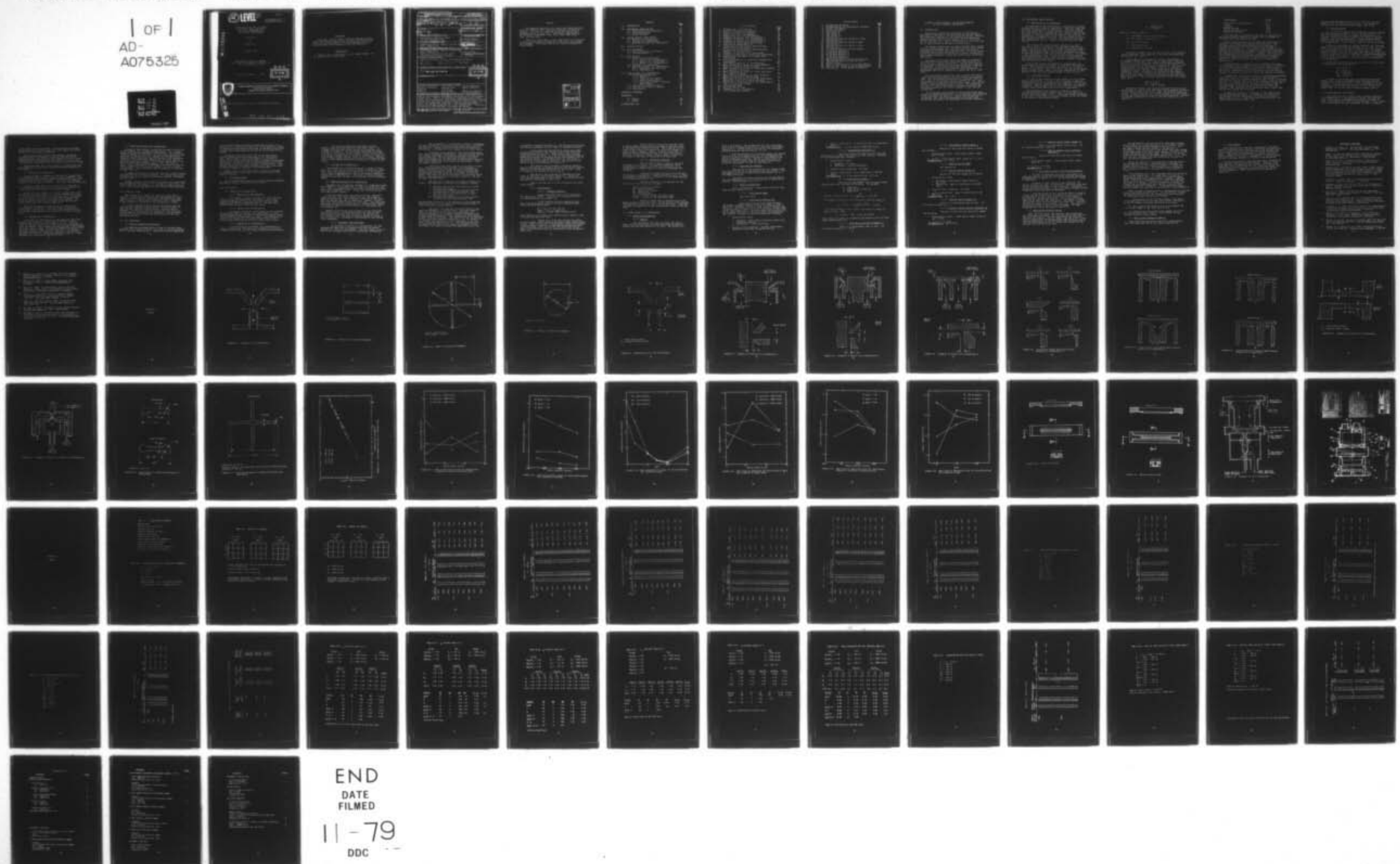
AD-A075 325   ENVIRONMENTAL RESEARCH CO  ST PAUL MN   F/G 15/2
SYSTEMATIC INVESTIGATION OF THE DESIGN PARAMETERS OF A SLIT AER--ETC(U)
NOV 78  L GRAF   DAAA15-77-C-0007
UNCLASSIFIED  ERC-8-7850   ARCSL-CR-79003   NL

1 OF 1
AD-
A075325



END
DATE
FILMED
11-79
DDC

CONTRACTOR REPORT ARCSL-CR-79003

# SYSTEMATIC INVESTIGATION OF THE DESIGN PARAMETERS OF A SLIT AEROSOL CONCENTRATOR

Final Report

by

Leonard Graf

November 1978

ENVIRONMENTAL RESEARCH COMPANY
DIV. OF DART ENVIRONMENT & SERVICES CO.
St. Paul, Minnesota 55112



Contract No. DAAA15-77-C-0007

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
Chemical Systems Laboratory
Aberdeen Proving Ground, Maryland 21010



Approved for public release; distribution unlimited.

## Disclaimer

The views, opinions and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

## Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

# (19) REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: ARCSL-CR-79003, AD-E410 189
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER: (18) ARCSL, SBIE
4. TITLE (and Subtitle): (6) SYSTEMATIC INVESTIGATION OF THE DESIGN PARAMETERS OF A SLIT AEROSOL CONCENTRATOR
5. TYPE OF REPORT & PERIOD COVERED: Final, Nov. 1976 to Nov. 1978
6. PERFORMING ORG. REPORT NUMBER: ERC Report No. 8-7850
7. AUTHOR(s): (10) Leonard Graf
8. CONTRACT OR GRANT NUMBER(s): (15) DAAA15-77-C-0007 new
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Environmental Research Company, 3725 North Dunlap Street, St. Paul, Minnesota 55112
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: (16) 1M464724DF45
11. CONTROLLING OFFICE NAME AND ADDRESS: Commander/Director, Chemical Systems Lab, Attn: DRDAR-CLJ-R, Aberdeen Proving Ground, MD 21010
12. REPORT DATE: (11) Nov[redacted]78
13. NUMBER OF PAGES: 86
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Commander/Director, Chemical Systems Lab, Attn: DRDAR-CLC-B, Aberdeen Proving Ground, MD 21010 (CPO Richard B. Saxon, 671-2598)
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: NA
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.

(12) 85 (14) ERC-8-7850

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report): (9) Final rept. Nov 76-Nov 78,



18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

| | | |
|---|---|---|
| Aerosol concentrator | Concentration ratio | Nozzle dimensions |
| Particle collector | Pressure drop | Nozzle velocity |
| Impactor | Slit nozzle | $\sigma_g$ |
| Aerosols | Inlet nozzle | 50 percent cutpoint |
| Collection efficiency | Receiver nozzle | Variance analysis |

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An investigation was made of the parameters which affect performance of a slit aerosol concentrator. Some of the parameters investigated were nozzle shape, air flow patterns, inlet nozzle width and velocity, receiver nozzle width, and spacing between inlet and receiver nozzle. Graphical and mathematical analysis of the test data was made to define the optimum parameters for a slit concentrator. Four slit concentrators were designed, fabricated and tested.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE 388 254

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

## PREFACE

The research covered by this report was authorized under Citation #1M464 724 DF45--Biological Detection and Warning Material. The work was conducted buring the period from 4 November 1976 to 31 July 1978. The original research notes are recorded in notebooks: 1534, 1565, 1591, 1592, 1628, 1633, 1635 and 1669.

The use of trade names in this report does not constitute an official endorsement or approval of the use of such commercial hardware. This report may not be cited for purposes of advertisement.

CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

# SYSTEMATIC INVESTIGATION OF THE DESIGN PARAMETERS OF A SLIT AEROSOL CONCENTRATOR

## 1.0 INTRODUCTION

The particle concentration principle is used by the Department of the Army in the XM19 Alarm and the XM2 Sampler. The concentrator operates on the impaction principle, removing large particles from the air stream by inertial separation. However, the particles are not impacted on a solid surface but are directed into a region of low-flow air. This low-flow air is then directed to the particle assay device.

The present concentrator has been developed from a single circular nozzle concept into a multinozzle array which reduces the energy requirements when high-flow rates are desired. Although this unit performs satisfactorily, a slit-type concentrator has the potential advantage of a simpler construction and attendant reduction of both fabrication costs and maintenance costs.

The scope of this contract was to conduct a systematic investigation of the design, fabrication and evaluation of a slit air-to-air aerosol concentrator. Factors which were to be considered in determining an optimum design were stability of operation, criticalness of physical dimensions, slope of particulate separation, concentration ratio, economy of maintenance and cost in production of quantities up to 1,000 units.

The concentrator design shall have an input flow rate of 1,000 ℓ/min. with a maximum of 30 cm of water total pressure drop. The 50% separation characteristic (cutpoint) shall be for aerosol of 2.5 μm with a specific gravity of 1.25. The output flow rate containing the particles greater than the 50% cutpoint shall be between 10 and 15 ℓ/min. The concentrator will have an inlet or pre-impactor designed to minimize the entrance of particles of 15 μm or greater in size into the concentrator.

After thorough investigation of the various design parameters, a proposed design of the slit concentrator was submitted to the Government for approval. Having received approval of the design, four identical concentrators were fabricated, tested and delivered to the Government for further evaluation.

## 2.0 PRELIMINARY INVENSTIGATION

### 2.1 Description of a Concentrator

As described in the introduction, a concentrator operates on the principle of inertial separation. Figure A-1 shows the principle of operation of a concentrator. Air flows through the inlet nozzle and is divided into two fractions, $Q_p$ and $Q_c$. Large particles will be impacted by their inertia into the dead air space or low-flow region of the receiver nozzle and be removed by $Q_c$ (concentration flow). The ratio $Q_i/Q_c$ is called the concentration factor, since all the large particles have been concentrated into $Q_c$. Typical values of $Q_i/Q_c$ are from 4 to 10.

Part of the small particles will also be in $Q_c$; this fraction is $Q_c/Q_i$. In order to more completely separate the small particles from the large, a second concentrating stage is added. The flow $Q_c$ from the first stage is subjected to this second concentrating stage. The overall concentration factor is then the product of the factors for both stages. For example, if the concentration factor for each stage is 8, the overall concentration factor is 64. Small particle contamination in the large particle stream has been reduced to about 1.5 percent after processing by both stages.

Some of the critical parameters of a concentrator are nozzle shape and nozzle slit width for both inlet and receiver nozzle. Also, the spacing between the nozzles is critical. Ratios of flow rates are not so critical, but must be maintained within certain values. When a two-stage concentrator is used, balance of the flow rates between stages is very critical.

### 2.2 Literature Review

In order to help develop a design concept for a slit-type aerosol concentrator, a review of the literature on impactor concentrators and virtual impactors was conducted. Most of the references cited are concerned with slit impactors or impactors in general. Only Forney(5) and Loo et al(8) deal with concentrators; with Forney specifically on slit concentrators.

The performance of an impactor is generally shown by plotting particle collection efficiency, E, versus the square root of the Stokes number, $(Stk)^{1/2}$. The Stokes number is defined as the ratio of the particle stopping distance to the half width or the radius of the impactor throat,

$$Stk = \frac{\rho_p C V_o D_p^2 / 18\mu}{W/2}$$

Where $\rho_p$ = particle density

$C$ = Cunningham slip correction factor

$V_o$ = air velocity at the throat

$D_p$ = particle diameter

$\mu$ = fluid viscosity

$W$ = jet width or diameter

From this s-shaped curve, the 50% cutpoint of the impactor can be determined. The steepness of the curve determines the sharpness of the cutpoint.

A good theoretical analysis of impactor performance is presented by Marple and Liu(12) and is summarized in the book by Liu(7). In the study, the impactors were characterized by three dimensionless parameters--S/W, T/W, and Re--where S = jet-to-plate distance, W = jet width or diameter, T = jet throat length and Re = jet Reynolds Number based on the hydraulic diameter of the jet, $D_h$ ($D_h$ = W for round jets, $D_h$ = 2W for rectangular jets). In general, the theoretical performance curves are similar in shape and the position of the curves on the $(Stk)^{\frac{1}{2}}$ axis remains relatively constant provided the parameters are held to the following approximate values (for rectangular jets):

S/W = 1 to 1.5
T/W = 0.5 to 1
Re = 500 to 15,000

According to Marple, the agreement between theoretical and experimental is very good for both round and rectangular impactors <u>if</u> the impactor inlet conditions, shape, and Reynolds Number are <u>similar</u>. A glance through the literature shows that experimental results can vary widely as shown in the following table. Presented are the approximate $(Stk)^{\frac{1}{2}}$ values at the 50% cutpoint of the impactors.

| INVESTIGATOR | $(Stk)^{1/2}$ |
|---|---|
| Marple and Liu (Theoretical) | 0.7 |
| Forney | 0.36 |
| Lundgren | 0.6 |
| Mercer and Chow | 0.85 |
| Willeke (Sierra Hi Vol) | 0.7 |
| Cooper and Spielman | 0.45 |

This variation in performance shows that an impactor will perform according to theoretical values only if designed in accordance with the theoretical model.

Aerosol characteristics can influence the calibration of impactors, as discussed by Jaenicke and Blifford[6]. They have made calculations showing that aerosols must have a standard deviation ($\sigma$) of $\leq 5\%$ in order for calibrations of impactors to be realistic. For aerosols with a larger $\sigma$, calibrations will result in an s-shaped curve and with a slope not as steep as that predicted by theory. However, the value of the 50% cutpoint will not be affected. The shape of the curve can also be affected by using such monodisperse aerosols such as polystyrene spheres which contain some fraction of doublet particles. Even 2% of doublet particles will produce an s-shaped curve.

The performance of impactors is also affected by various other parameters as discussed by Marple and Willeke in reference 7. The inlet should be tapered or conical in order for the particles to accelerate to the fluid velocity in the throat of the nozzle. Obstructions at the inlet which cause the flow to approach the nozzle horizontally affects the impactor performance.

Forney[5] has designed a variable slit concentrator patterned after the variable slit impactor of Cooper and Spielman[3]. Essentially this is a standard impactor sliced in half; a verticle wall cuts off one half the slit and the impaction plate or virtual surface. The tapered half of the slit is moveable so that the slit width, W, can be varied, yet maintain a constant S/W. Reynolds number is held constant by holding the total flow constant. The instrument is calibrated by using a single size aerosol and varying the slit width.

Neither the variable slit impactor not the concentrator perform according to theory. For example, the $(Stk)^{1/2}$ at the 50% cutpoint for the concentrator of Forney is 0.36 while theory puts it at 0.7. Also, the slope of the curve is 1.32 while theory puts it at about 1.05.

Possibly some disagreement may be due to the fact that the length of the slit was very short (2 cm). The theory was derived for a slit with very large aspect ratio (L/W).

## 2.3 Design Concepts

In Liu's book[7], Marple and Willeke have written a section entitled "Inertial Impactors: Theory, Design, and Use". In this article they describe a procedure for designing a slit impactor. Basically, one must choose a 50% particle cutpoint diameter and a jet Reynolds number. From a nomogram the jet width, W, and the flow rate per unit length of the jet, Q/L, can be deteremined. Total length of the slit can be calculated.

Taking 2.5 micrometers as the 50% cutpoint, and a Reynolds number of 3,000, then from the nomogram, W = 0.16 cm, Q/L = 15, and L = 66.7 cm for a flow rate of 1,000 ℓ/min. This length is rather excessive if the unit is to be as small in size as practical (even if the slit is broken down into several parallel slits). Choosing a value of 10,000 for the Reynolds number gives a value for W of 0.3 cm, Q/L = 50, and L = 20 cm. This length of slit is more reasonable as a starting point for design of a slit concentrator.

Taking some convenient size, such as 1/8" = 0.317 cm, the following values can be determined:

$$
\begin{aligned}
W &= 0.317 \text{ cm} \\
Q/L &= 53 \\
L &= 18.87 \text{ cm} \\
\text{Area} &= 5.98 \text{ cm}^2 \\
V_O &= 2787 \text{ cm/sec} \\
Re &= 11{,}800
\end{aligned}
$$

In order to incorporate this slit length into the most compact unit, various arrangements were conceived and are presented in figures A-2 to A-4. Other arrangements are also possible. The arrangement shown in figure A-4 appears to be advantageous for at least two reasons: (1) it is the most compact and; (2) the slit has an infinite aspect ratio.

# 3.0 DESIGN CONCEPTS INVESTIGATED

Since there was very little in the literature regarding slit concentrators, it was decided to design, fabricate and test briefly various arrangements and shapes of nozzles in order to determine which would perform the best. In all cases, only single-stage units were considered in order to simplify design, fabrication and testing. Any design which performed satisfactorily as a single-stage unit could readily be incorporated into a two-stage concentrator.

Two criteria used in determining whether a design was acceptable were (1) steepness of slope of the particulate separation curve; and (2) particulate impaction or loss in the concentration or large-particle flow channel. Losses in the small-particle flow channel were of little concern in this study.

Figure A-5 shows the critical parts of a concentrator and the nomenclature to be used in identifying these dimensions in this report.

### 3.1 Annular Slit Concentrator

Figure A-6 shows a schematic of annular slit concentrator 1. Air flow entered the circular inlet slit nozzle downward. The large-particle flow continued downward while the small-particle flow was directed radially outward. The inlet slit width was 0.366 cm, with an area of 6.99 $cm^2$. Inlet flow rate was 1000 ℓ/min.

Figure A-7 shows details of annular slit concentrator 2. This concentrator was very similar in design and operation to 1, but with some modification in the nozzles shape.

Annular slit concentrator 3 is shown in figure A-8. This concentrator was approximately 10.2 cm in diameter with inlet air flowing radially inward. The large-particle flow continued radially inward to the center and then down, while the small-particle flow was directed circumferentially downward. The inlet nozzle slit width was adjustable as was the receiver nozzle slit width. Air flow was 1000 ℓ/min.

Other nozzle shapes were fabricated for annular slit concentrator 3 and tested. These are shown in figure A-9. Various modifications were also made in the large-particle or concentrator flow channel and are depicted in figure A-10 and A-11.

### 3.2 Straight Slit Concentrator

A straight slit concentrator was designed and fabricated as shown in figure A-12. Wide steps were milled in thick material down to the desired thickness, T or $T_R$. Then the inlet and receiver nozzle slits were milled to the appropriate width and length. This concentrator would be one of the simplest and least costly to make. The spacing between the nozzles could be readily varied. Other variables such as T or W required permanent alteration or making up a new plate. The length of the inlet slit was 7.62 cm and the width was 0.196 cm. It was designed for a flow rate of about 210 ℓ/min.

### 3.3 Modified Straight Slit Concentrator

Because of heavy aerosol losses near the ends of the slits in the straight slit concentrator described in 3.2, a unique design was conceived, designed and fabricated. This design is shown in figures A-13 and A-14. The slits are made by drilling two holes of appropriate size, separated by the approximate length of the slit desired, then milling out a slit connecting the holes. The relationship between the slit width and end holes was arbitrarily chosen. For the inlet nozzle d/W = 1.54, while for the receiver nozzle $d_R/W_R = 1.87$. The ratio of $d_R/d = 1.26$, a value which is the same as the ratio of receiver nozzle diameter to inlet nozzle diameter in circular nozzle concentrators. This concentrator was designed for a flow rate of about 125 ℓ/min.

As shown in figure A-13, both the inlet and receiver nozzles protrude from their respective plates. This design feature was borrowed from circular nozzle concentrators because it reduces aerosol losses.

Another variation of the modified straight slit concentrator was designed and fabricated. This is shown in figure A-15. The nozzle shape and flow patterns are the same as shown in figure A-13. This unit was designed for a flow rate of about 900 l/min.

## 4.0 SELECTED DESIGN

Upon completion of testing all the units described in Section 3, it was obvious that the modified straight slit was superior as far as aerosol losses were concerned and at least equal to others in the slope of separation curve. Therefore, it was selected as the design to be systematically tested.

A single stage concentrator was designed which could be used for this systematic investigation. It was designed so that both the inlet and receiver nozzles could be readily replaced. The inlet and receiver nozzles would be precisely aligned when the concentrator was assembled. Spacing between the inlet and receiver nozzles could be readily varied and determined exactly.

## 5.0 TEST PROCEDURES

### 5.1 Aerosol Generator and Analysis

The laboratory generated aerosols used in the tests were generated from alcohol solutions of uranine or uranine-methylene blue of various concentrations. These particles were generated with the ERC Spinning Disk Aerosol Generator and have a $\sigma_g$ of about 1.15. This aerosol generator is equipped with a radioactive source which reduces the charge on the aerosol particles to that closely approximating the equilibrium Boltzman distribution.

To measure the aerosol distribution for these tests, absolute filters were used downstream of the concentrator unit. Particulates in the flow streams are collected on these filters, which are then analyzed by standard fluorescence techniques. The various parts of the concentrator are rinsed off and this solution is also analyzed fluorometrically. This analysis gives the fractional distribution of the total amount of aerosol sampled or ingested by the concentrator.

Aerosol size is determined using an optical microscope. All aerosol sizes in this report refer to particles of 1.25 specific gravity.

### 5.2 Flow Measurements

Air flow measurements were made with calibrated rotometers, gas meters, and/or a calibrated orifice meter.

## 6.0 TEST RESULTS

### 6.1 Annular Slit Concentrators

#### 6.1.1 Annular Slit Concentrator 1

This design is shown in figure A-6. This unit was tested only briefly because of high losses. Part of the reason for these high losses was that the unit had a very audible sound (whistle) emanating from it. Various minor modifications failed to eliminate this sound.

#### 6.1.2 Annular Slit Concentrator 2

As shown in figure A-7, this design is only slightly different than that of annular slit concentrator 1. This design change was made in hopes of reducing the aerosol losses and eliminating the characteristic sound. The characteristic sound was eliminated but losses were higher than in unit 1. Various minor modifications failed to reduce these losses.

