25-76
CHK		
APP		
APP		

TOLERANCES UNLESS OTHERWISE SPECIFIED
2 PL DEC ± .06
3 PL DEC ± .015
ANGLES ± 2°

TITLE SHIELD, JOINT

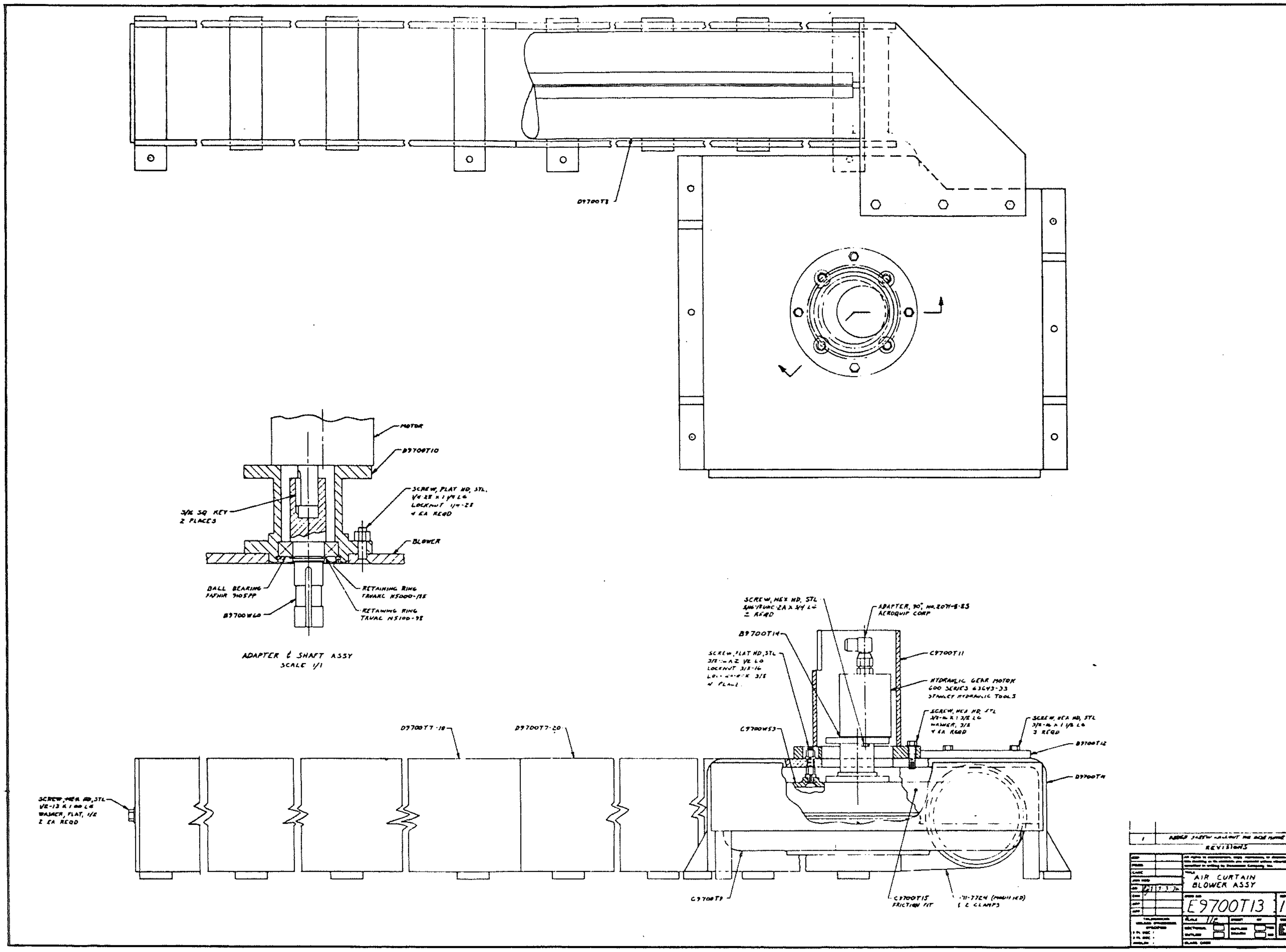
DWG NO. B9700T12 REV 0

SCALE 1/2 SHEET OF SIZE B

SECTIONAL OUTLINE | OUTLINE DRAWN YES NO

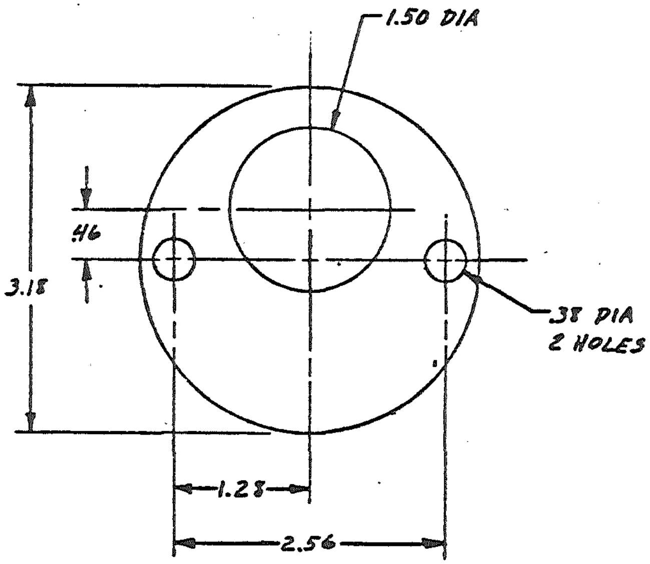
CLASS. CODE

corad division
Donaldson Company, Inc.
1400 West 94th Street
Minneapolis, Minnesota
55431


D9700T3
MOTOR
B9700T10
SCREW, FLAT HD, STL.
1/4-28 x 1 1/4 LG
LOCKNUT 1/4-28
4 EA REQD
3/16 SQ KEY
2 PLACES
BLOWER
BALL BEARING
FAFNIR 9105PP
RETAINING RING
TRUARC N5000-135
B9700W60
RETAINING RING
TRUAC N5100-98
ADAPTER & SHAFT ASSY
SCALE 1/1
SCREW, HEX HD, STL
ADAPTER, 90°, NO.2071-8-8S
AEROQUIP CORP
B9700T14
C9700T11
HYDRAULIC GEAR MOTOR
600 SERIES 63643-33
STANLEY HYDRAULIC TOOLS
C9700W53
D9700T7-18
D9700T7-20
SCREW, HEX HD, STL
3/8-16 x 1 1/8 LG
3 REQD
B9700T12
D9700T4
C9700T9
C9700T15
FRICTION FIT
REVISIONS
AIR CURTAIN
BLOWER ASSY
E9700T13
1