#### 6.1.3 Annular Slit Concentrator 3

A third design of an annular slit concentrator is shown in figure A-8. This design is different from 1 and 2 in that the air flows radially inward through the inlet nozzle.

This unit was tested more thoroughly because aerosol losses were substantially lower than 1 and 2. In attempts to bring these losses down to an acceptable level, a number of changes in the nozzle shape were made and tested as shown in figure A-9. Also a number of modifications were made in the large-particle flow channel (figures A-10 and A-11) in attempts to reduce aerosol losses in this region. However, none of these changes reduced the losses to an acceptable level. Losses in this design were especially heavy for larger aerosol sizes.

### 6.2 Straight Slit Concentrator

The straight slit concentrator design is shown in figure A-12. This unit also had losses that were substantailly lower than some of the annular slit concentrators. It was tested over a range of parameters but none of the changes reduced the losses to an acceptable level. The slope of the particulate separation curve was shallow, indicating poor cut off characteristics.

### 6.3 Modified Straight Slit Concentrator

The design for the modified straight slit (sometimes called the "dumbbell" slit) concentrator is shown in figures A-13 and A-14. The unit showed marked superiority in both aerosol losses and slope of separation curve. Losses near the ends of the slits was greatly reduced.

Since this design had a very short slit and, therefore, a low flow rate (125 ℓ/min) another unit was fabricated as shown in figure A-15. This unit had a flow rate of 900 ℓ/min, near the desired flow rate of 1000 ℓ/min. However, it had a very loud, low-pitched sound at all flow rates. This persisted even after various minor modifications. The sound was finally eliminated by blocking off the cross slits, thus having just one straight slit.

Another unit with one long straight slit was fabricated and briefly tested. Although the results of tests on this unit were not as good as the results for the shorter slit unit (figure A-14), they were encouraging enough to decide to use this design for a systematic investigation of the various design parameters.

#### 6.3.1 Systematic Test Plan Data

As described in Section 4, a concentrator unit was designed and fabricated to systematically test the design parameters of the slit concentrator. Table B-1 shows a list of some of the variables which affect concentrator performance.

Nozzle length is a variable only in that it determines the total volumetric flow rate for any given nozzle slit width and velocity. Another factor which may affect concentrator performance is the angle of fluid approach to the inlet nozzle.

Initially it was decided to test the variables which most affect concentrator performance. These are nozzle velocity (V), aerosol size ($D_p$), inlet nozzle width (W) and receiver nozzle width ($W_R$). Of the remaining variables, some have numerical relationships to each other as determined by previous work, while others will be assigned arbitrary values. These are shown in table B-2.

Initially a test matrix was set up as shown in table B-3. After this matrix was completed, it was decided to conduct additional tests in order to better deteremine the effect of velocity and the effect of receiver nozzle width. An additional test matrix was set up as shown in table B-4. Some of the results of the initial matrix fit into this second matrix. Some tests were also conducted at $W_R/W$ of 2.50, not included in either matrix.

The results of these tests are shown in tables B-5 to B-8. The total aerosol sampled was divided as follows:

1) That which was in the concentration or large-particle flow stream.
2) That which was impacted or lost and could be re-entrained into the concentration flow.
3) That which was in the penetration or small-particle flow stream.
4) That which was impacted or lost and could be re-entrained into the penetration flow.

The percentage of aerosol in the penetration flow stream and penetration losses is not shown since this fraction was of little interest to the Government.

The tables also show the calculated values of the impaction parameter, $\psi$, for each test. From each group of tests, paired values of efficiency (concentration) and impaction parameter can be used to determine mathematically a linear equation which will best represent the relationship between these two variables. The relationship can be expressed in the form of the regression equation $Y = a + bX$, where b is the slope of the line and a is the Y intercept. Y in this case is the efficiency and X is $\psi$. From this equation, one can determine the value of the impaction parameter at 50% efficiency, the slope of the particle separation curve, and the geometric standard deviation $\sigma_g$. The 50% particle cutpoint size can be calculated from the impaction parameter equation.

It was noted that concentration losses were higher inside the end holes of the receiver nozzle than inside the straight portion of the slit. Penetration losses are also higher near the end holes. A series of tests was performed to determine the effect of changing the end hole diameter ($d_R$) of the receiver nozzle. The pertinent data for this series (Series B-1) is presented in table B-9. The results of this series of tests are presented in table B-10.

Test Series D was performed to determine the best value of the spacing (S) between the inlet and receiver nozzle. Table B-11 lists the pertinent data for this series. Table B-12 presents the results of Test Series D.

Test Series E was conducted to determine the best value for the inlet nozzle throat length (T). Table B-13 lists the pertinent data for this series. The results of this test series is presented in table B-14.

Table B-15 shows the air flow calibration for three inlet nozzles.

### 6.3.2 Data Analysis

#### 6.3.2.1 Graphical Analysis

Figure A-16 shows the air flow calibration for three inlet nozzles. Points for all three nozzles are all represented by one straight line.

In the graphical analysis generally only the following parameter values were used to determine mean values for plotting purposes:

$W$ = .254, .317 and .381 cm
$W_R/W$ = 1.50, 1.75 and 2.00
Velocity = 3500, 4900 and 6000 cm/sec

The exception is in figure A-19, where values of $W_R/W$ of 1.00, 1.20, and 2.50 were also used.

Figures A-17, A-18 and A-19 show the effect of nozzle width, nozzle velocity and $W_R/W$ on mean concentration losses. There is no trend in concentration losses with changes in nozzle width. There is a trend showing decreasing losses with increasing nozzle velocity for the velocities tested. There is a definite minimum in concentration losses at $W_R/W$ of about 2.00.

Figures A-20, A-21 and A-22 show the effect of nozzle width, nozzle velocity and $W_R/W$ on the mean slope of the particulate separation curve. There appears to be no trend in the slope of the separation curve with changes in nozzle width or changes in $W_R/W$. It appears that there is a possible trend of decreasing slope with increasing nozzle velocity, at least for larger values of $W_R/W$. A high value for slope is desirable for sharp particle separation.

#### 6.3.2.2 Statistical Analysis

The statistical analysis used for the data is analysis of variance. This analysis determines which variables have a significant effect on performance of the concentrator, or whether there is inter-action between the variables.

Tables B-16 through B-20 are various analysis of variance of the geometric standard deviation, $\sigma_g$ of $\psi$, taken from tables B-5 through B-8. Table B-21 is a variance analysis of the mean concentration loss.

The identification of the headings for the last part of each table is as follows:

Souce - source of variation
SS - sum of squares
DF - degrees of freedom
MS - mean square
VR - variance ratio
$F_{0.95}$ - F factor at 95% confidence level
$F_{0.99}$ - F factor at 99% confidence level

Table B-16 shows that a combination of V and W has an effect at the 95% level. Tables B-19 and B-20 indicate that $W_R/W$ has an effect on $\sigma_g$ of $\psi$ at the 95% level. Table B-21 indicates that $W_R/W$ effects the concentration losses at the 95% level.

# 7.0 FINAL DESIGN, SLIT CONCENTRATOR

## 7.1 Design Recommendations

### 7.1.1 General

The concentrator will have an inlet flow rate of 1000 ℓ/min with an output flow rate containing the particle greater than the 50% cutpoint of 15 ℓ/min. The nozzles will be of a slit design. The concentrator will be a two-stage unit, with the concentrating ratio of each stage being approximately 8:1. The 50% cutpoint will be for 2.5 micrometer particles having a specific gravity of 1.25.

With the exception of the nozzle design, the concentrator will be of the same design and interchangeable with the units supplied to Bendix Corporation, Environmental and Process Instruments Division. ERC was a subcontractor to Bendix on Contract Number DAAA15-77-C-0009, "Concentrator/Collector Improvements for XM2 and XM19 Sampler."

7.1.2 Inlet and Pre-impactor

This portion of the concentrator will remove larger particles from the air stream entering the concentrator. The pre-impactor will have an approximate 50% cutpoint for 15 micrometer particles.

The design of the pre-impactor will be the same as, and interchangeable with, the units supplied to Bendix Corporation. (See paragraph 2 of 7.1.1).

7.1.3 Nozzle Configuration

Nozzle configuration is deteremined primarily from data analysis (Section 6.3.2).

7.1.3.1 Inlet Nozzle Shape

See figure A-23.

7.1.3.2 Inlet Nozzle Velocity (V)

According to the contract specifications, the maximum allowable pressure drop is 12 inches of water (30.5 cm). Therefore, the first stage pressure deop must be limited to about 9 inches (23 cm) or a velocity of about 5400 cm/sec (see figure A-16). The inlet nozzle velocity must also be correlated with the slit width to obtain the appropriate 50% cutpoint. Analysis of the data showed the following:

1. Concentration losses

   a. Graphical: trend toward decreasing losses with increasing velocity.
   b. Statistical: V not significant.

2. Slope of curve, graphical: possible trend toward decreasing slope with increasing velocity.

3. $\sigma_g$ of $\psi$, statistical: V significant only in combination with W.

Recommendation: V in the range of 4800-5200 cm/sec.

7.1.3.3 Inlet Nozzle Slit Width, W

The inlet nozzle slit width must be correlated with velocity to obtain the appropriate 50% cutpoint. Analysis of the data showed the following:

1. Concentration losses

   a. Graphical: no trend
   b. Statistical: W not significant

2. Slope of curve, graphical: no trend

3. $\sigma_g$ of $\psi$, statistical: W is significant at the 95% level.

Recommendation: W in the range of 0.25 - 0.27 cm.

7.1.3.4 Inlet Nozzle Length, L

This must be determined from the nozzle width, velocity and inlet flow rate relationship. For example:

$$Q = 1000 \text{ ℓ/min}$$
$$W = 0.254 \text{ cm } (d = 0.391 \text{ cm})$$
$$V = 5000 \text{ cm/sec}$$

$$\text{Area A, of inlet nozzle} = \frac{Q}{V} = \frac{10^6}{5000 \times 60} = 3.333 \text{ cm}^2$$

The length of the inlet slit exclusive of the end holes is:

$$L_S = \frac{3.333 - 2 \times 3.14(.391)^2/4}{.254} = 12.18 \text{ cm}$$

L has been defined as the distance from center to center of the end holes. Then:

$$L = 12.18 + .391 = 12.57 \text{ cm } (4.95")$$

This single slit could be replaced by two parallel slits of area equal to the single slit.

7.1.3.5 Inlet Nozzle End Hole Diameter, d

There is no experimental data on this. For all nozzles tested, d = 1.55 W.

7.1.3.6 Inlet Nozzle Throat Length, T

Analysis of data from Test Series E showed the following:

1. Concentration losses: trend toward lowest losses at T = 1.5 W.

2. $\sigma_g$ of $\psi$: trend toward lowest values at T = 1.5 W.

Recommendation: T = 1.5 W

7.1.3.7 Receiver Nozzle Shape

See figure A-24.

7.1.3.8 Receiver Nozzle Width, $W_R$

Analysis of the data showed the following:

1. Concentration losses

   a. Graphical: trend toward lowest losses at $W_R$ = 2.0 W
   b. Statistical: $W_R/W$ is significant at the 95% level.

2. Slope of curve, graphical: *no trend.*

3. $\sigma_g$ of $\psi$, statistical: $W_R/W$ is significant at the 95% level.

Recommendation: $W_R$ = 2.0 W

7.1.3.9 Receiver Nozzle Length, $L_R$

There is no experimental data on this. For all nozzles tested, $L_R$ = L.

7.1.3.10 Receiver Nozzle End Hole Diameter, $d_R$

Analysis of data from Test Series B-1 showed the following:

1. Concentration losses: trend toward lowest losses at $d_R$ = 2.76 W.

2. $\sigma_g$ of $\psi$: no trend.

Recommendation: $d_R$ = 2.76 W

7.1.3.11 Receiver Nozzle Throat Length, $T_R$

There is no experimental data on this. For all nozzles tested $T_R = 0.254$ cm.

7.1.3.12 Spacing Between Inlet & Receiver Nozzles, S

Analysis of data from Test Series D showed the following:

1. Concentration losses: trend toward lowest losses at $S \cong W$.

2. $\sigma_g$ of $\psi$: no trend.

Recommendation: S = W.

7.1.4 Inlet Nozzle Width - Velocity Relationship

In order to determine this exact relationship, an inlet and receiver nozzle were fabricated following the design recommendations in Section 7.1.3. The pertinent data is shown in table B-22.

A series of tests (Series G) was conducted, the results of which are shown in table B-23. Duplicate tests were run for five aerosol sizes, at two velocities. Calculated values are shown (assuming a linear relationship between percent concentration and the impaction parameter).

From the results of this series of tests, a value of .254 cm for the inlet nozzle slit width requires a velocity of 5000 cm/sec to give a 50% cutpoint of 2.5 micrometer particles of 1.25 specific gravity. This is the slit width that will be used for the final units. The length, L, using two parallel slits, will be 6.009 cm for each slit. This will also be the length of the receiver slits, $L_R$. The slits will be spaced at 4.445 cm apart, center-to-center. All other dimensions will be as described in table B-22.

7.2 Fabrication and Modification

After the final design was approved, one concentrator was fabricated and tested. This unit was tested and found to have poor performance. The 50% cutpoint was too high and aerosol losses were considerably higher than hoped for. After some experimentation it was deteremined that at least some of the poor performance was due to interaction between the two parallel slits of the first stage.

The two parallel slits of the first stage were replaced with a single slit of the same width, W, but somewhat shorter in length than the combined length of the two slits. This was done to reduce the 50% cutpoint to the desired 2.5 micrometers. Also the nozzles of the second stage were changed to the same shape as the first stage nozzles, since most of the losses had been on the second stage. Originally, the second stage nozzles had been of the Bendix design (See 7.1.1). Tests with this unit indicated that the concentrator now had very near the desired performance.

All of the tests up to this point were conducted without the preimpactor attached. The preimpactor is designed to prevent particles of 15 micrometers diameter or larger from entering the concentrator. The preimpactor was attached to the concentrator and tests conducted for various particle sizes.

The preimpactor had a very pronounced effect on the performance of the concentrator. It caused sharp fluctuations in the pressure drop of the unit of about 0.5 inches of water. These fluctuations were accompanied by a popping or bubbling noise. (The noise is reminiscent of an erratically burning gas flame in a furnace.) With the preimpactor attached, the cutpoint of the concentrator was altered; it was increased to approximately 4.5 micrometers. The concentration losses were not appreciably affected by the addition of the preimpactor.

After a number of modifications, a configuration was arrived at which performed satisfactorily. The concentrator is shown in figures A-25 and A-26. The changes which were necessary for satisfactory performance are as follows:

1. Positioning a 6 inch (15 cm) diameter plate about 3.8 cm upstream of the first stage inlet nozzle, forcing all of the air stream to approach the nozzle at an angle.

2. This required the addition of a 25 cm diameter and 7.6 cm high chamber to the inlet section, and

3. Locating the flow control holes between the first and second stage closer to and on lines parallel to the receiver nozzle to reduce losses.

### 7.3 Data on Final Design of Nozzles

Table B-24 shows the data on the first stage nozzles. Table B-25 shows the data on the second stage nozzles.

### 7.4 Test Results

After fabrication of the four concentrators, they were tested to determine their individual operating characteristics. For all of the units, the pressure drop at the designed flow rate of 1000 liters per minute was 11.2 inches = 28.4 cm of water. Presented in table B-26 are the aerosol separation characteristics of the units. Concentrator 2 was not tested because it had been shipped for testing to the Government.

For each concentrator, duplicate tests were conducted for three aerosol sizes near the 50% cutpoint. These six tests were then used to compute the 50% cutpoint and slope of the separation curve (See Section 6.3.1). Tests with larger size aerosols were also conducted to determine the 50% cutpoint of the preimpactor. These results are also presented in table B-26.

## REFERENCE LITERATURE


1. Carson, G. A. and H. J. Paulus (1974) "A High Volume Cascade Seive Impactor", Am. Ind. Hyg. Assoc. J., May, 1974:262-268.

2. Cohen, J.J. and D.N. Montan (1967) "Theoretical Considerations, Design, and Evaluation of a Cascade Impactor", Am. Ind. Hyg. Assoc. J., March-April, 1967:95-104.

3. Cooper, D.W. and L.A. Spielman (1974) "A New Particle Size Classifier: Variable Slit with Photo-Counting", Atmos. Environ., 8:221-232.

4. Cushing, D.M., J.D. McCain, and W.B. Smith (1976) "Experimental Determination of Sizing Parameters and Wall Losses of Five Commerically Available Cascade Impactors", Paper #76-37.4 presented at the 69th Annual Meeting of the Air Pollution Control Association, June 27-July 1, 1976, Portland, Oregon.

5. Forney, L.J. (1976) "Aerosol Fractionator for Large-Scale Sampling", Rev. Sci. Instrum., 47:1264-1269.

6. Jaenicke, R. and I.H. Blifford (1974) "The Influence of Aerosol Characteristics on the Calibration of Impactors", Aerosol Science, 5:457-464.

7. Liu, B.Y.H. (1976) "Fine Particle Aerosol Generation, Measurement, Sampling, and Analysis", Academic Press Inc., New York, Pages 411-446.

8. Loo, B.W., J.M. Jaklevic and F.S. Goulding (1974) "Dichtomous Virtual Impactors for Large-Scale Monitoring of Airborne Particulate Matter", Lawrence Berkeley Laboratory Publication LBL-3854, Berkeley, California.

9. Lundgren, D.A. (1967) "An Aerosol Sampler for Determination of Particle Concentration as a Function of Size and Time", J. Air Pollut. Control Association, 17:225-228.

10. Marple, V.A. (1970) "A Fundamental STudy of Inertial Impactors", Ph.D. Thesis, Mechanical Engineering Dept., University of Minnesota, Minneapolis, Minnesota.

11. Marple, V.A.,B.Y.H. Liu and K.T. Whitby (1974) "On the Flow Fields of Inertial Impactors", Am. Soc. Mech. Eng. Trans., Dec., 1974:394-403.

12. Marple, V. A. and B.Y.H. Liu (1974) "Characteristics of Laminar Jet Impactors", Environ. Sci. & Technol., 8:648-654.

13. Marple, V.A. and B.Y.H. Liu (1975) "On Fluid Flow and Aerosol Impaction in Inertial Impactors", J. Colloid and Interface Sci., 53:31-34.

14. Mercer, T.T. and H.Y. Chow (1968) "Impaction from Rectangular Jets", J. Colloid and Interface Sci., 27:75-83.

15. Rao, A.K. (1975) "An Experimental Study of Inertial Impactors", Ph.D. Thesis, Environmental Sciences Dept., University of Minnesota, Minneapolis, Minnesota.

16. Stern, S.C., H.W. Zeller and A.I. Schekman (1962) "Collection Efficiency of Jet Impactors at Reduced Pressures", Ind. Eng. Chem. Fundam., 1:273-277.

17. Tomb, T.F. and H.N. Treaftis (1975) "A New Two-Stage Respirable Dust Sampler", Am. Ind. Hyg. Assoc. J., Jan., 1975:1-9.

18. Willeke, K. (1975) "Performance of the Slotted Impactor", Am. Ind. Hyg. Assoc. J., Sept., 1975:683-691.

19. Willeke, K. and J.J. McFeters (1975) "The Influence of Flow Entry and Collecting Surface on the Impaction Efficiency of Inertial Impactors", J. Colloid and Interface Sci., 53:121-127.

APPENDIX A

FIGURES

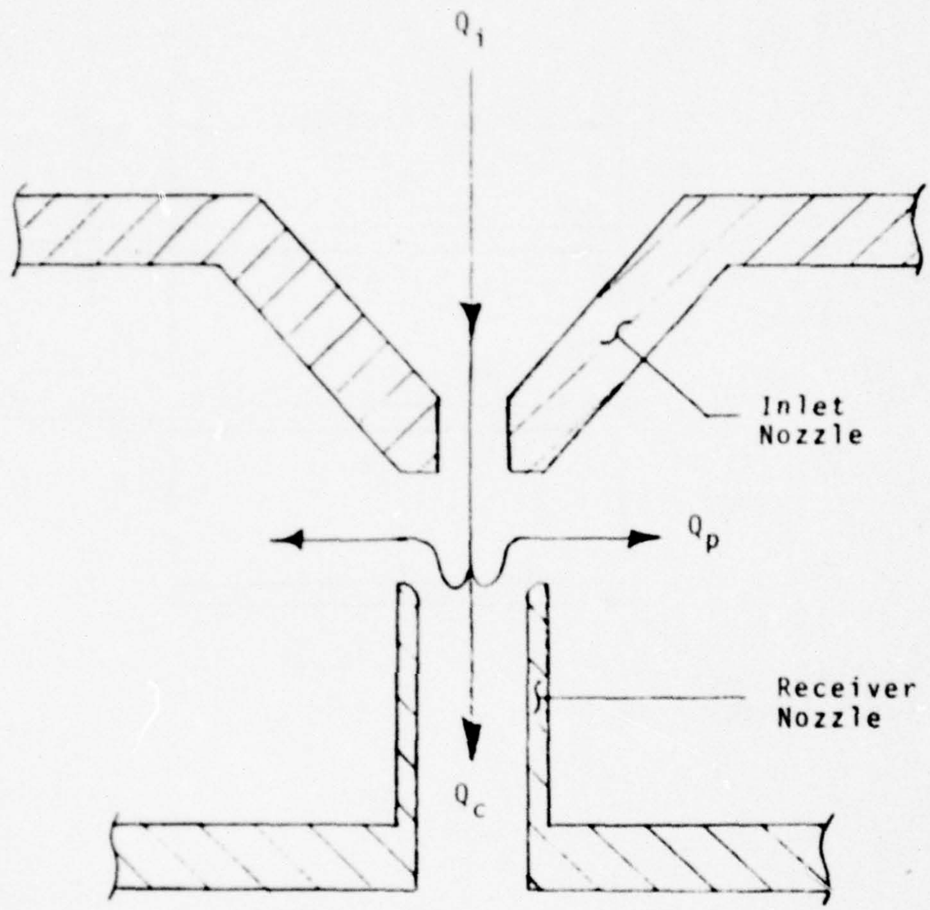
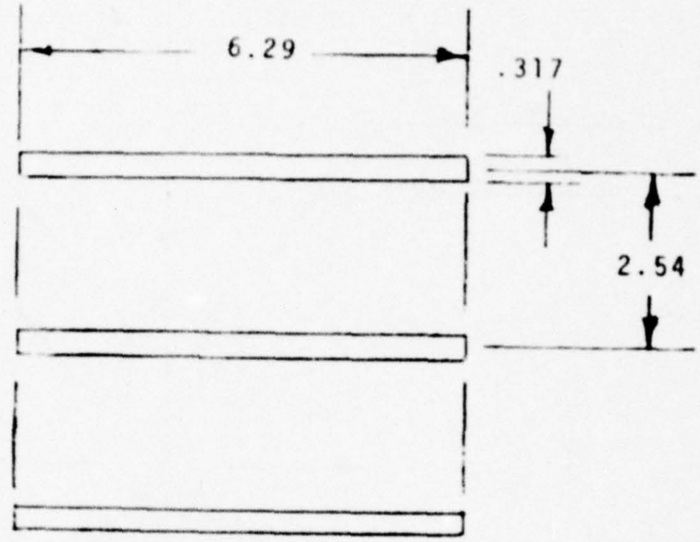
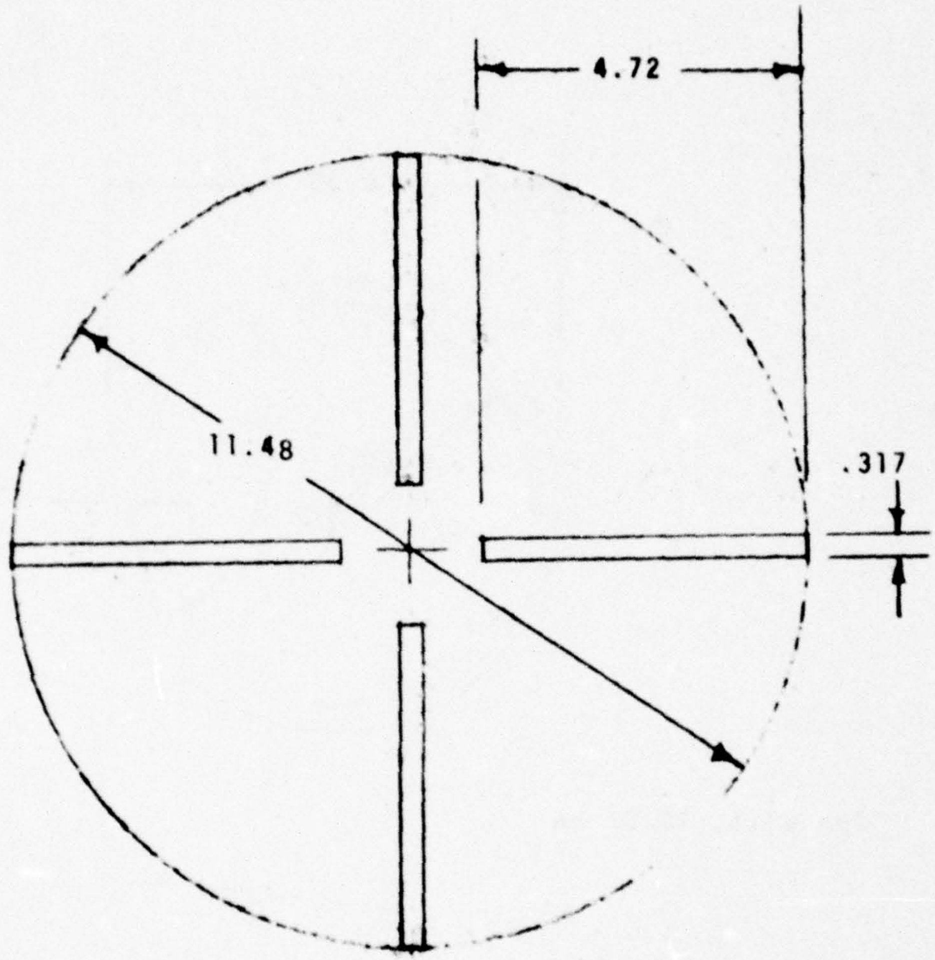



FIGURE A-1. Schematic of a Concentrator



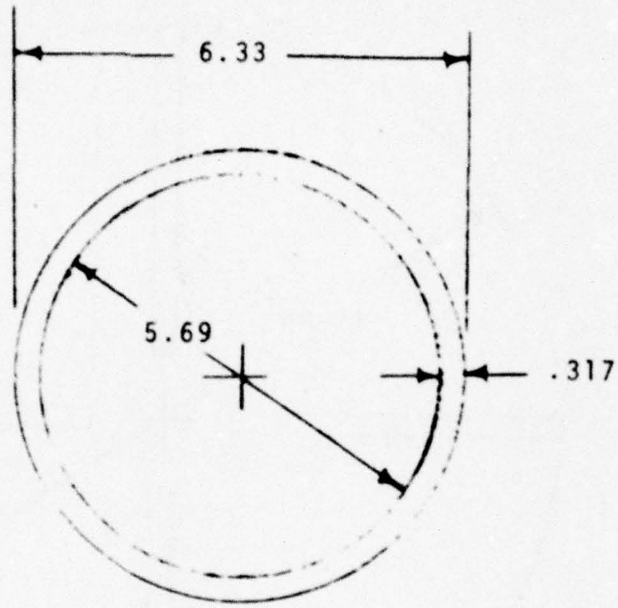

3 slits, each 6.29 cm
Total Length = 18.87 cm

FIGURE A-2. Parallel Slit Nozzle Arrangement



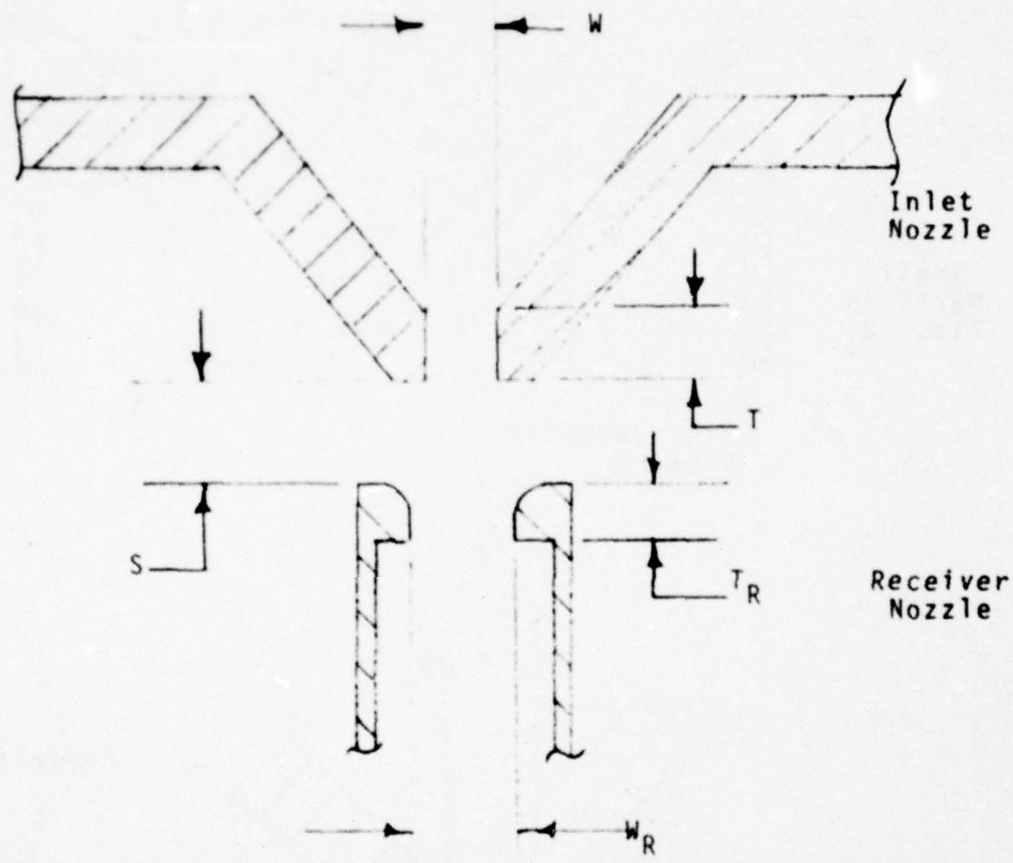

4 slits, each 4.72 cm
Total Length = 18.87 cm

FIGURE A-3. Radial Slit Nozzle Arrangement




One slit, 18.87 cm

FIGURE A-4. Annular Slit Nozzle Arrangement




L = Inlet Nozzle Length
$L_R$ = Receiver Nozzle Length

FIGURE A-5. Nomenclature of a Slit Concentrator

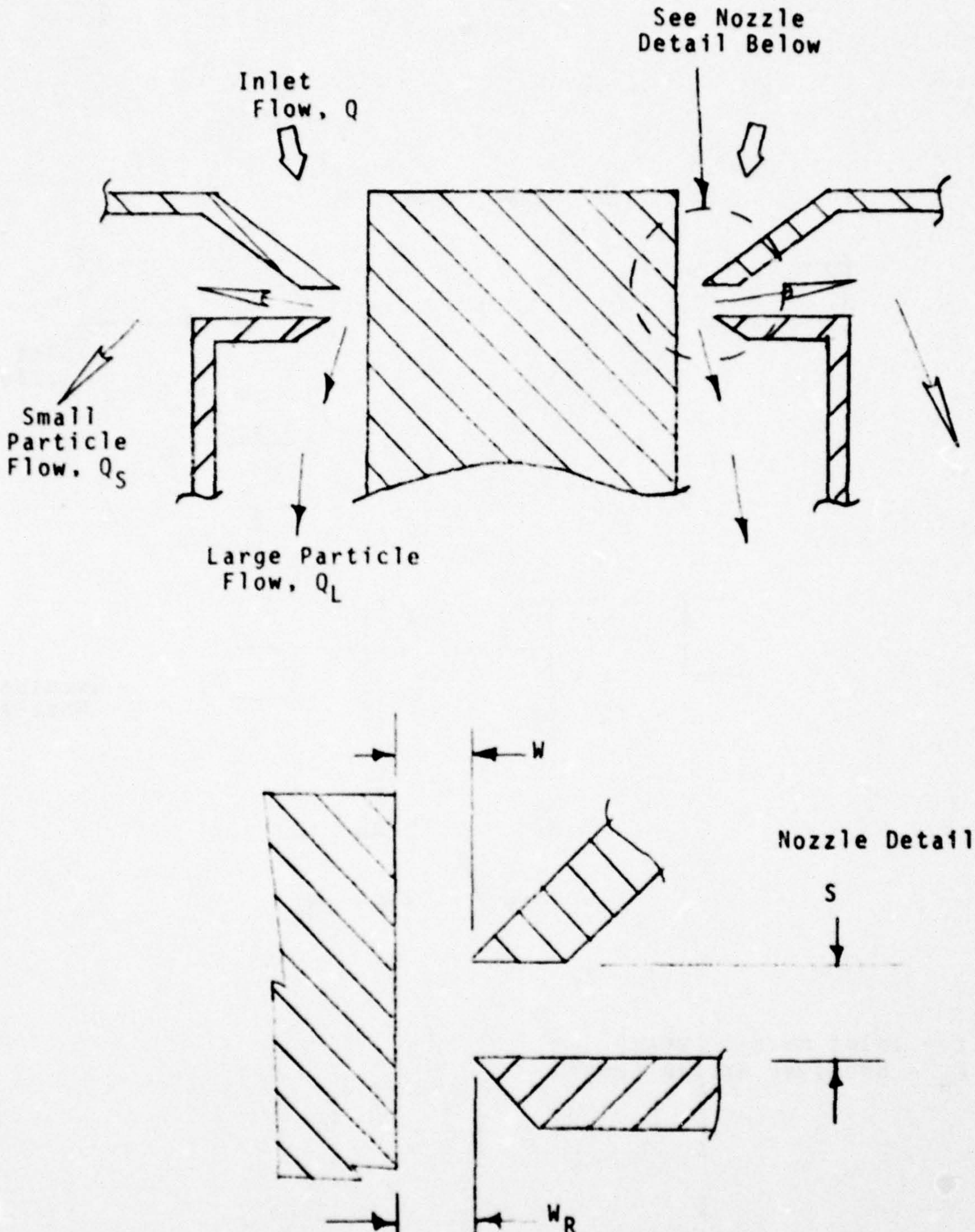
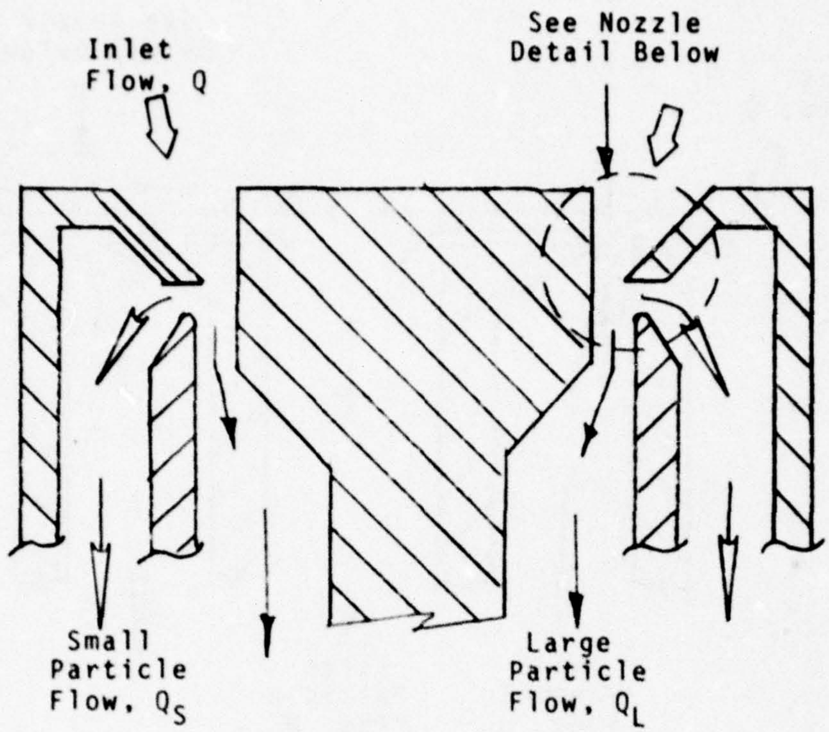



FIGURE A-6. Schematic of Annular Slit Concentrator 1



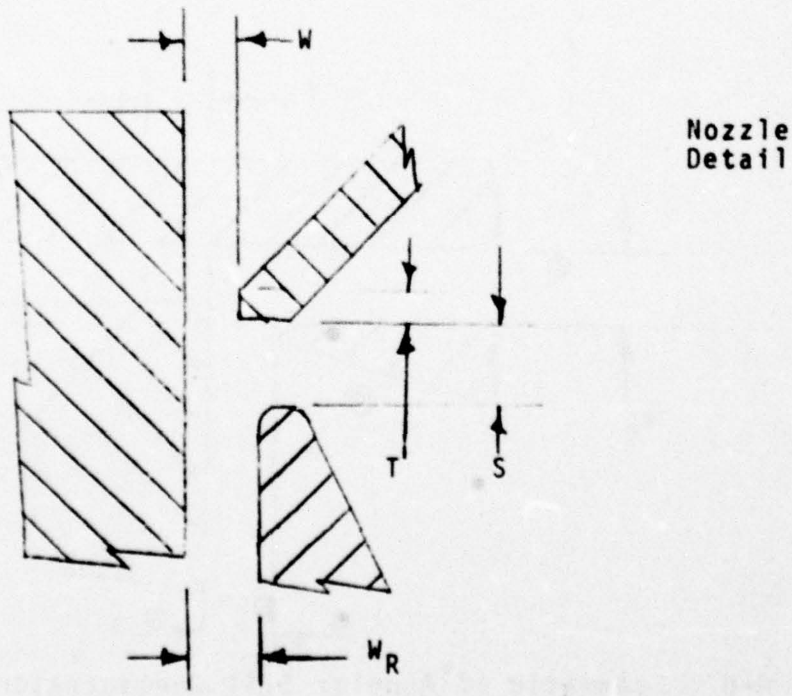
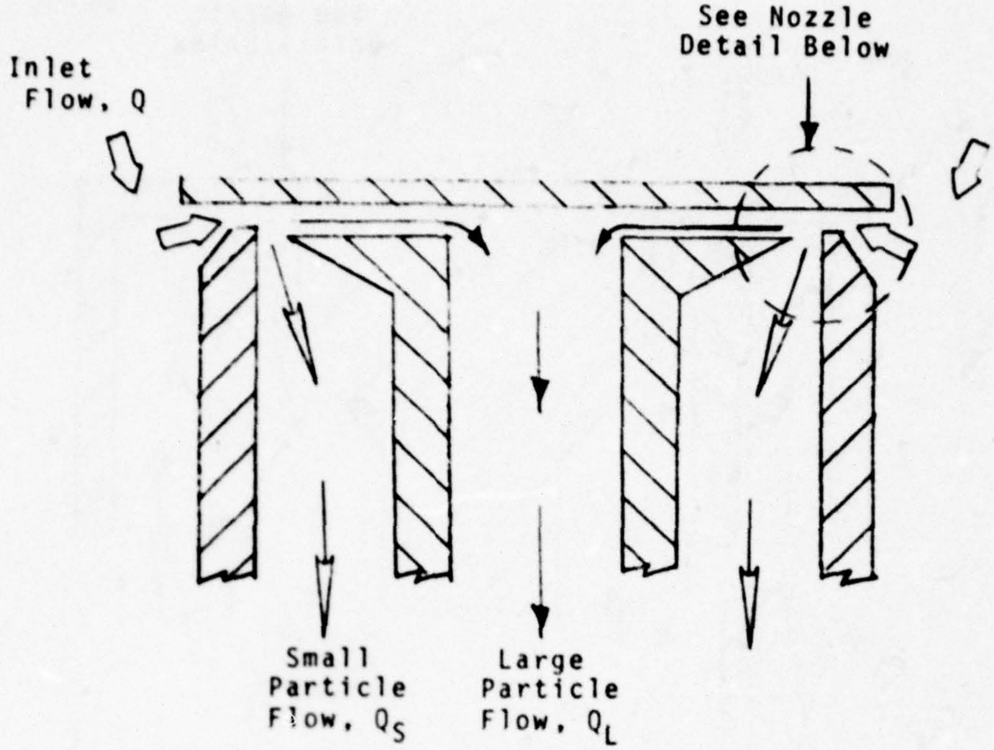