DWG NO. B9700T14

SYM	ZONE	REVISIONS	APP	DATE



DRAWING MADE IN THIRD ANGLE PROJECTION

MATERIAL
RUBBER SH, 60 DURO,
1/16 NOM STK THK

REFERENCES E9700T13

CODE IDENT. NO. 18265

DO NOT SCALE DRAWING

EXP	
PROD.	
CANC	
JOB REQ	
DR	3-5-76
CHK	
APP	
APP	

TOLERANCES UNLESS OTHERWISE SPECIFIED
2 PL DEC ± .06
3 PL DEC ±
ANGLES ±

TITLE WASHER, INSULATING

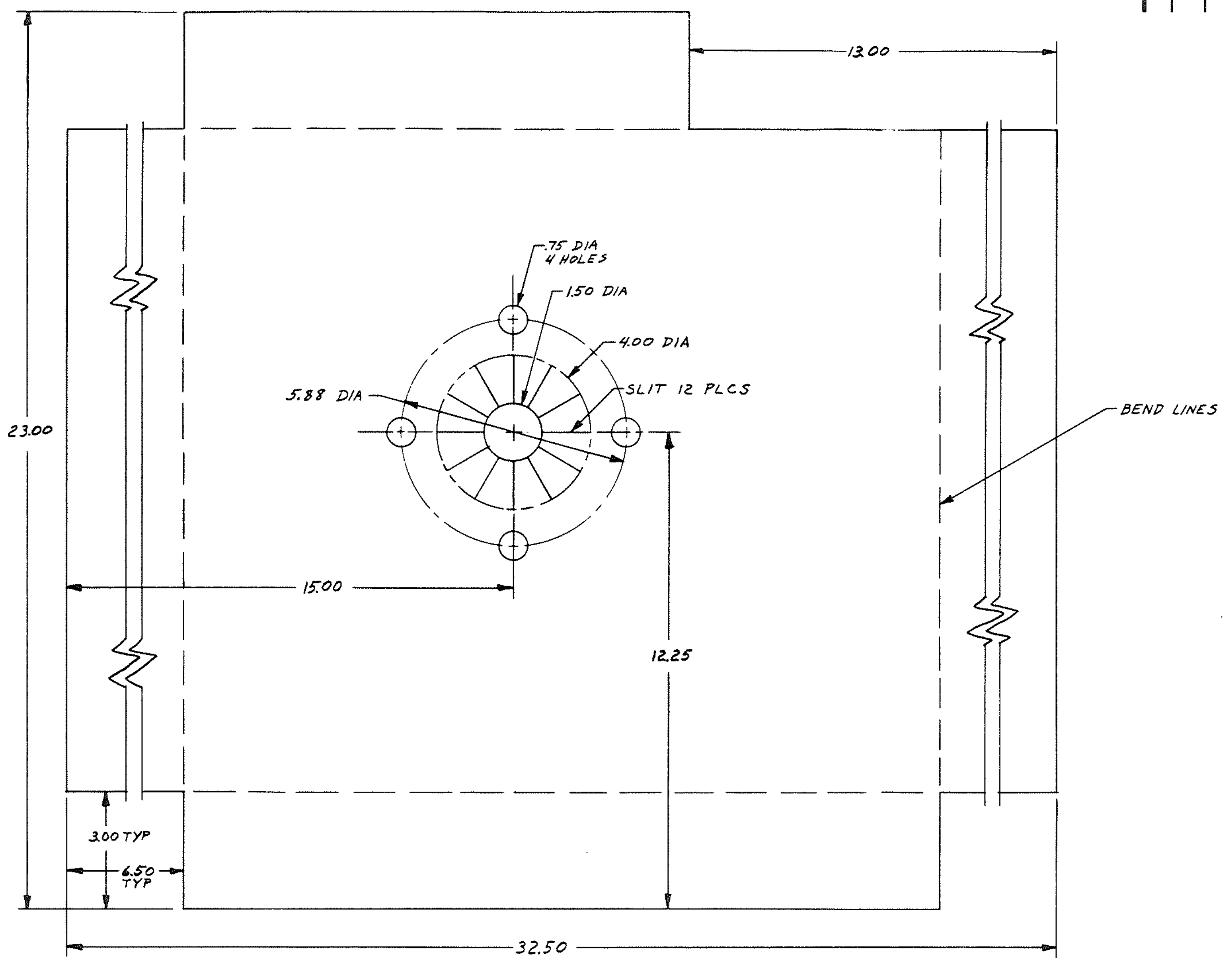
DWG NO. B9700T14 REV 0

SCALE 1/1 SHEET OF SIZE B

SECTIONAL OUTLINE ☐ OUTLINE DRAWN ☐ YES ☐ NO

CLASS. CODE

corad division
Donaldson Company, Inc.
1400 West 94th Street
Minneapolis, Minnesota
55431



SYM	ZONE	REVISIONS	APP	DATE

DWG NO. C9700T15

DRAWING MADE IN THIRD ANGLE PROJECTION

MATERIAL
ULTRA LINER
FIBER GLASS 1 IN. THK
GUSTIN-BACON CO

EXP
PROD.
CANC
JOB REQ
DR DJE 3-5-76
CHK
APP
APP

REFERENCES E9700T13

CODE IDENT NO. 18265

DO NOT SCALE DRAWING

TOLERANCES UNLESS OTHERWISE SPECIFIED
2 PL DEC ± .12
3 PL DEC ±
ANGLES ±

TITLE
LINER, ACOUSTICAL
(FLAT LAYOUT)