FIGURE A-7. Schematic of Annular Slit Concentrator 2



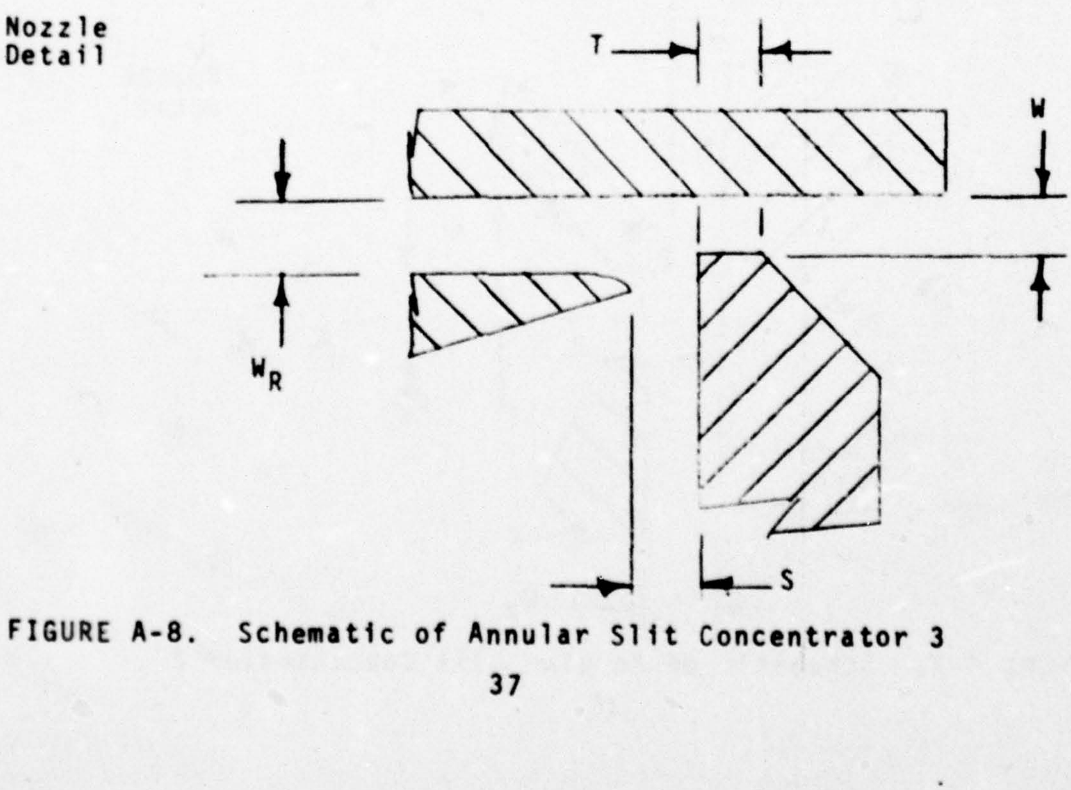




FIGURE A-8. Schematic of Annular Slit Concentrator 3

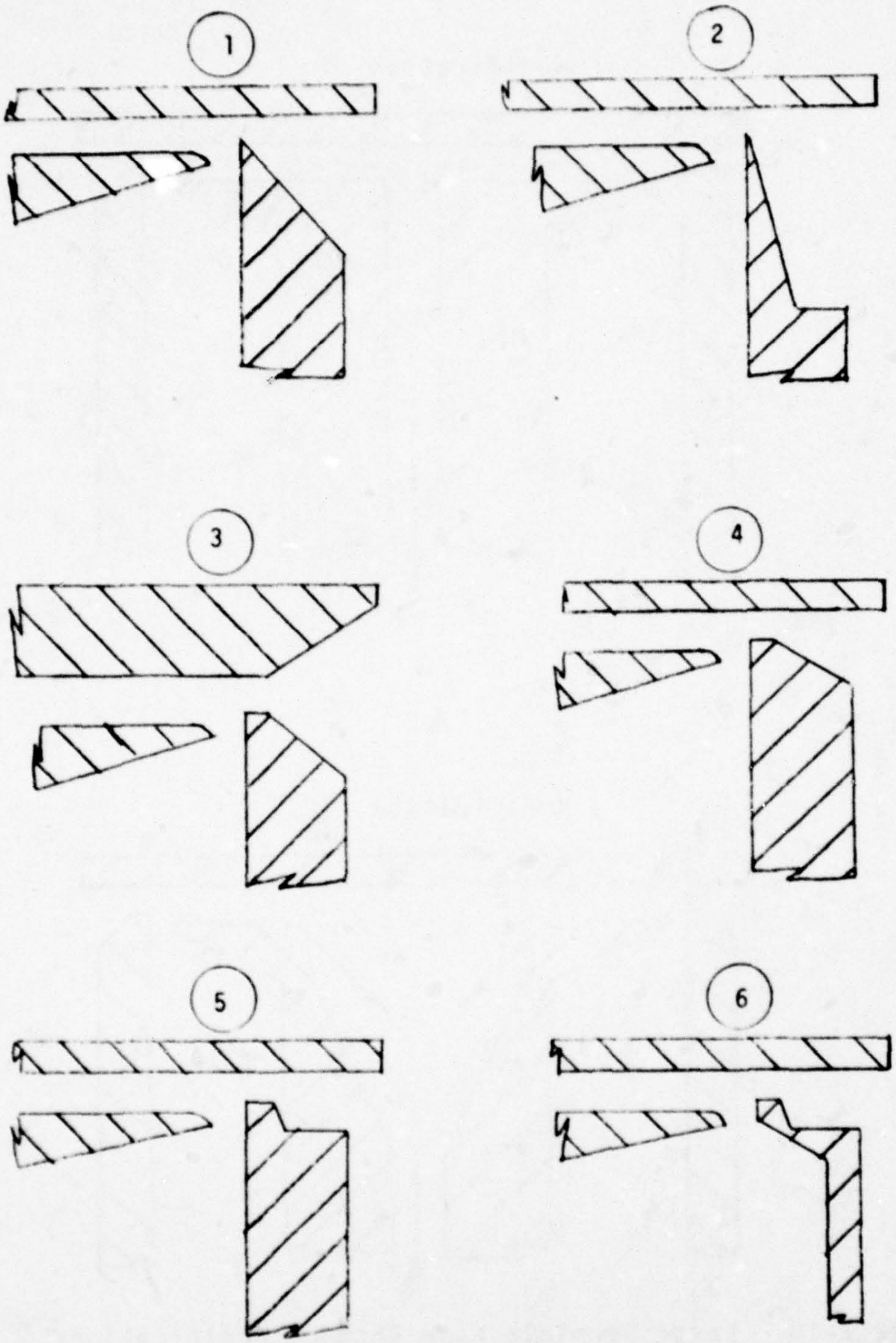
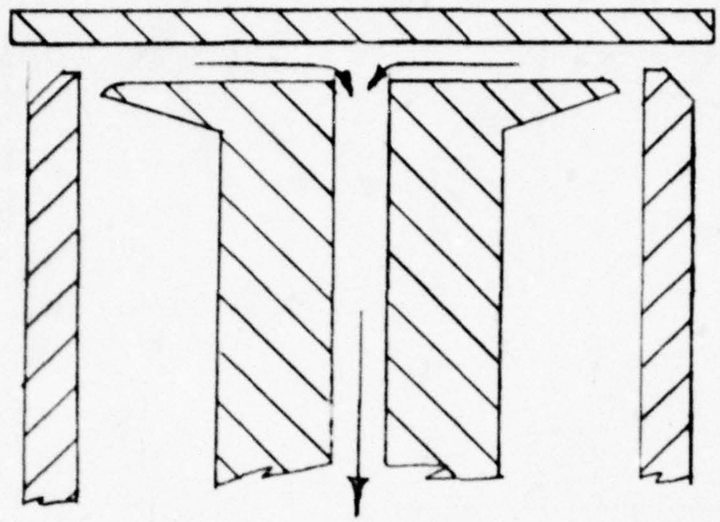



FIGURE A-9. Inlet Nozzle Shapes Which were Tested, Annular Slit Concentrator 3

Modification 1



Modification 2

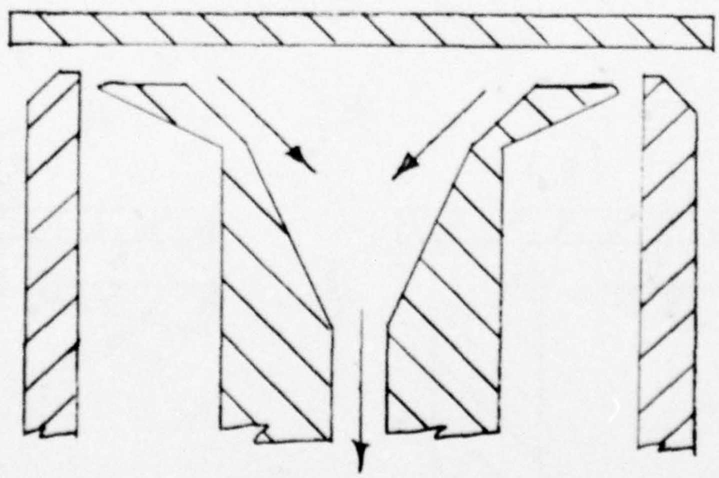
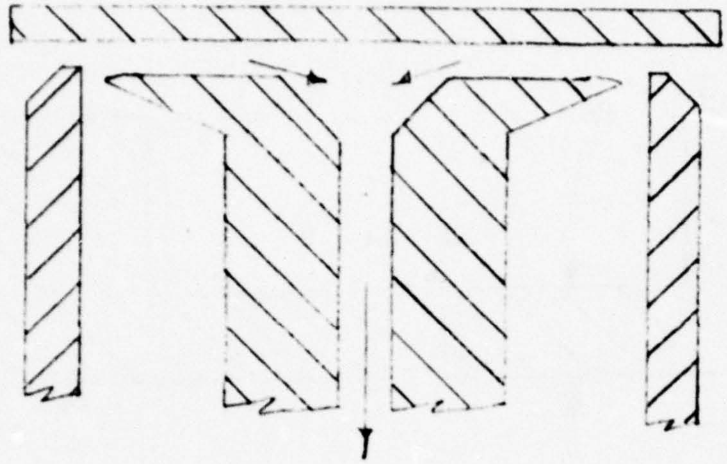


FIGURE A-10. Large Particle Flow Channel Modifications, Annular Slit Concentrator 3

Modification 3



Modification 4

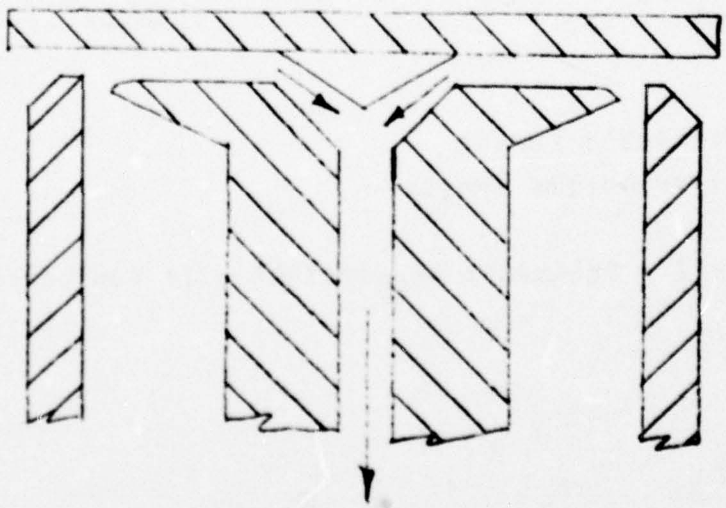
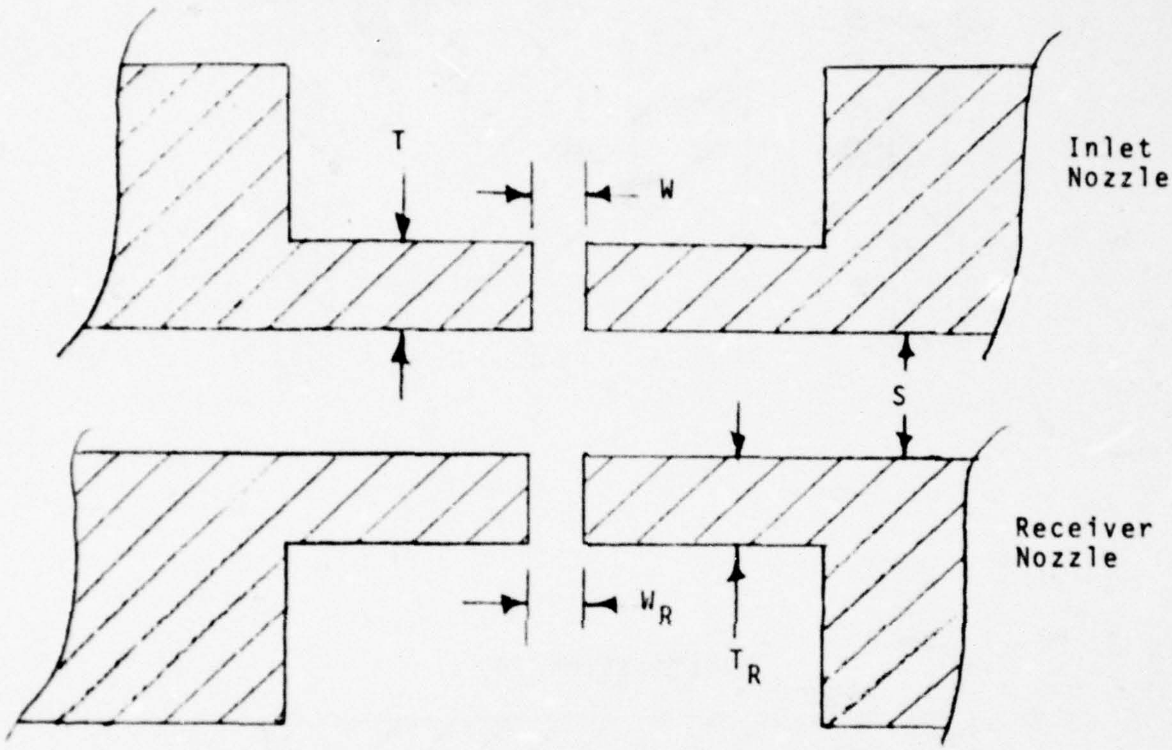


FIGURE A-11. Large Particle Flow Channel Modifications, Annular Slit Concentrator 3




L = Inlet nozzle length

$L_R$ = Receiver nozzle length

FIGURE A-12. Schematic of Straight Slit Concentrator

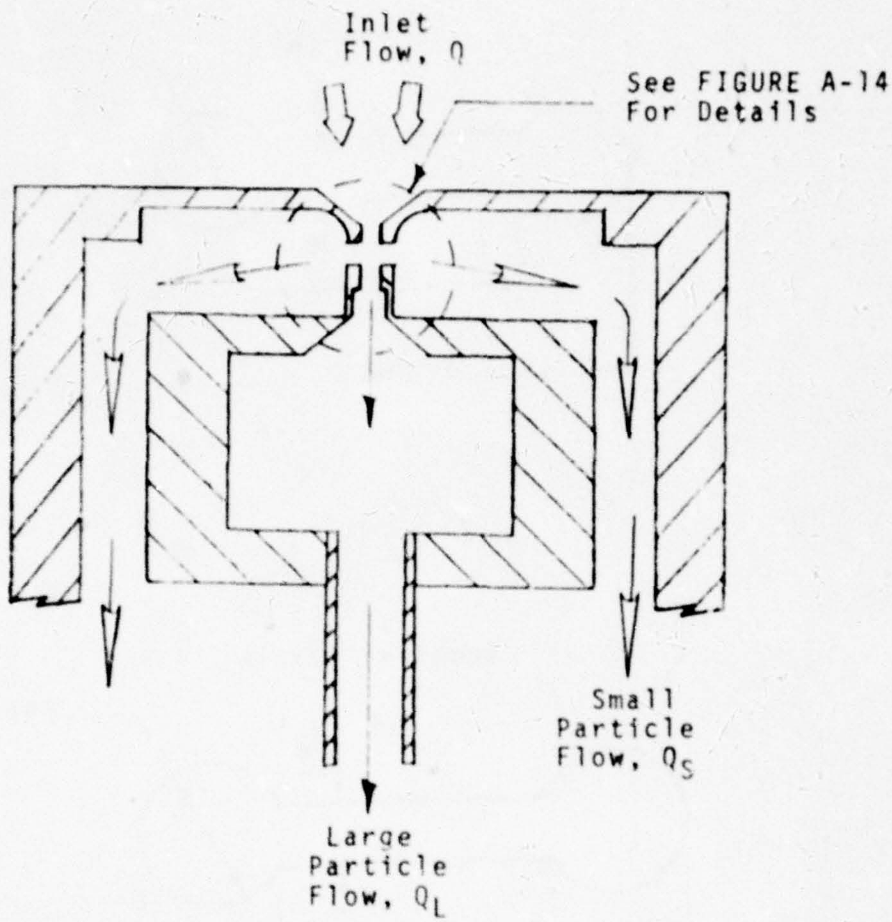
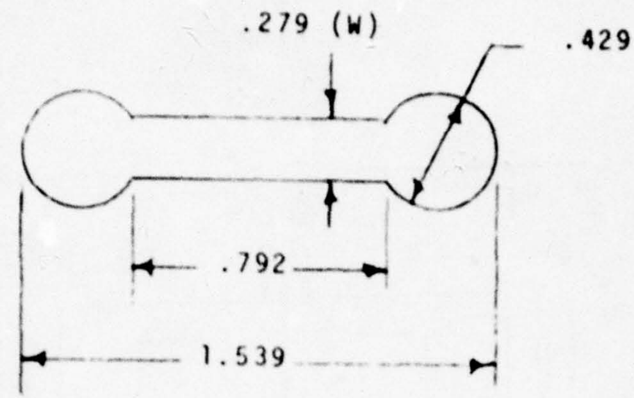
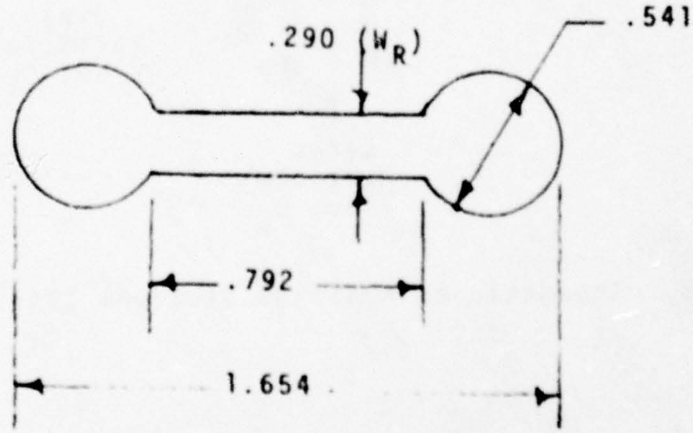



FIGURE A-13. Schematic of Modified Straight Slit Concentrator

Inlet Nozzle

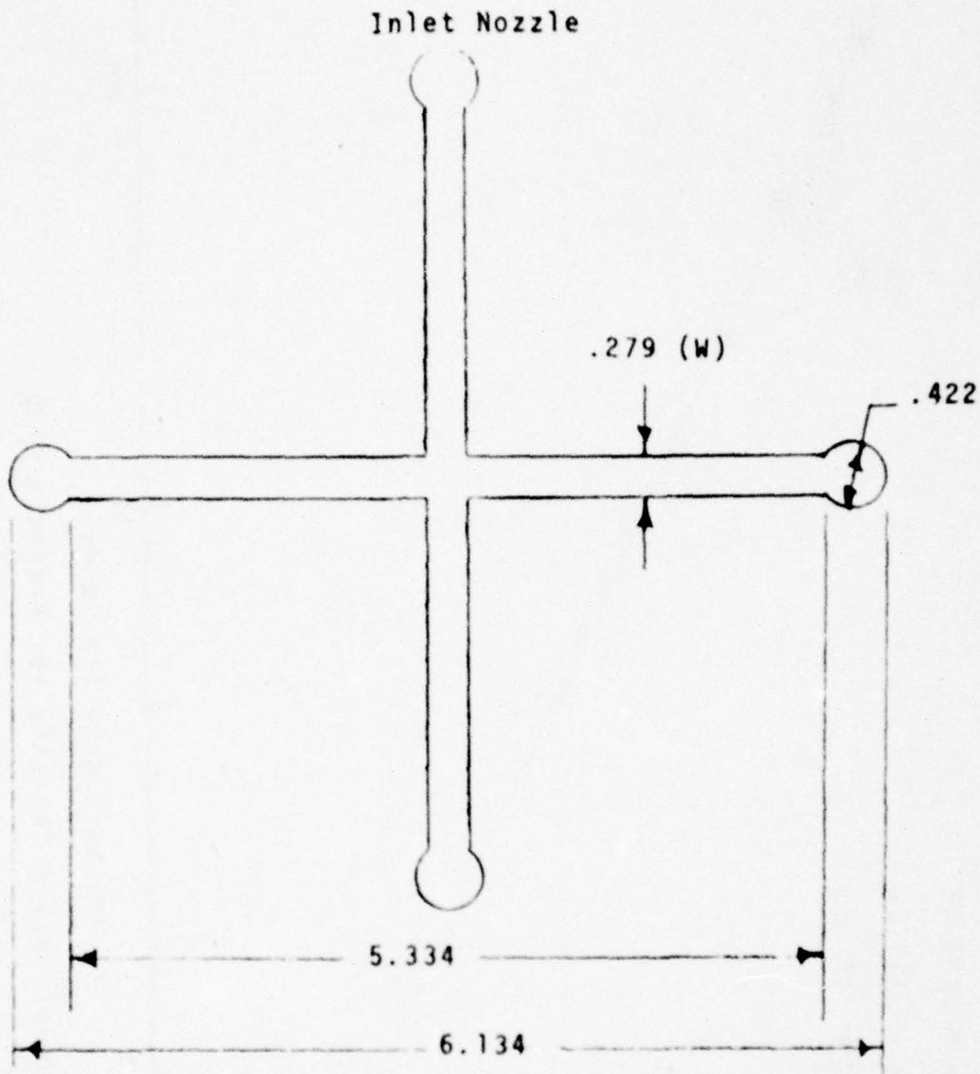



Receiver Nozzle




Dimensions are in cm.

FIGURE A-14. Nozzle Detail for Modified Straight Slit Concentrator




Dimensions are in cm.

Receiver nozzle is the same shape and dimensions except end hole diameter is .541 cm.

FIGURE A-15. Cross Design Nozzle for Modified Straight Slit Concentrator

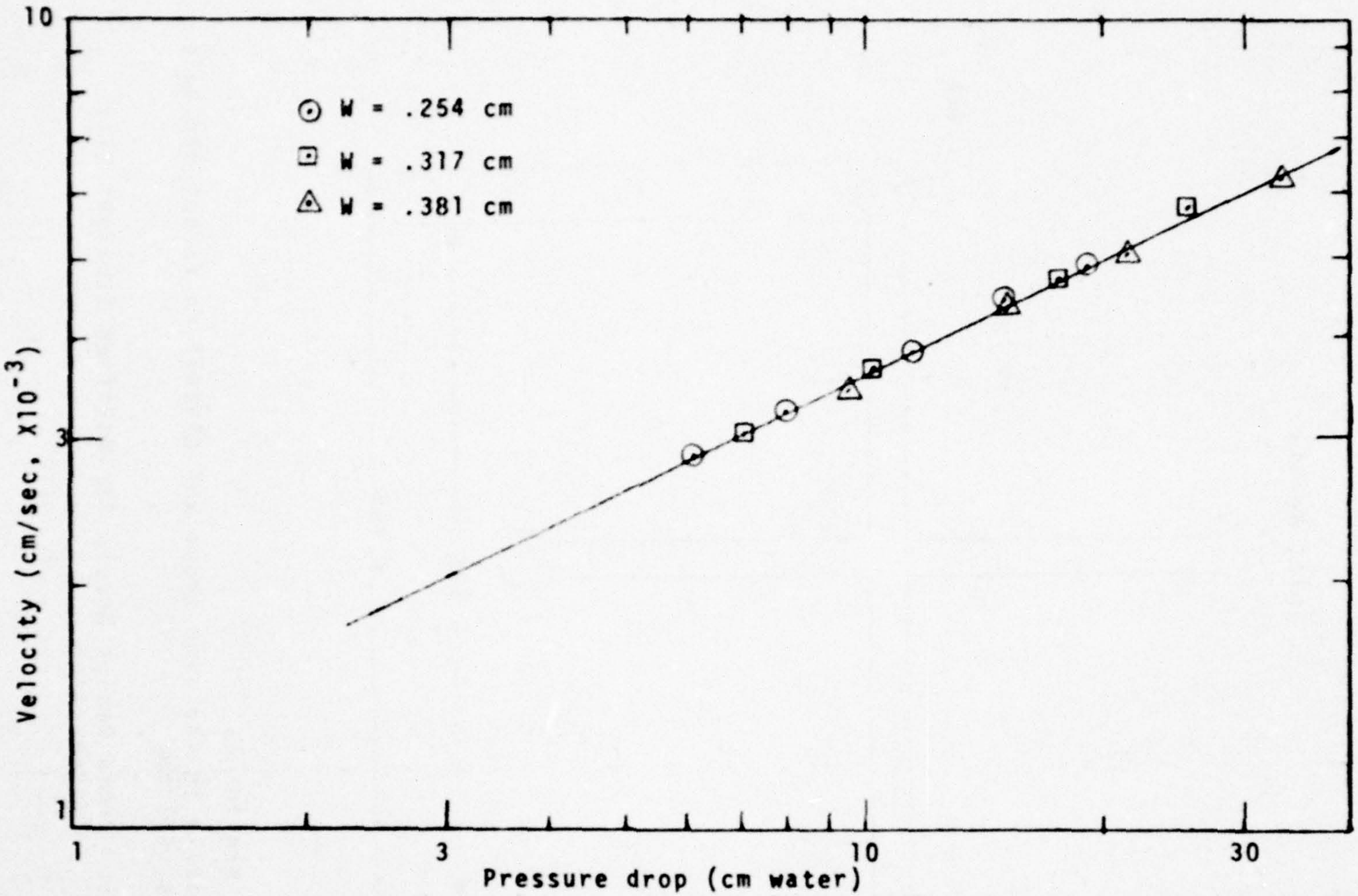



FIGURE A-16. Inlet Nozzle Velocity vs. Pressure Drop

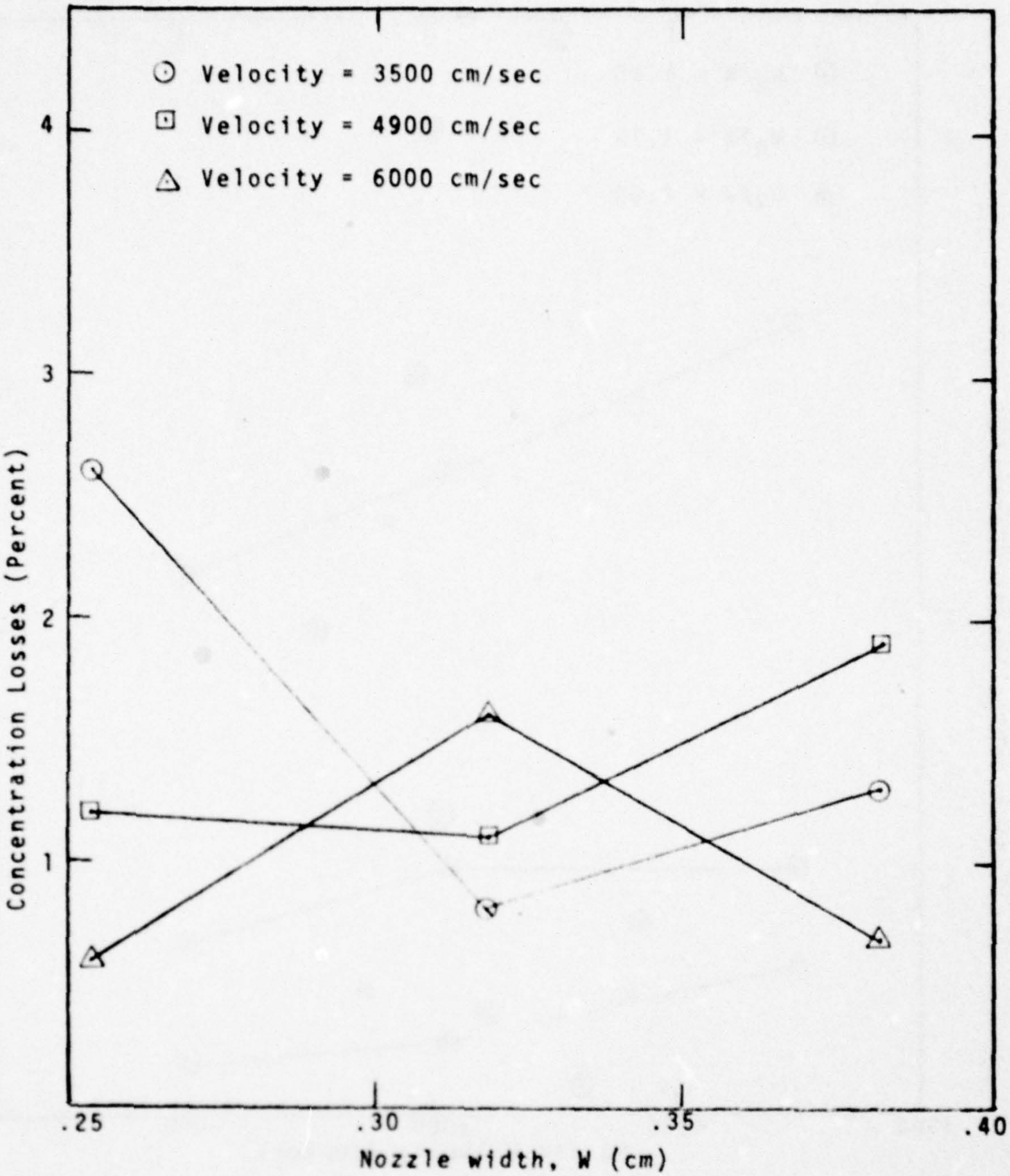



FIGURE A-17. Mean Concentration Losses for Three Values of $W_R/W$ as a Function of Nozzle Width

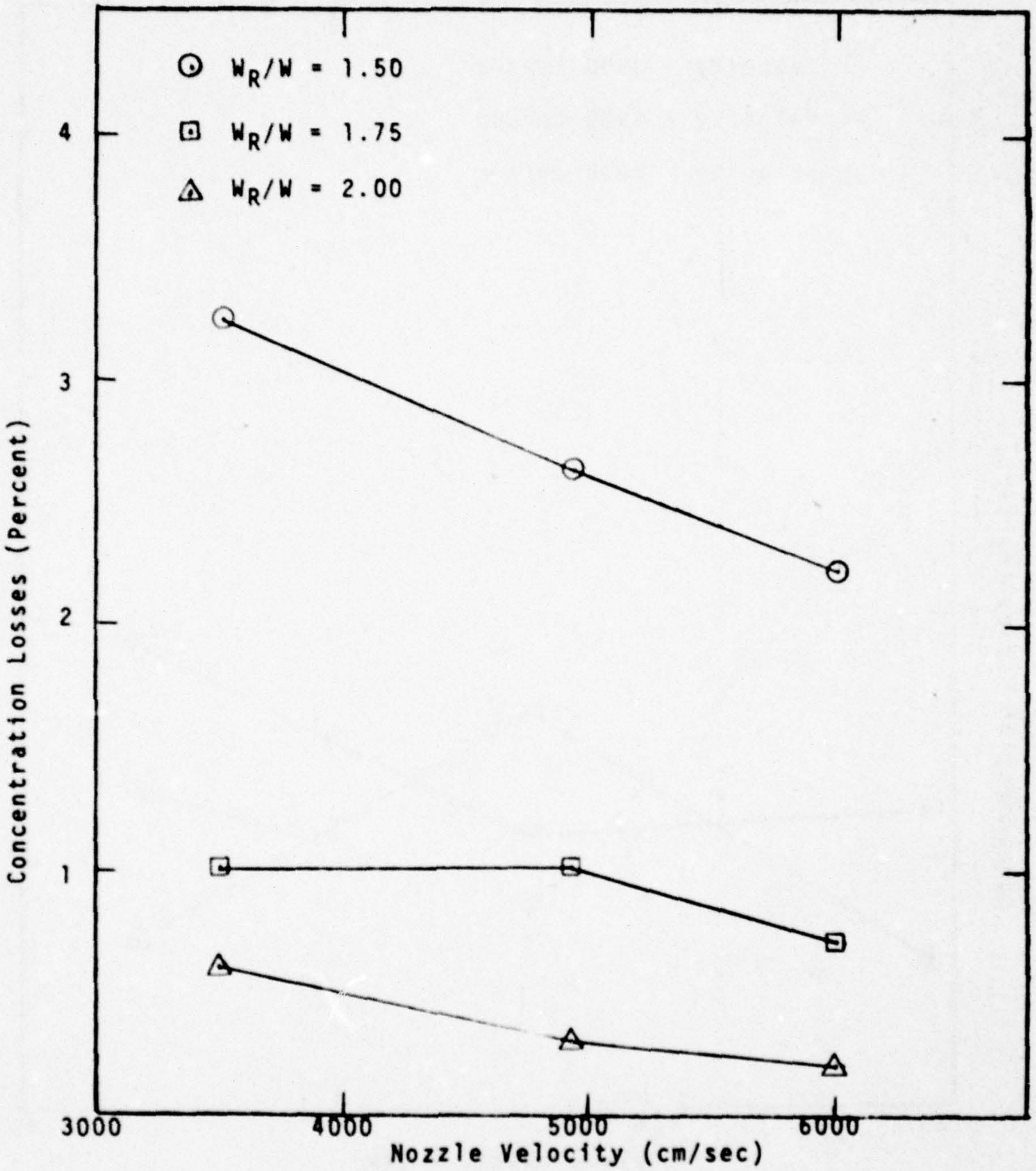



FIGURE A-18. Mean Concentration Losses for Three Nozzle Widths as a Function of Velocity

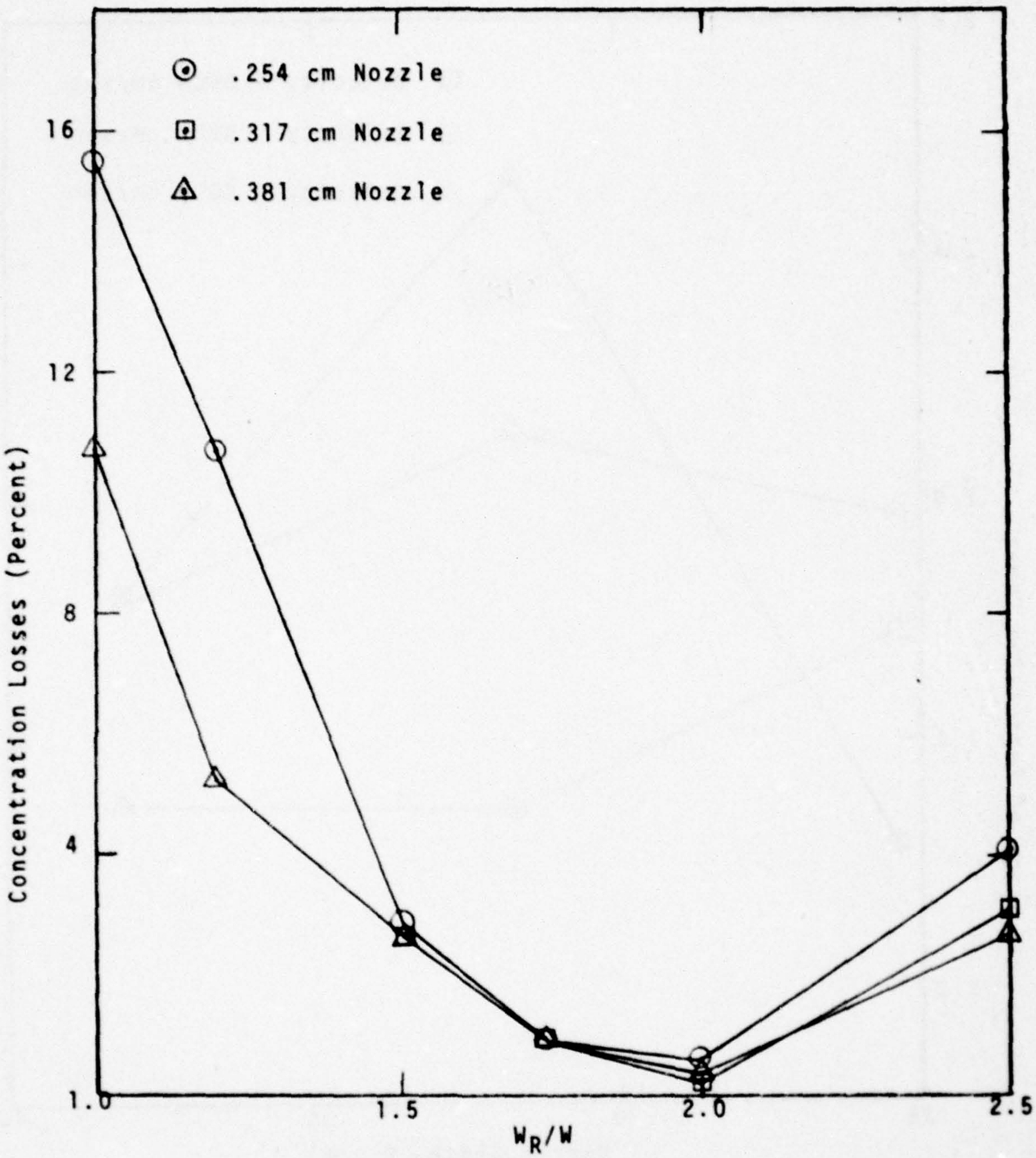



FIGURE A-19. Mean Concentration Losses for Three Velocities as a Function of $W_R/W$

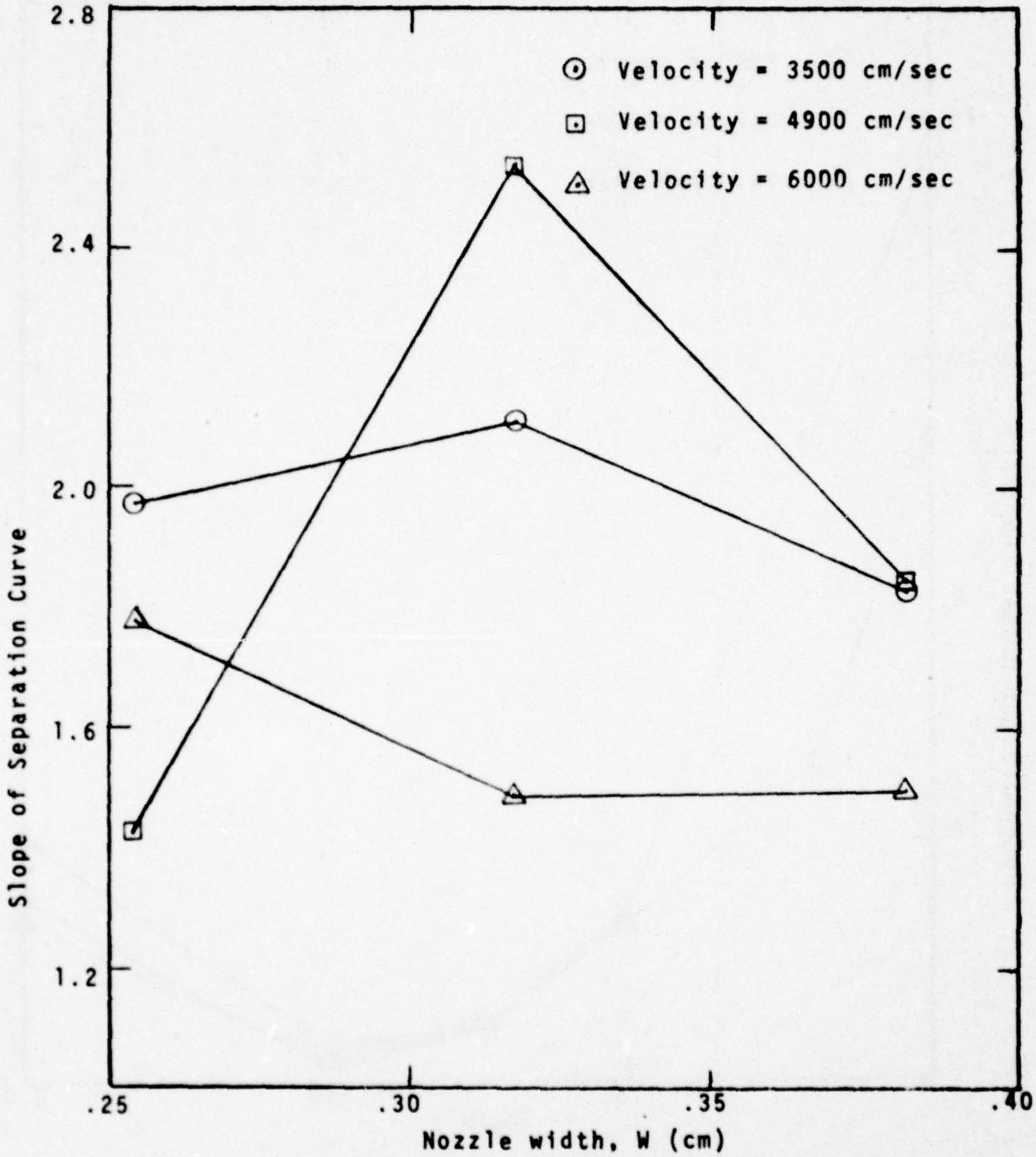



FIGURE A-20. Mean Slope of Separation for Three Values of $W_R/W$ as a Function of Nozzle Width

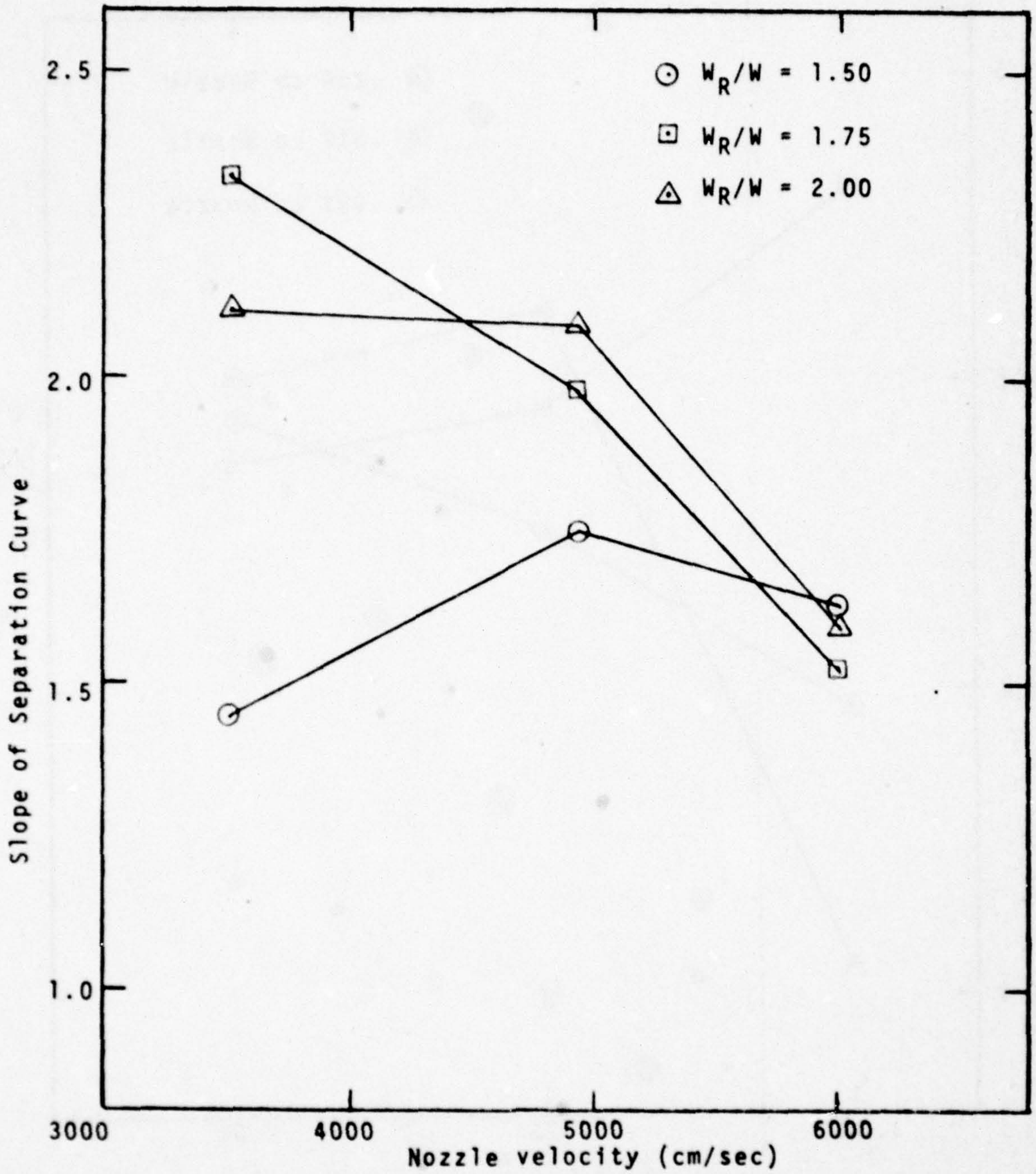



FIGURE A-21. Mean Slope of Separation Curve for Three Nozzle Widths as a Function of Nozzle Velocity