DWG NO. C9700T15 REV 0

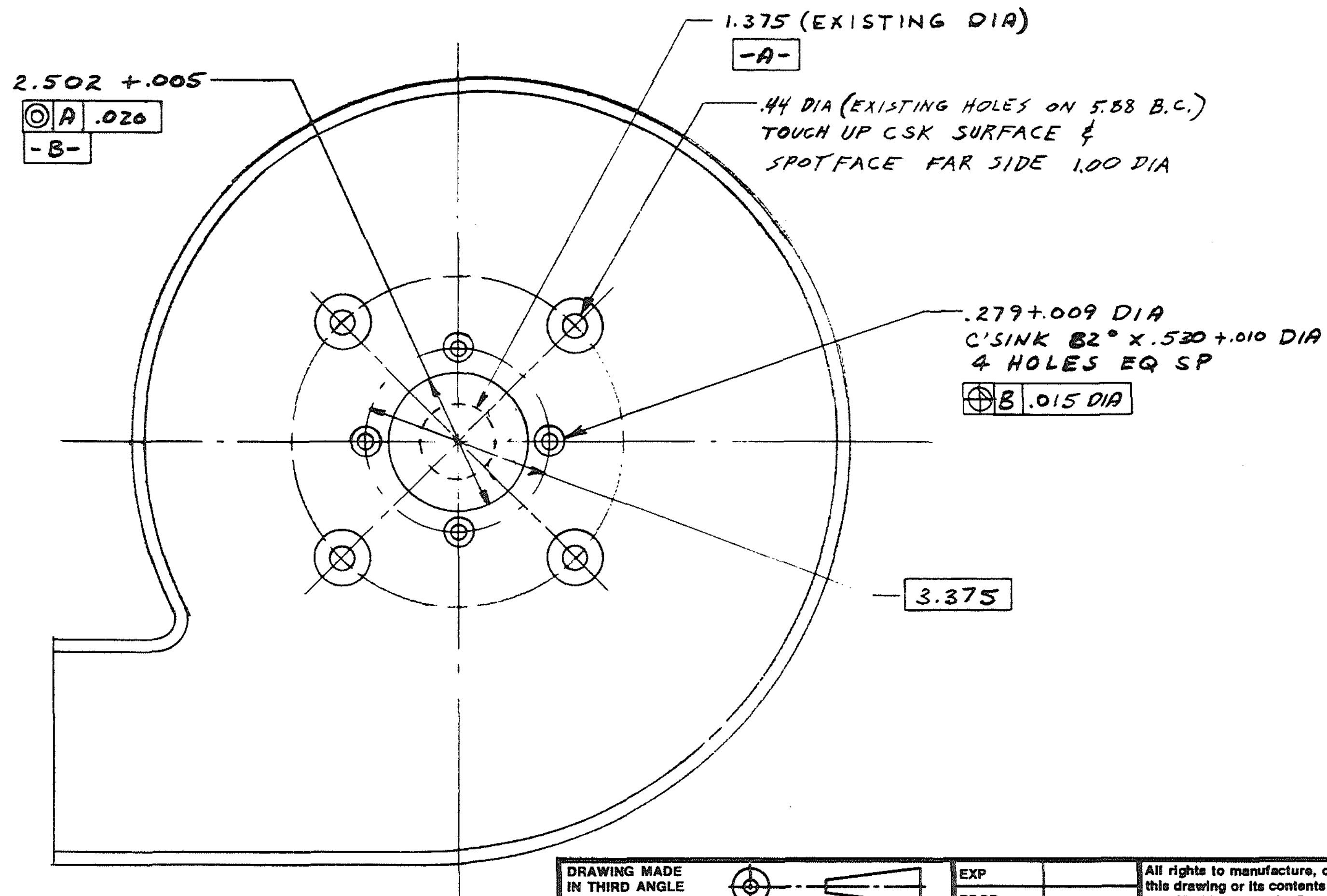
SCALE 1/2 SHEET OF SIZE C

SECTIONAL OUTLINE
OUTLINE DRAWN YES NO

CLASS. CODE

corad division

Donaldson Company, Inc.
1400 West 94th Street
Minneapolis, Minnesota
55431



DRAWING MADE IN THIRD ANGLE PROJECTION

EXP			
PROD.			
CANC			
JOB REQ			
DR	DJ	2-25-75	
CHK			
APP			
APP			

MATERIAL

REFERENCES E9700T13

TOLERANCES UNLESS OTHERWISE SPECIFIED

TITLE FAN HOUSING, REWORK

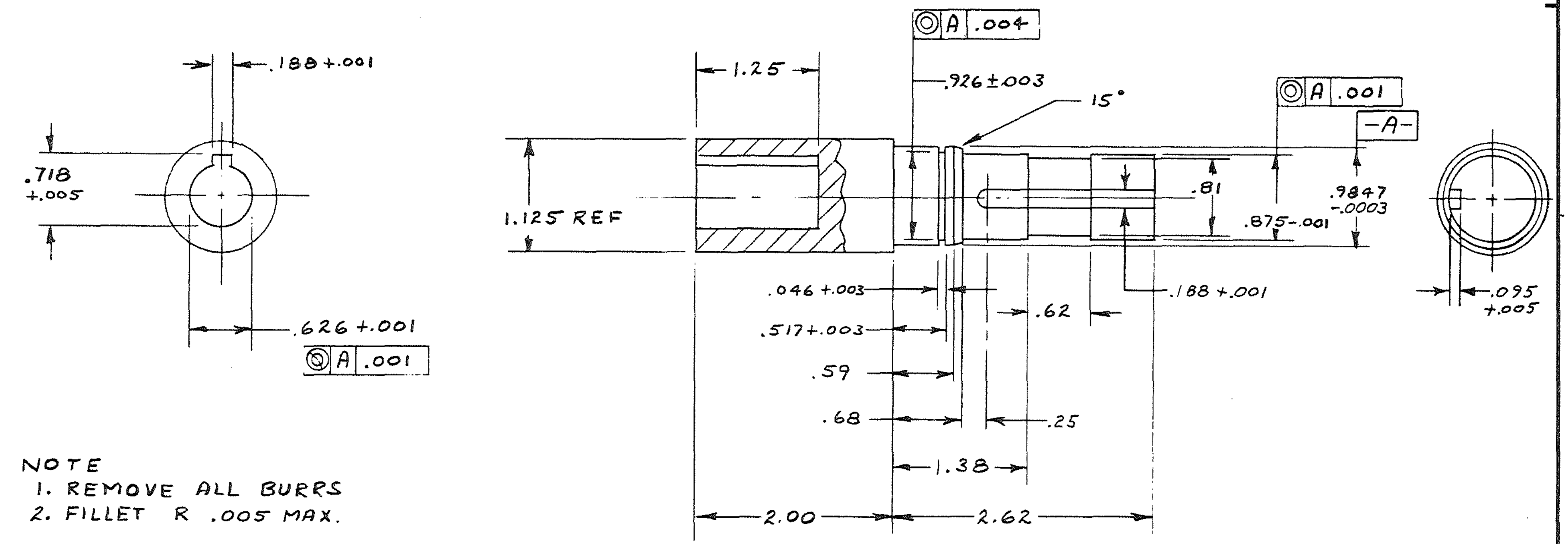
DWG NO. C9700W53 REV 1

SCALE 1/2 SHEET OF SIZ

SECTIONAL OUTLINE YES

DWG NO. B9700W60

SYM	ZONE	REVISIONS	APP	DATE
1		ADDED R.H. VIEW & KEYWAY		1-7-76



NOTE
1. REMOVE ALL BURRS
2. FILLET R .005 MAX.

DRAWING MADE IN THIRD ANGLE PROJECTION

MATERIAL
STEEL BAR
B1112 OR B 1113
1.125 DIA STK

REFERENCES

CODE IDENT. NO. 18265

DO NOT SCALE DRAWING

EXP		
PROD.		
CANC		
JOB REQ		
DR	[illegible]	3-18-75
CHK		
APP		
APP		

TOLERANCES UNLESS OTHERWISE SPECIFIED
2 PL DEC ± .02
3 PL DEC ± .005
ANGLES ± 2°

TITLE
SHAFT

DWG NO. 9700W60 REV 1

SCALE 1/1 SHEET OF SIZE B

SECTIONAL ☐ OUTLINE ☐
OUTLINE DRAWN ☐ YES ☐ NO

CLASS. CODE

corad division
Donaldson Company, Inc.
1400 West 94th Street
Minneapolis, Minnesota
55431