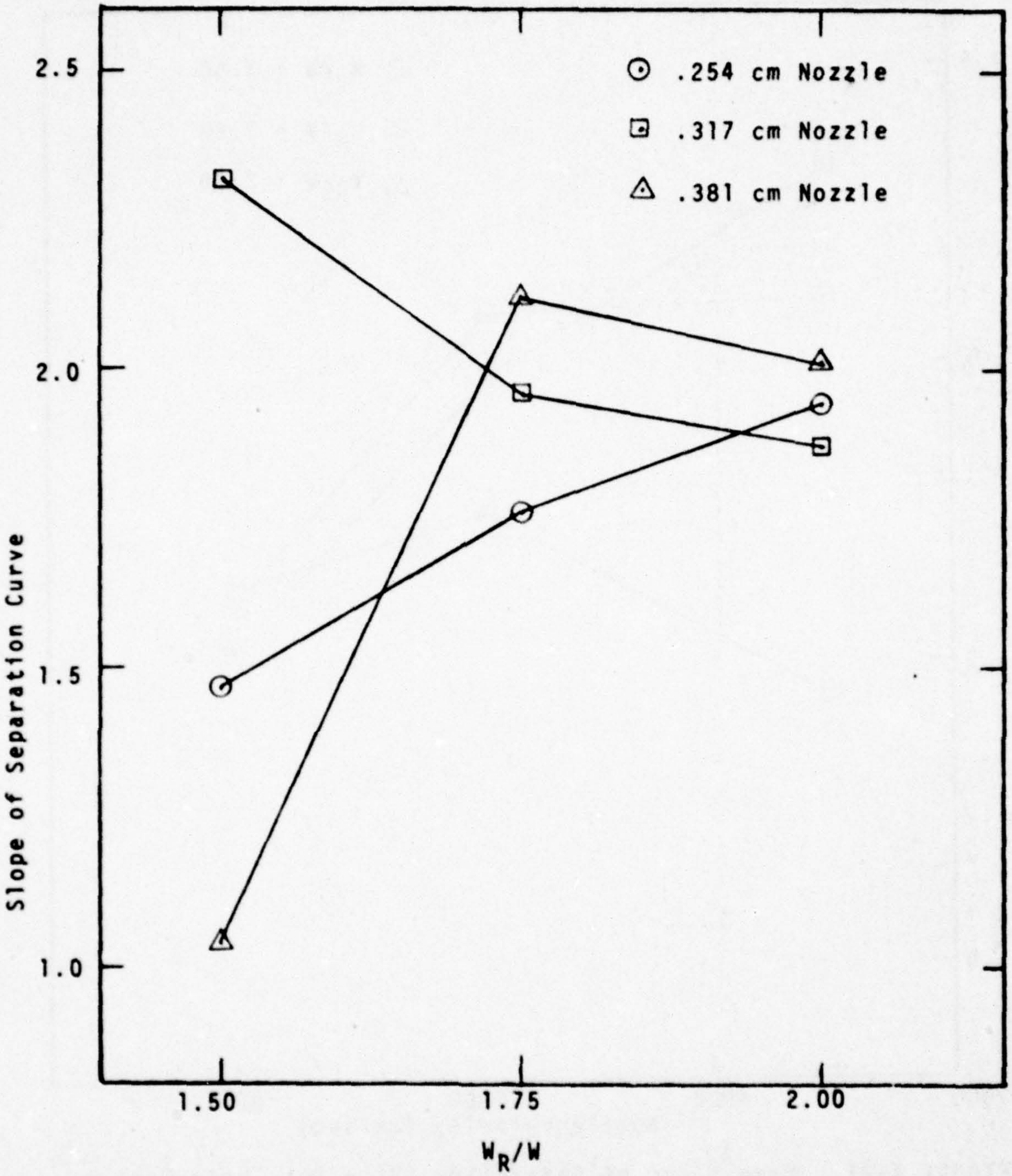



FIGURE A-22. Mean Slope of Separation Curve for Three Velocities as a Function of $W_R/W$

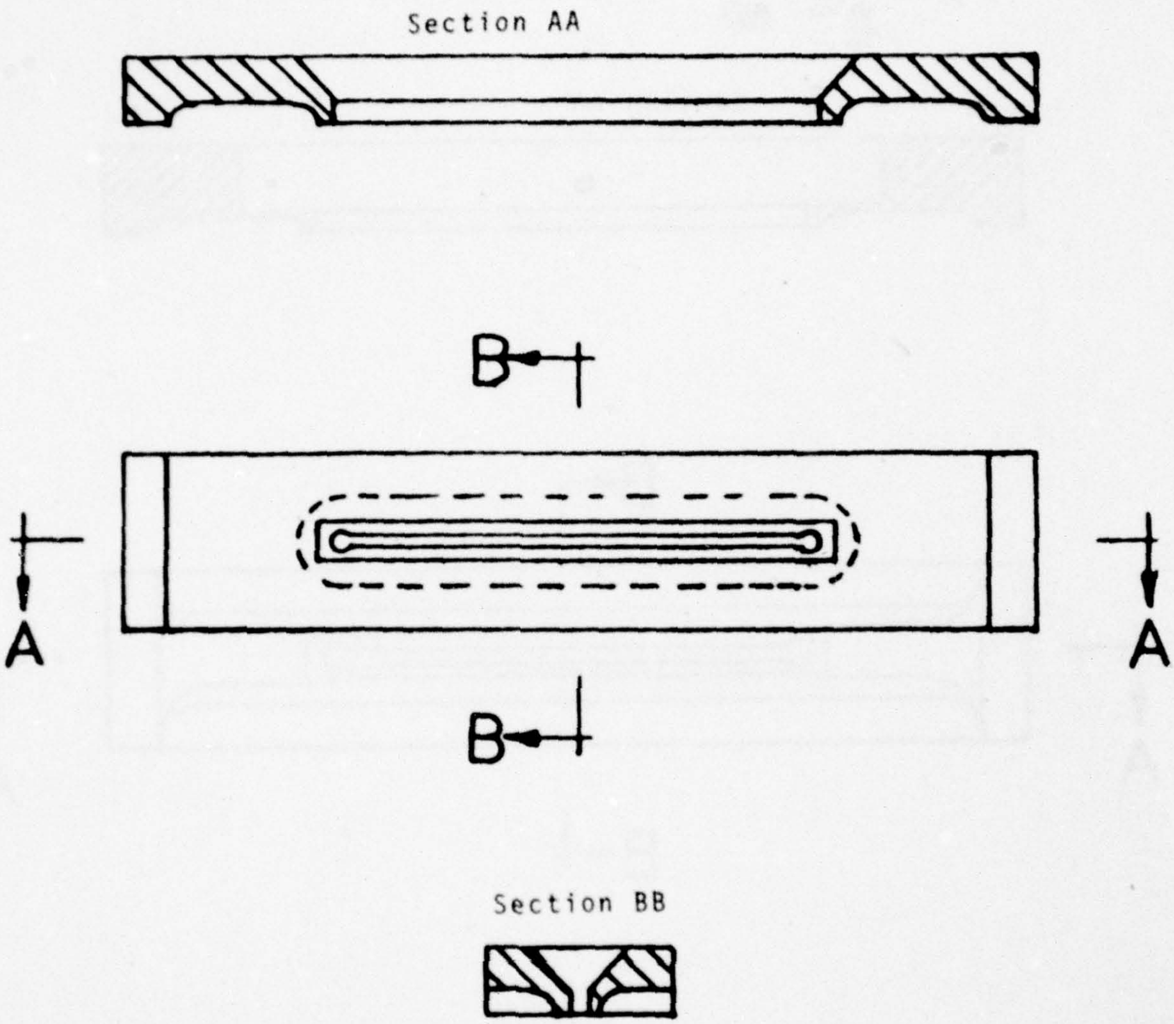



FIGURE A-23. Inlet Nozzle Shape

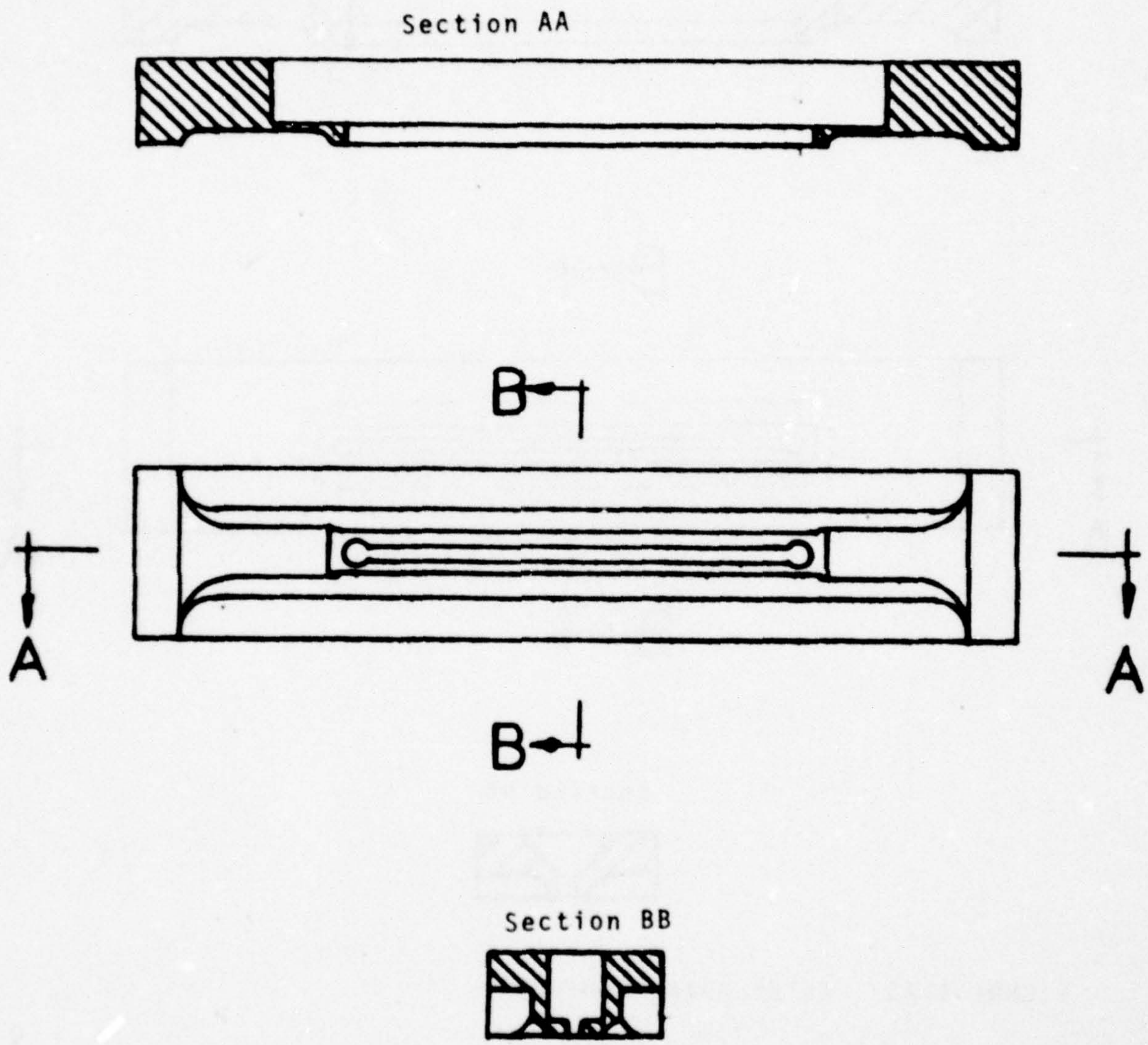



FIGURE A-24. Receiver Nozzle Shape

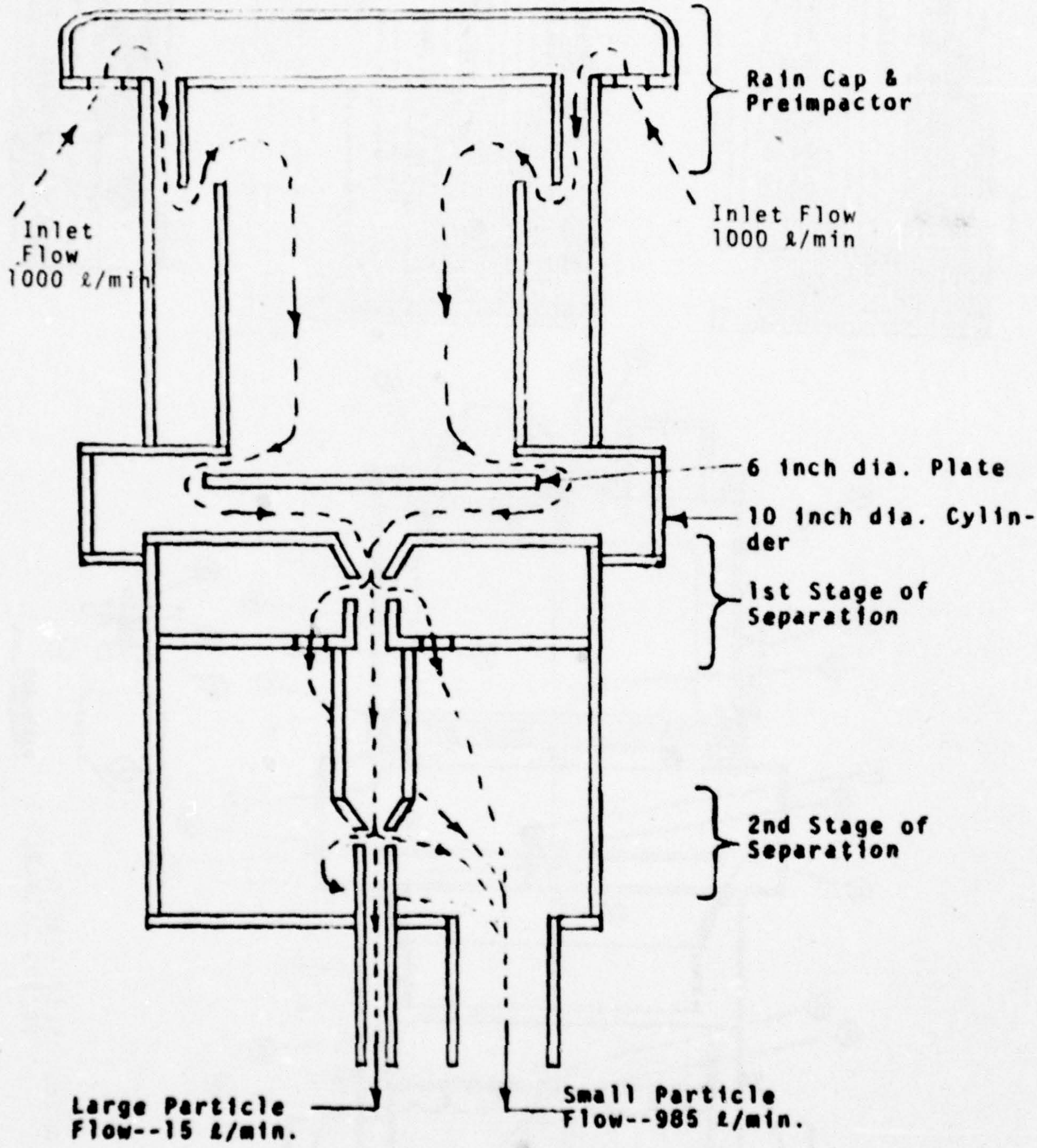



FIGURE A-25. Schematic of Slit Concentrator

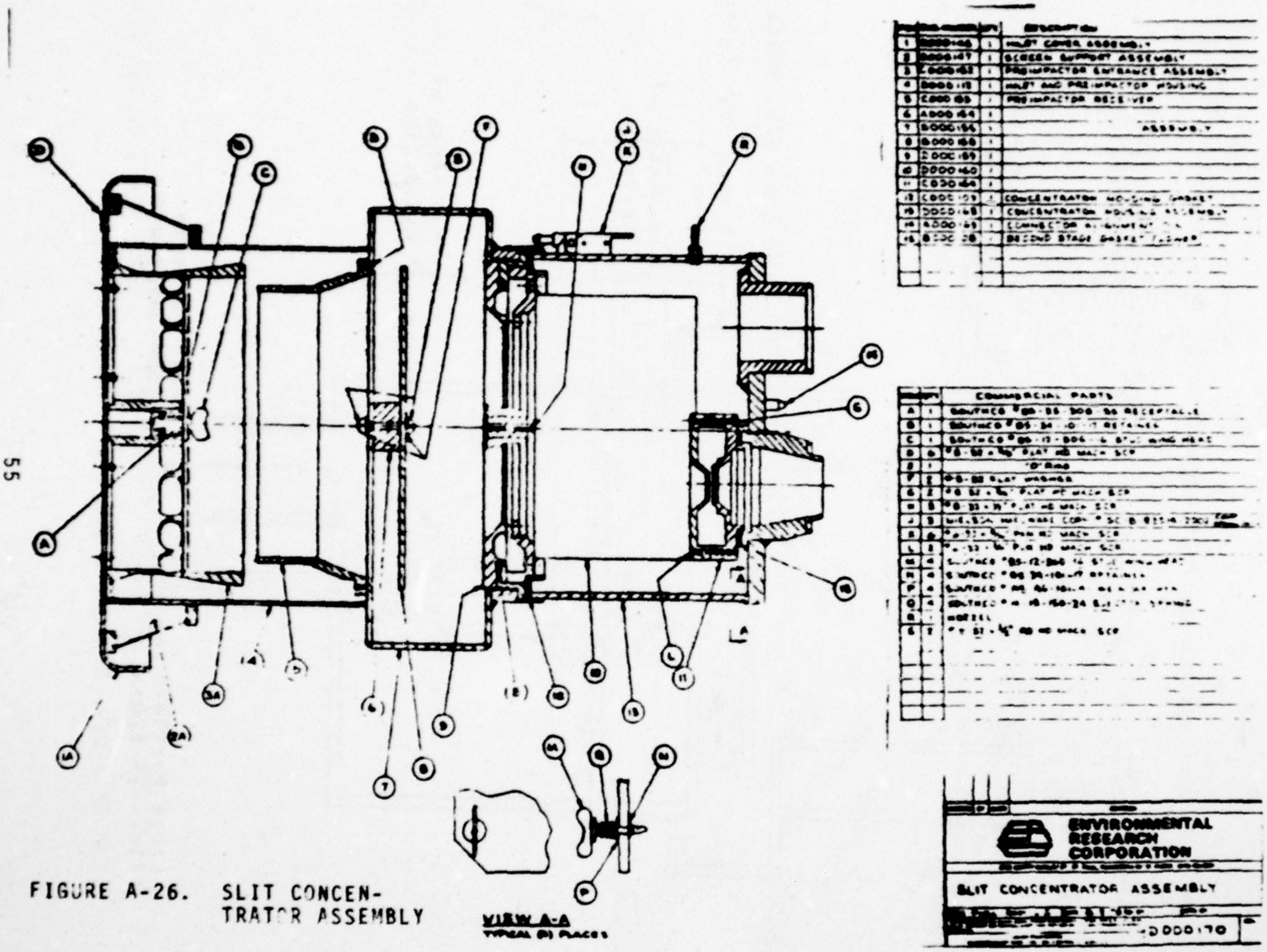



FIGURE A-26. SLIT CONCENTRATOR ASSEMBLY

APPENDIX B

TABLES

TABLE B-1. CONCENTRATOR VARIABLES

| |
|---|
| Nozzle shape |
| Inlet nozzle velocity, V |
| Aerosol size, Dp |
| Spacing between nozzles, S |
| Concentration ratio |
| Inlet nozzle width, W |
| Inlet nozzle end-hole diameter, d |
| Inlet nozzle throat length, T |
| Receiver nozzle width, $W_r$ |
| Receiver nozzle end-hole diameter, $d_r$ |
| Receiver nozzle throat length, $T_r$ |

TABLE B-2. ASSIGNED VALUES FOR CONCENTRATOR VARIABLES

$L = L_R = 6.35$ cm

$S = 0.8\ W$

$d = 1.54\ W$

$T = W$

$d_R = 1.26\ d = 1.94\ W$

$T_R = 0.25$ cm

Nozzle shape = as in Figures A-13 & A-14

Concentration ratio = approximately 8:1

TABLE B-3. INITIAL TEST MATRIX

| | W = .198 | | | W = .254 | | | W = .381 | | |
|---|---|---|---|---|---|---|---|---|---|
| | $W_R/W$ | | | $W_R/W$ | | | $W_R/W$ | | |
| | 1.0 | 1.2 | 1.5 | 1.0 | 1.2 | 1.5 | 1.0 | 1.2 | 1.5 |
| $V_A$ | | | | | | | | | |
| $V_B$ | | | | | | | | | |
| $V_C$ | | | | | | | | | |

$V_B$ was selected to provide an approximate 50% cutpoint for 2.5 μm particles.

$V_A$ was a lower velocity than $V_B$.

$V_C$ was a higher velocity than $V_B$.

Each square represents a minimum of 3 tests, each test with a different size aerosol. Aerosol size was selected in the range of 25%-90% efficiency.

## TABLE B-4. SECOND TEST MATRIX

| | W = .254 | | | W = .317 | | | W = .381 | | |
|---|---|---|---|---|---|---|---|---|---|
| | $W_R/W$ | | | $W_R/W$ | | | $W_R/W$ | | |
| | 1.5 | 1.75 | 2.0 | 1.5 | 1.75 | 2.0 | 1.5 | 1.75 | 2.0 |
| $V_1$ | | | | | | | | | |
| $V_2$ | | | | | | | | | |
| $V_3$ | | | | | | | | | |

$V_1$ = 3500 cm/sec

$V_2$ = 4900 cm/sec

$V_3$ = 6000 cm/sec

Each square represents a minimum of 3 tests, each test with a different size aerosol. Aerosol size was selected in the range of 25%-90% efficiency.

TABLE B-5. TEST SERIES A

$W = .198$ cm

| $W_R / W$ | V (Cm/sec) | $D_p$ (μm) | Percent of aerosol: Conc | Percent of aerosol: Conc loss | ψ | ψ @50% | 50% Cut | $\sigma_g$ of ψ | Slope |
|---|---|---|---|---|---|---|---|---|---|
| 1.00 | 2600 | 2.6 | 38.4 | 10.0 | .361 | | | | |
| | | 3.1 | 46.8 | 22.6 | .511 | .552 | 3.20 | 1.97 | .635 |
| | | 4.1 | 71.3 | 27.4 | .884 | | | | |
| | 3500 | 2.3 | 38.6 | 10.2 | .382 | | | | |
| | | 2.6 | 47.3 | 20.1 | .484 | .532 | 2.71 | 1.88 | .725 |
| | | 3.1 | 60.6 | 35.6 | .682 | | | | |
| | 4900 | 1.6 | 31.8 | 7.1 | .266 | | | | |
| | | 2.3 | 51.6 | 25.6 | .534 | .480 | 2.18 | 1.92 | .804 |
| | | 2.6 | 65.4 | 32.0 | .679 | | | | |
| 1.20 | 2600 | 2.6 | 31.1 | 1.0 | .361 | | | | |
| | | 3.1 | 42.5 | 8.4 | .511 | .606 | 3.36 | 1.72 | .777 |
| | | 4.1 | 71.6 | 25.9 | .884 | | | | |
| | 3500 | 2.3 | 34.7 | 5.8 | .382 | | | | |
| | | 2.6 | 49.8 | 16.9 | .484 | .548 | 2.75 | 1.84 | .741 |
| | | 3.1 | 58.4 | 18.7 | .682 | | | | |
| | 4900 | 1.6 | 35.3 | 8.0 | .266 | | | | |
| | | 2.3 | 56.4 | 22.3 | .534 | .433 | 2.07 | 1.83 | .948 |
| | | 2.6 | 75.4 | 15.0 | .679 | | | | |
| 1.50 | 2600 | 2.6 | 36.7 | 0.7 | .362 | | | | |
| | | 3.1 | 39.0 | 1.2 | .511 | .572 | 3.26 | 1.71 | .834 |
| | | 4.1 | 77.7 | 16.2 | .884 | | | | |
| | 3500 | 2.3 | 36.3 | 1.6 | .382 | | | | |
| | | 2.6 | 42.6 | 3.0 | .484 | .580 | 2.83 | 1.80 | .738 |
| | | 3.1 | 56.4 | 8.7 | .682 | | | | |
| | | 4.1 | 94.6 | 4.7 | 1.179 | | | | |
| | 4900 | 1.6 | 28.5 | 0.6 | .266 | | | | |
| | | 2.3 | 45.3 | 2.0 | .534 | .504 | 2.23 | 1.66 | 1.017 |
| | | 2.6 | 72.8 | 12.7 | .679 | | | | |

TABLE B-6. TEST SERIES B

W = .254 cm

| $\frac{W_R}{W}$ | V (Cm/sec) | $D_p$ (µm) | Percent of aerosol: Conc | Percent of aerosol: Conc loss | ψ | ψ @50% | 50% Cut | $\sigma_g$ of ψ | Slope |
|---|---|---|---|---|---|---|---|---|---|
| 1.00 | 2600 | 2.6 | 27.9 | 1.0 | .286 | | | | |
| | | 3.1 | 35.0 | 5.3 | .403 | .573 | 3.70 | 1.74 | .802 |
| | | 4.1 | 60.3 | 36.3 | .697 | | | | |
| | 3500 | 2.3 | 32.4 | 2.4 | .299 | | | | |
| | | 2.6 | 42.6 | 8.7 | .379 | .479 | 2.91 | 1.77 | .917 |
| | | 3.1 | 54.4 | 26.8 | .533 | | | | |
| | 4900 | 2.3 | 34.6 | 5.6 | .419 | | | | |
| | | 2.6 | 53.4 | 23.9 | .530 | .555 | 2.65 | 1.71 | .866 |
| | | 3.1 | 64.9 | 28.4 | .748 | | | | |
| 1.20 | 2600 | 2.6 | 37.6 | 3.7 | .286 | | | | |
| | | 3.1 | 37.1 | 3.8 | .403 | .494 | 3.43 | 1.87 | .792 |
| | | 4.1 | 67.7 | 27.3 | .697 | | | | |
| | 3500 | 2.3 | 43.0 | 5.6 | .299 | | | | |
| | | 2.6 | 42.2 | 7.3 | .379 | .437 | 2.78 | 2.02 | .763 |
| | | 3.1 | 56.4 | 19.3 | .533 | | | | |
| | | 4.1 | 87.8 | 10.0 | .922 | | | | |
| | 4900 | 2.3 | 34.3 | 2.3 | .419 | | | | |
| | | 2.6 | 53.6 | 14.1 | .530 | .577 | 2.70 | 1.83 | .707 |
| | | 3.1 | 59.8 | 12.2 | .748 | | | | |
| 1.50 | 2600 | 3.1 | 34.7 | 0.4 | .403 | | | | |
| | | 4.1 | 58.1 | 5.2 | .697 | .545 | 3.61 | 1.46 | 1.36 |
| | | 4.5 | 98.3 | 0.8 | .837 | | | | |
| | 3500 | 2.6 | 42.0 | 1.1 | .379 | | | | |
| | | 3.1 | 45.9 | 1.2 | .533 | .537 | 3.08 | 1.93 | .677 |
| | | 4.1 | 77.2 | 16.3 | .922 | | | | |
| | 4900 | 2.3 | 32.7 | 0.4 | .419 | | | | |
| | | 2.6 | 49.1 | 2.5 | .530 | .614 | 2.79 | 1.80 | .690 |
| | | 3.1 | 58.5 | 2.7 | .748 | | | | |
| | | 4.1 | 96.3 | 2.4 | 1.290 | | | | |
| | 6000 | 2.1 | 31.2 | 0.1 | .430 | | | | |
| | | 2.3 | 44.0 | 0.3 | .513 | .561 | 2.41 | 1.43 | 1.396 |
| | | 2.6 | 62.1 | 1.4 | .650 | | | | |

TABLE B-6 (Continued) TEST SERIES B

W = .254 cm

| $\frac{W_R}{W}$ | V (Cm/sec) | $D_p$ (μm) | Percent of aerosol Conc | Conc loss | ψ | ψ @50% | 50% Cut | $\sigma_g$ of ψ | Slope |
|---|---|---|---|---|---|---|---|---|---|
| 1.75 | 3500 | 2.6 | 37.7 | 0.4 | .379 | | | | |
| | | 2.9 | 45.7 | 0.6 | .469 | .464 | 2.87 | 1.49 | 1.494 |
| | | 3.2 | 72.4 | 2.2 | .569 | | | | |
| | | 3.8 | 97.7 | 0.7 | .796 | | | | |
| | 4900 | 2.3 | 39.2 | 0.4 | .419 | | | | |
| | | 2.6 | 54.7 | 1.2 | .530 | .519 | 2.56 | 1.75 | .876 |
| | | 2.9 | 60.2 | 1.2 | .656 | | | | |
| | 6000 | 2.0 | 32.0 | 0.2 | .392 | | | | |
| | | 2.3 | 46.5 | 0.6 | .513 | .544 | 2.37 | 1.53 | 1.178 |
| | | 2.6 | 62.4 | 1.9 | .650 | | | | |
| 2.00 | 3500 | 2.6 | 42.3 | 0.4 | .379 | | | | |
| | | 2.9 | 56.5 | 0.8 | .469 | .425 | 2.74 | 1.44 | 1.830 |
| | | 3.2 | 77.0 | 2.3 | .569 | | | | |
| | 4900 | 2.3 | 36.0 | 0.2 | .419 | | | | |
| | | 2.6 | 48.4 | 0.4 | .530 | .540 | 2.61 | 1.53 | 1.183 |
| | | 2.9 | 64.0 | 0.8 | .656 | | | | |
| | 6000 | 2.0 | 34.0 | 0.2 | .392 | | | | |
| | | 2.3 | 51.5 | 0.3 | .513 | .527 | 2.33 | 1.60 | 1.070 |
| | | 2.6 | 61.8 | 0.3 | .650 | | | | |
| 2.50 | 3500 | 2.9 | 28.5 | 2.1 | .469 | | | | |
| | | 3.2 | 30.1 | 4.0 | .569 | 2.038 | 6.01 | 2.24 | .135 |
| | | 3.8 | 34.3 | 5.4 | .796 | | | | |
| | | 4.5 | 37.0 | 4.6 | 1.109 | | | | |
| | 4900 | 2.9 | 25.6 | 2.1 | .656 | | | | |
| | | 3.2 | 28.1 | 5.2 | .796 | 2.478 | 5.60 | 2.04 | .132 |
| | | 3.8 | 31.8 | 4.9 | 1.113 | | | | |
| | 6000 | 2.9 | 26.5 | 3.0 | .805 | | | | |
| | | 3.2 | 30.6 | 5.2 | .974 | 4.368 | 6.72 | 2.25 | .062 |
| | | 3.8 | 30.7 | 4.8 | 1.364 | | | | |

TABLE B-7. TEST SERIES C-1

$W$ = .317 cm

| $W_R/W$ | V (cm/sec) | $D_p$ (μm) | Percent of aerosol: Conc | Percent of aerosol: Conc loss | ψ | ψ @50% | 50% Cut | $\sigma_g$ of ψ | Slope |
|---|---|---|---|---|---|---|---|---|---|
| 1.50 | 3500 | 2.6 | 34.3 | 0.2 | .304 | | | | |
| | | 2.9 | 39.1 | 0.3 | .376 | .408 | 3.00 | 1.47 | 1.775 |
| | | 3.2 | 61.0 | 3.5 | .456 | | | | |
| | 4900 | 2.6 | 40.7 | 0.5 | .425 | | | | |
| | | 2.9 | 57.2 | 1.8 | .526 | .477 | 2.74 | 1.33 | 2.144 |
| | | 3.2 | 86.0 | 4.0 | .637 | | | | |
| | 6000 | 1.6 | 29.6 | 0.4 | .202 | | | | |
| | | 2.3 | 51.5 | 2.3 | .404 | .354 | 2.14 | 1.65 | 1.477 |
| | | 2.6 | 77.4 | 10.5 | .514 | | | | |
| 1.75 | 3500 | 2.6 | 34.6 | 0.4 | .304 | | | | |
| | | 2.9 | 41.3 | 0.7 | .376 | .400 | 2.97 | 1.46 | 1.837 |
| | | 3.2 | 62.3 | 1.7 | .456 | | | | |
| | 4900 | 2.3 | 33.2 | 0.2 | .335 | | | | |
| | | 2.6 | 45.7 | 0.7 | .425 | .451 | 2.67 | 1.47 | 1.606 |
| | | 2.9 | 57.3 | 1.4 | .526 | | | | |
| | | 3.2 | 82.9 | 1.9 | .637 | | | | |
| | 6000 | 2.0 | 33.3 | 0.2 | .312 | | | | |
| | | 2.3 | 46.4 | 0.3 | .404 | .459 | 2.43 | 1.71 | 1.045 |
| | | 2.6 | 55.3 | 0.9 | .514 | | | | |
| | | 2.9 | 68.1 | 1.2 | .635 | | | | |
| 2.00 | 3500 | 2.6 | 36.7 | 0.1 | .304 | | | | |
| | | 2.9 | 41.5 | 0.3 | .376 | | | | |
| | | 3.2 | 57.6 | 0.4 | .456 | .412 | 3.02 | 1.58 | 1.418 |
| | | 3.8 | 82.1 | 0.3 | .637 | | | | |
| | 4900 | 2.6 | 41.4 | 0.1 | .425 | | | | |
| | | 2.9 | 55.3 | 0.2 | .526 | .484 | 2.76 | 1.44 | 1.593 |
| | | 3.2 | 75.1 | 0.5 | .637 | | | | |
| | 6000 | 2.3 | 42.6 | 0.1 | .404 | | | | |
| | | 2.6 | 53.7 | 0.1 | .514 | .480 | 2.49 | 1.76 | .934 |
| | | 2.9 | 64.2 | 0.2 | .635 | | | | |
| 2.50 | 4900 | 2.9 | 27.4 | 2.5 | .526 | | | | |
| | | 3.2 | 34.4 | 4.0 | .637 | 1.305 | 4.54 | 1.97 | .269 |
| | | 3.8 | 38.2 | 3.1 | .893 | | | | |

TABLE B-8. TEST SERIES C

W = .381 cm

| $\frac{W_R}{W}$ | V (Cm/sec) | $D_p$ (μm) | Percent of aerosol Conc | Conc loss | ψ | ψ @ 50% | 50% Cut | $\sigma_g$ of ψ | Slope |
|---|---|---|---|---|---|---|---|---|---|
| 1.00 | 3500 | 2.6 | 32.6 | 1.9 | .261 | | | | |
| | | 3.1 | 37.5 | 3.5 | .367 | .488 | 3.60 | 1.83 | .840 |
| | | 4.1 | 63.0 | 25.4 | .635 | | | | |
| | 4900 | 2.3 | 36.9 | 2.6 | .274 | | | | |
| | | 2.6 | 44.3 | 9.2 | .348 | .443 | 2.90 | 2.05 | .728 |
| | | 3.1 | 53.0 | 18.2 | .490 | | | | |
| | 6000 | 2.3 | 44.7 | 5.7 | .346 | | | | |
| | | 2.6 | 53.4 | 17.3 | .438 | .421 | 2.55 | 2.70 | .476 |
| | | 3.1 | 58.5 | 12.9 | .618 | | | | |
| 1.20 | 3500 | 2.6 | 32.3 | 0.4 | .261 | | | | |
| | | 3.1 | 37.8 | 0.5 | .367 | .499 | 3.64 | 1.86 | .795 |
| | | 4.1 | 61.3 | 16.3 | .635 | | | | |
| | 4900 | 2.3 | 33.4 | 0.3 | .274 | | | | |
| | | 2.6 | 45.5 | 3.3 | .348 | .463 | 2.96 | 2.01 | .730 |
| | | 3.1 | 51.0 | 6.0 | .490 | | | | |
| | | 4.1 | 77.8 | 16.3 | .846 | | | | |
| | 6000 | 2.3 | 36.7 | 0.9 | .346 | | | | |
| | | 2.6 | 54.6 | 4.7 | .438 | .474 | 2.71 | 2.07 | .674 |
| | | 3.1 | 57.3 | 3.0 | .618 | | | | |
| 1.50 | 3500 | 2.6 | 31.6 | 0.8 | .261 | | | | |
| | | 3.1 | 38.2 | 0.8 | .367 | .492 | 3.62 | 1.82 | .839 |
| | | 4.1 | 62.4 | 5.0 | .635 | | | | |
| | 4900 | 2.3 | 44.8 | 0.6 | .274 | | | | |
| | | 2.6 | 47.2 | 0.9 | .348 | .398 | 2.75 | 2.40 | .611 |
| | | 3.1 | 51.4 | 0.7 | .490 | | | | |
| | | 4.1 | 78.9 | 12.3 | .846 | | | | |
| | 6000 | 2.3 | 39.8 | 0.6 | .346 | | | | |
| | | 2.6 | 51.9 | 2.7 | .438 | .449 | 2.64 | 1.93 | .816 |
| | | 3.1 | 62.9 | 1.2 | .618 | | | | |

TABLE B-8 (Continued) TEST SERIES C

W = .381 cm

| $\frac{W_R}{W}$ | V (Cm/sec) | Dp (µm) | Percent of aerosol Conc | Conc loss | ψ | ψ @50% | 50% Cut | $\sigma_g$ of ψ | Slope |
|---|---|---|---|---|---|---|---|---|---|
| 1.75 | 3500 | 2.9 | 35.3 | 0.3 | .323 | | | | |
| | | 3.2 | 52.1 | 0.8 | .391 | .393 | 3.23 | 1.47 | 1.859 |
| | | 3.8 | 78.1 | 2.6 | .548 | | | | |
| | 4900 | 2.6 | 41.9 | 0.3 | .348 | | | | |
| | | 2.9 | 52.6 | 1.0 | .430 | .400 | 2.76 | 1.46 | 1.853 |
| | | 3.2 | 73.8 | 2.1 | .521 | | | | |
| | 6000 | 2.3 | 42.4 | 0.2 | .346 | | | | |
| | | 2.6 | 50.4 | 0.4 | .438 | .422 | 2.56 | 1.73 | 1.101 |
| | | 2.9 | 63.9 | 1.0 | .542 | | | | |
| 2.00 | 3500 | 2.9 | 39.1 | 0.2 | .323 | | | | |
| | | 3.2 | 53.8 | 0.3 | .391 | .385 | 3.20 | 1.62 | 1.424 |
| | | 3.8 | 72.3 | 0.5 | .548 | | | | |
| | 4900 | 2.6 | 39.8 | 0.1 | .348 | | | | |
| | | 2.9 | 52.8 | 0.2 | .430 | .410 | 2.79 | 1.49 | 1.695 |
| | | 3.2 | 69.1 | 0.5 | .521 | | | | |
| | 6000 | 2.3 | 34.9 | 0.1 | .346 | | | | |
| | | 2.6 | 44.3 | 0.1 | .438 | | | | |
| | | 2.9 | 57.1 | 0.2 | .542 | .471 | 2.70 | 1.53 | 1.362 |
| | | 3.2 | 77.3 | 0.7 | .656 | | | | |
| 2.50 | 4900 | 2.9 | 36.5 | 1.0 | .430 | | | | |
| | | 3.2 | 48.0 | 2.3 | .521 | | | | |
| | | 3.8 | 50.1 | 2.2 | .729 | .950 | 4.25 | 3.58 | .139 |
| | | 6.4 | 64.1 | 4.9 | 2.025 | | | | |

TABLE B-9. CONCENTRATOR DATA FOR SERIES B-1 TESTS

$L = L_R = 6.35$ cm

$W = .254$ cm

$T = .305$ cm

$T/W = 1.20$

$S = .203$ cm

$S/W = .80$

$d = .391$ cm

$d/W = 1.54$

$W_R = .381$ cm

$W_R/W = 1.50$

$T_R = .254$ cm

TABLE B-10. TEST SERIES B-1

W = .254 cm

| $\frac{d_R}{W}$ | V (Cm/sec) | $D_p$ (µm) | Percent of aerosol: Conc | Percent of aerosol: Conc loss | ψ | ψ @50% | 50% Cut | $\sigma_g$ of ψ | Slope |
|---|---|---|---|---|---|---|---|---|---|
| 1.94 | 4900 | 2.1 | 29.4 | 0.3 | .350 | | | | |
| | | 2.3 | 41.3 | 2.8 | .419 | | | | |
| | | 2.6 | 54.3 | 4.9 | .530 | .494 | 2.50 | 1.48 | 1.422 |
| | | 2.9 | 69.4 | 9.1 | .656 | | | | |
| | | 3.2 | 95.4 | 3.8 | .796 | | | | |
| 2.16 | | 2.3 | 43.6 | 1.3 | .419 | | | | |
| | | 2.6 | 56.1 | 3.4 | .530 | .478 | 2.46 | 1.70 | 1.019 |
| | | 2.9 | 67.8 | 5.7 | .656 | | | | |
| 2.38 | | 2.3 | 42.0 | 0.9 | .419 | | | | |
| | | 2.6 | 55.9 | 2.2 | .530 | .490 | 2.49 | 1.52 | 1.342 |
| | | 2.9 | 67.3 | 2.3 | .656 | | | | |
| | | 3.2 | 94.1 | 1.9 | .796 | | | | |
| 2.76 | | 2.3 | 38.0 | 0.6 | .419 | | | | |
| | | 2.6 | 53.5 | 1.0 | .530 | | | | |
| | | 2.9 | 61.2 | 1.4 | .656 | .519 | 2.56 | 1.52 | 1.269 |
| | | 3.2 | 88.3 | 1.8 | .796 | | | | |

TABLE B-11. CONCENTRATOR DATA FOR SERIES D TESTS

$L = L_R = 6.35$ cm

$W = .254$ cm

$T = .305$ cm

$T/W = 1.20$

$d = .391$ cm

$d/W = 1.54$

$W_R = .381$ cm

$W_R/W = 1.50$

$T_R = .254$ cm

$d_R = .594$

$d_R/d = 1.52$ cm

TABLE B-12. TEST SERIES D

W = .254 cm

| S/W | V (Cm/sec) | $D_p$ (μm) | Percent of aerosol Conc | Conc loss | ψ | ψ @50% | 50% Cut | $\sigma_g$ of ψ | Slope |
|---|---|---|---|---|---|---|---|---|---|
| 0.62 | 4900 | 2.1 | 30.0 | 0.3 | .350 | | | | |
| | | 2.3 | 41.0 | 1.7 | .419 | | | | |
| | | 2.6 | 51.3 | 1.6 | .531 | .508 | 2.54 | 1.50 | 1.350 |
| | | 2.9 | 60.7 | 2.0 | .656 | | | | |
| | | 3.2 | 95.4 | 1.9 | .796 | | | | |
| 0.80 | | 2.1 | 31.7 | 0.4 | .350 | | | | |
| | | 2.3 | 38.3 | 0.7 | .419 | | | | |
| | | 2.6 | 52.3 | 0.8 | .531 | .504 | 2.53 | 1.49 | 1.378 |
| | | 2.9 | 64.2 | 1.9 | .656 | | | | |
| | | 3.2 | 95.4 | 1.8 | .796 | | | | |
| 1.02 | | 2.1 | 30.5 | 0.2 | .350 | | | | |
| | | 2.3 | 41.2 | 0.9 | .419 | | | | |
| | | 2.6 | 52.7 | 0.6 | .531 | .499 | 2.51 | 1.49 | 1.387 |
| | | 2.9 | 65.1 | 1.5 | .656 | | | | |
| | | 3.2 | 96.1 | 1.5 | .796 | | | | |
| *1.24 | | 2.1 | 30.5 | 0.3 | .350 | | | | |
| | | 2.3 | 42.3 | 0.7 | .419 | | | | |
| | | 2.6 | 53.5 | 1.4 | .531 | .497 | 2.51 | 1.51 | 1.340 |
| | | 2.9 | 64.8 | 1.5 | .656 | | | | |
| | | 3.2 | 94.4 | 1.8 | .796 | | | | |

*Unstable operation at this and higher values of S/W.

TABLE B-13. CONCENTRATOR DATA FOR SERIES E TESTS

$L = L_R = 6.35$ cm

$W = .254$ cm

$T =$ (See Table 14)

$S = .259$ cm

$S/W = 1.02$

$d = .391$ cm

$d/W = 1.54$

$W_R = .381$ cm

$W_R/W = 1.50$

$T_R = .254$ cm

$d_R = .594$ cm

$d_R/d = 1.52$

TABLE B-14. TEST SERIES E

W = .254 cm

| T/W | V (Cm/sec) | $D_p$ (μm) | Percent of aerosol: Conc | Percent of aerosol: Conc loss | ψ | ψ @50% | 50% Cut | $\sigma_g$ of ψ | Slope |
|---|---|---|---|---|---|---|---|---|---|
| 1.00 | 4900 | 2.3 | 49.2 | 1.2 | .419 | | | | |
| | | 2.6 | 60.9 | 3.8 | .527 | .429 | 2.33 | 1.66 | 1.197 |
| | | 2.9 | 77.5 | 3.3 | .656 | | | | |
| 1.20 | | 2.3 | 37.2 | 0.6 | .419 | | | | |
| | | 2.6 | 60.6 | 4.3 | .527 | .492 | 2.50 | 1.53 | 1.294 |
| | | 2.9 | 68.4 | 4.8 | .656 | | | | |
| 1.50 | | 2.3 | 42.7 | 0.7 | .419 | | | | |
| | | 2.6 | 63.4 | 2.6 | .527 | .457 | 2.41 | 1.48 | 1.556 |
| | | 2.9 | 79.8 | 2.6 | .656 | | | | |
| *2.00 | | 2.3 | 47.6 | 1.2 | .419 | | | | |
| | | 2.6 | 62.0 | 3.6 | .527 | .433 | 2.34 | 1.69 | 1.134 |
| | | 2.9 | 74.6 | 4.1 | .656 | | | | |

*Unstable operation

TABLE B-15 AIR FLOW CALIBRATION OF THREE NOZZLES

| Nozzle width (cm) | Nozzle area ($cm^2$) | Pressure drop (cm water) | Air flow rate (l/min) | Nozzle velocity (cm/sec) |
|---|---|---|---|---|
| .254 | 1.754 | 6.2 | 302 | 2870 |
| | | 7.9 | 341 | 3240 |
| | | 11.4 | 401 | 3810 |
| | | 15.0 | 466 | 4430 |
| | | 19.0 | 517 | 4910 |
| .317 | 2.235 | 7.0 | 408 | 3040 |
| | | 10.2 | 493 | 3680 |
| | | 17.5 | 634 | 4730 |
| | | 25.4 | 776 | 5790 |
| .381 | 2.747 | 9.5 | 565 | 3430 |
| | | 15.2 | 715 | 4340 |
| | | 21.3 | 834 | 5060 |
| | | 25.9 | 927 | 5630 |
| | | 33.3 | 1029 | 6250 |

TABLE B-16 $\sigma_g$ VARIANCE ANALYSIS A

| Column | Row | Group |
|---|---|---|
| $(W_R/W)_1$ = 1.00 | $V_1$ = 2600 cm/sec | $W_1$ = 0.198 cm |
| $(W_R/W)_2$ = 1.20 | $V_2$ = 3500 cm/sec | $W_2$ = 0.254 cm |
| $(W_R/W)_3$ = 1.50 | $V_3$ = 4900 cm/sec | |

| | $(W_R/W)_1$ | | $(W_R/W)_2$ | | $(W_R/W)_3$ | | |
|---|---|---|---|---|---|---|---|
| | $W_1$ | $W_2$ | $W_1$ | $W_2$ | $W_1$ | $W_2$ | Total |
| $V_1$ | 1.97 | 1.74 | 1.72 | 1.87 | 1.71 | 1.46 | 10.47 |
| $V_2$ | 1.88 | 1.77 | 1.84 | 2.02 | 1.80 | 1.93 | 11.24 |
| $V_3$ | 1.92 | 1.71 | 1.83 | 1.83 | 1.66 | 1.80 | 10.75 |
| Total | 5.77 | 5.22 | 5.39 | 5.72 | 5.17 | 5.19 | 32.46 |

| Source | SS | DF | MS | VR | $F_{0.95}$ |
|---|---|---|---|---|---|
| $W_R/W$ | .04 | 2 | .020 | 4.00 | 6.94 |
| V | .05 | 2 | .025 | 5.00 | 6.94 |
| W | .00 | 1 | .00 | .00 | 7.71 |
| $W_R/W$, V | .06 | 4 | .015 | 3.00 | 6.39 |
| $W_R/W$, W | .03 | 2 | .015 | 3.00 | 6.94 |
| V, W | .08 | 2 | .040 | 8.00 | 6.94 |
| $W_R/W$, V, W | .02 | 4 | .005 | | |

Combination of V, W are significant at the 95% level.

TABLE B-17 $\sigma_g$ VARIANCE ANALYSIS B

| Column | Row | Group |
|---|---|---|
| $(W_R/W)_1$ = 1.00 | $W_1$ = .381 cm | $V_1$ = 3500 cm/sec |
| $(W_R/W)_2$ = 1.20 | $W_2$ = .254 cm | $V_2$ = 4900 cm/sec |
| $(W_R/W)_3$ = 1.50 | $W_3$ = .198 cm | |

| | $(W_R/W)_1$ | | $(W_R/W)_2$ | | $(W_R/W)_3$ | | |
|---|---|---|---|---|---|---|---|
| | $V_1$ | $V_2$ | $V_1$ | $V_2$ | $V_1$ | $V_2$ | Total |
| $W_1$ | 1.83 | 2.05 | 1.86 | 2.01 | 1.82 | 2.40 | 11.97 |
| $W_2$ | 1.77 | 1.71 | 2.02 | 1.83 | 1.93 | 1.80 | 11.06 |
| $W_3$ | 1.88 | 1.92 | 1.84 | 1.83 | 1.80 | 1.66 | 10.93 |
| Total | 5.48 | 5.68 | 5.72 | 5.67 | 5.55 | 5.86 | 33.96 |

| Source | SS | DF | MS | VR | $F_{0.95}$ | $F_{0.99}$ |
|---|---|---|---|---|---|---|
| $W_R/W$ | .01 | 2 | .005 | .28 | 6.94 | 18 |
| V | .01 | 1 | .010 | .56 | 7.71 | [illegible] |
| W | .11 | 2 | .055 | 3.06 | 6.94 | 18 |
| $W_R/W$, V | .01 | 2 | .005 | .28 | 6.94 | 18 |
| $W_R/W$, W | .09 | 4 | .023 | 1.28 | 6.39 | [illegible] |
| V, W | .16 | 2 | .080 | 4.44 | 6.94 | 18 |
| $W_R/W$, V, W | .07 | 4 | .018 | | | |

Nothing Significant

TABLE B-18 $\sigma_g$ VARIANCE ANALYSIS C

| Column | Row | Group |
|---|---|---|
| $(W_R/W)_1$ = 1.50 | $W_1$ = .254 cm | $V_1$ = 3500 cm/sec |
| $(W_R/W)_2$ = 1.75 | $W_2$ = .317 cm | $V_2$ = 4900 cm/sec |
| $(W_R/W)_3$ = 2.00 | $W_3$ = .381 cm | $V_3$ 6000 cm/sec |

| | $(W_R/W)_1$ | | | $(W_R/W)_2$ | | | $(W_R/W)_3$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $V_1$ | $V_2$ | $V_3$ | $V_1$ | $V_2$ | $V_3$ | $V_1$ | $V_2$ | $V_3$ | TOTAL |
| $W_1$ | 1.93 | 1.80 | 1.43 | 1.49 | 1.75 | 1.53 | 1.44 | 1.53 | 1.60 | 14.50 |
| $W_2$ | 1.47 | 1.33 | 1.65 | 1.46 | 1.47 | 1.71 | 1.58 | 1.44 | 1.76 | 13.87 |
| $W_3$ | 1.82 | 2.40 | 1.93 | 1.47 | 1.46 | 1.73 | 1.62 | 1.49 | 1.53 | 15.45 |
| Total | 5.22 | 5.53 | 5.01 | 4.42 | 4.68 | 4.97 | 4.64 | 4.46 | 4.89 | 43.82 |

| Source | SS | DF | MS | VR | $F_{0.95}$ |
|---|---|---|---|---|---|
| $W_R/W$ | .22 | 2 | .110 | 3.52 | 4.46 |
| V | .02 | 2 | .010 | .32 | 4.46 |
| W | .14 | 2 | .070 | 2.24 | 4.46 |
| $W_R/W$, V | .11 | 4 | .028 | .90 | 3.84 |
| $W_R/W$, W | .36 | 4 | .080 | 2.56 | 3.84 |
| V, W | .19 | 4 | .048 | 1.54 | 3.84 |
| $W_R/W$, V, W | .25 | 8 | .031 | | |

Nothing Significant

TABLE B-19 $\sigma_9$ VARIANCE ANALYSIS D

| Column | Row |
|---|---|
| $(W_R/W)_1$ = 1.00 | $V_1$ = 3500 cm/sec |
| $(W_R/W)_2$ = 1.20 | $V_2$ = 4900 cm/sec |
| $(W_R/W)_3$ = 1.50 | |
| $(W_R/W)_4$ = 1.75 | |
| $(W_R/W)_5$ = 2.00 | (W = .254 cm) |
| $(W_R/W)_6$ = 2.50 | |

| | $(W_R/W)_1$ | $(W_R/W)_2$ | $(W_R/W)_3$ | $(W_R/W)_4$ | $(W_R/W)_5$ | $(W_R/W)_6$ | TOTAL |
|---|---|---|---|---|---|---|---|
| $V_1$ | 1.77 | 2.02 | 1.93 | 1.49 | 1.44 | 2.24 | 10.89 |
| $V_2$ | 1.71 | 1.83 | 1.80 | 1.75 | 1.53 | 2.04 | 10.66 |
| Total | 3.48 | 3.85 | 3.73 | 3.24 | 2.97 | 4.28 | 21.55 |

| Source | SS | DF | MS | VR | $F_{0.95}$ | $F_{0.99}$ |
|---|---|---|---|---|---|---|
| $W_R/W$ | .54 | 5 | .108 | 10.00 | 5.05 | 11.0 |
| V | .00 | 1 | .000 | .00 | 6.61 | 16.3 |
| $W_R/W$, V | .09 | 5 | .0108 | | | |

$W_R/W$ is significant at the 95% level.

TABLE B-20 $\sigma_\theta$ VARIANCE ANALYSIS E

| Column | Row |
|---|---|
| $(W_R/W)_1$ = 1.50 | $V_1$ = 3500 cm/sec |
| $(W_R/W)_2$ = 1.75 | $V_2$ = 4900 cm/sec |
| $(W_R/W)_3$ = 2.00 | $V_3$ = 6000 cm/sec |
| $(W_R/W)_4$ = 2.50 | |
| | (W = .254 cm) |

| | $(W_R/W)_1$ | $(W_R/W)_2$ | $(W_R/W)_3$ | $(W_R/W)_4$ | Total |
|---|---|---|---|---|---|
| $V_1$ | 1.93 | 1.49 | 1.44 | 2.24 | 7.10 |
| $V_2$ | 1.80 | 1.75 | 1.53 | 2.04 | 7.12 |
| $V_3$ | 1.43 | 1.53 | 1.60 | 2.25 | 6.81 |
| Total | 5.16 | 4.77 | 4.57 | 6.53 | 21.03 |

| Source | SS | DF | MS | VR | $F_{0.95}$ | $F_{0.99}$ |
|---|---|---|---|---|---|---|
| $W_R/W$ | .78 | 3 | .260 | 7.8 | 4.76 | 9.78 |
| V | .01 | 2 | .005 | .150 | | |
| $W_R/W$, V | .20 | 6 | .033 | | | |

$W_R/W$ is significant at the 95% level.

TABLE B-21. MEAN CONCENTRATION LOSS VARIANCE ANALYSIS

| Column | Row | Group |
|---|---|---|
| $(W_R/W)_1$ = 1.50 | $W_1$ = .254 cm | $V_1$ = 3500 cm/sec |
| $(W_R/W)_2$ = 1.75 | $W_2$ = .317 cm | $V_2$ = 4900 cm/sec |
| $(W_R/W)_3$ = 2.00 | $W_3$ = .381 cm | $V_3$ = 6000 cm/sec |

| | $(W_R/W)_1$ | | | $(W_R/W)_2$ | | | $(W_R/W)_3$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $V_1$ | $V_2$ | $V_3$ | $V_1$ | $V_2$ | $V_3$ | $V_1$ | $V_2$ | $V_3$ | Total |
| $W_1$ | 6.2 | 2.0 | 0.6 | 1.0 | 0.9 | 0.9 | 1.2 | 0.5 | 0.3 | 13.6 |
| $W_2$ | 1.3 | 2.1 | 4.4 | 0.9 | 1.1 | 0.7 | 0.3 | 0.3 | 0.1 | 11.2 |
| $W_3$ | 2.2 | 3.6 | 1.4 | 1.2 | 1.1 | 0.5 | 0.3 | 0.3 | 0.3 | 10.9 |
| Total | 9.7 | 7.7 | 6.4 | 3.1 | 3.1 | 2.1 | 1.8 | 1.1 | 0.7 | 35.7 |

| Source | SS | DF | MS | VR | $F_{0.95}$ | $F_{0.99}$ |
|---|---|---|---|---|---|---|
| $W_R/W$ | 24.83 | 2 | 12.42 | 6.90 | 4.46 | 8.65 |
| W | 0.49 | 2 | 0.25 | 0.14 | 4.46 | 8.65 |
| V | 1.62 | 2 | 0.81 | 0.45 | 4.46 | 8.65 |
| $W_R/W$, W | 0.27 | 4 | 0.07 | 0.04 | 3.84 | 7.01 |
| W,V | 8.83 | 4 | 2.21 | 1.23 | 3.84 | 7.01 |
| $W_R/W$,V | 0.65 | 4 | 0.16 | 0.09 | 3.84 | 7.01 |
| $W_R/W$,W,V | 14.40 | 8 | 1.80 | | | |

$W_R/W$ is significant at the 95% level.

TABLE B-22. CONCENTRATOR DATA FOR SERIES G TESTS

$L = L_R = 6.35$ cm
$W = .254$ cm
$d = .391$ cm
$T = .381$ cm
$W_R = .508$ cm
$d_R = .704$ cm
$T_R = .254$ cm
$S = .259$ cm

TABLE B-23. SERIES G TESTS

| Nozzle velocity (cm/sec) | Aerosol diameter (μm) | Percent of aerosol: Conc | Percent of aerosol: Conc loss | ψ | ψ at 50% | 50% cut (μm) | $\sigma_g$ of ψ | Slope |
|---|---|---|---|---|---|---|---|---|
| 5300 | 2.0 | 36.1 | 0.3 | .346 | | | | |
| | 2.0 | 38.4 | 0.3 | .346 | | | | |
| | 2.3 | 42.3 | 0.3 | .453 | | | | |
| | 2.3 | 44.6 | 0.2 | .453 | | | | |
| | 2.6 | 59.8 | 0.9 | .575 | .497 | 2.41 | 1.74 | .920 |
| | 2.6 | 58.6 | 0.7 | .575 | | | | |
| | 2.9 | 66.2 | 0.7 | .711 | | | | |
| | 2.9 | 71.0 | 0.7 | .711 | | | | |
| | 3.2 | 83.4 | 0.6 | .861 | | | | |
| | 3.2 | 84.3 | 0.7 | .861 | | | | |
| | 3.8 | 87.5 | 0.6 | 1.206 | | | | |
| | 4.5 | 90.9 | 0.3 | 1.680 | | | | |
| | 6.4 | 94.9 | 0.4 | 3.345 | | | | |
| 5000 | 2.0 | 31.3 | 0.1 | .327 | | | | |
| | 2.0 | 33.1 | 0.1 | .327 | | | | |
| | 2.3 | 42.5 | 0.1 | .428 | | | | |
| | 2.3 | 38.6 | 0.1 | .428 | | | | |
| | 2.6 | 53.6 | 0.3 | .542 | .506 | 2.50 | 1.62 | 1.080 |
| | 2.6 | 52.9 | 0.4 | .542 | | | | |
| | 2.9 | 67.9 | 0.8 | .671 | | | | |
| | 2.9 | 64.5 | 0.6 | .671 | | | | |
| | 3.2 | 85.1 | 0.7 | .812 | | | | |
| | 3.2 | 84.1 | 0.5 | .812 | | | | |

TABLE B-24. DATA ON FINAL DESIGN OF FIRST STAGE NOZZLES

$L = L_R$ = 4.566" = 11.60 cm
$W$ = .100" = .254 cm
$T$ = .150" = .381 cm
$T/W$ = 1.50
$d$ = .154" = .391 cm
$d/W$ = .154
$S$ = .100" = .254 cm
$S/W$ = 1.00
$W_R$ = .200" = .508 cm
$W_R/W$ = 2.00
$T_R$ = .100" = .254 cm
$d_R$ = .277" = .704 cm
$d_R/W$ = 2.77

Area of inlet nozzle = 3.087 $cm^2$
Velocity through inlet nozzles = 5400 cm/sec

TABLE B-25. DATA ON FINAL DESIGN OF SECOND STAGE NOZZLES

| | |
|---|---|
| $L$ | $= L_R = .486" = 1.23$ cm |
| $W$ | $= .078" = .198$ cm |
| $T$ | $= .063" = .160$ cm |
| $T/W$ | $= 0.81$ |
| $d$ | $= .125" = .317$ cm |
| $d/W$ | $= 1.60$ |
| $S$ | $= .082" = .208$ cm |
| $S/W$ | $= 1.05$ |
| $W_R$ | $= .157" = .399$ cm |
| $W_R/W$ | $= 2.01$ |
| $T_R$ | $= .077" = .196$ cm |
| $d_R$ | $= .213" = .541$ cm |
| $d_R/W$ | $= 2.73$ |

Area of inlet nozzle = .339 $cm^2$

*Velocity through inlet nozzle = 6100 cm/sec

*Estimated, since the exact flow rate has not been determined.

TABLE B-26. TEST RESULTS - FINAL DESIGN CONCENTRATOR

| Concentrator number | Aerosol diameter (μm) | % of aerosol: Conc | % of aerosol: Conc loss | $\psi$ | $\psi$ at 50% | 50% cut (μm) | $\sigma_g$ | Slope |
|---|---|---|---|---|---|---|---|---|
| 1 | 2.3 | 39.0 | 2.2 | .451 | | | | |
| | 2.3 | 43.6 | 2.7 | .451 | | | | |
| | 2.6 | 57.2 | 4.4 | .577 | .533 | 2.47 | 1.73 | .868 |
| | 2.6 | 54.8 | 4.6 | .577 | | | | |
| | 3.3 | 84.9 | 3.8 | .929 | | | | |
| | 3.3 | 82.7 | 3.7 | .929 | | | | |
| | 4.5 | 87.7 | 2.6 | | | | | |
| | 6.4 | 68.5 | 10.3 | | | | | |
| | 9.0 | 36.9 | 12.4 | | | | | |
| 2 | NOT TESTED | | | | | | | |
| 3 | 2.3 | 32.0 | 3.6 | .451 | | | | |
| | 2.3 | 34.4 | 2.5 | .451 | | | | |
| | 2.6 | 47.9 | 3.6 | .577 | .641 | 2.71 | 1.65 | .811 |
| | 2.6 | 45.4 | 4.6 | .577 | | | | |
| | 3.3 | 76.0 | 5.2 | .929 | | | | |
| | 3.3 | 69.7 | 7.0 | .929 | | | | |
| | 4.5 | 82.8 | 4.6 | | | | | |
| | 6.4 | 56.8 | 18.8 | | | | | |
| | 9.0 | 22.0 | 24.1 | | | | | |
| 4 | 2.3 | 41.6 | 3.0 | .451 | | | | |
| | 2.3 | 38.0 | 2.2 | .451 | | | | |
| | 2.6 | 47.7 | 5.4 | .577 | .603 | 2.63 | 1.75 | .754 |
| | 2.6 | 44.8 | 3.9 | .577 | | | | |
| | 3.3 | 74.9 | 6.4 | .929 | | | | |
| | 3.3 | 75.1 | 6.1 | .929 | | | | |
| | 4.5 | 85.7 | 5.1 | | | | | |
| | 6.4 | 68.5 | 15.0 | | | | | |
| | 9.0 | 26.0 | 23.7 | | | | | |

DISTRIBUTION LIST

| ADDRESSEES | COPIES |
|---|---|
| COMMANDER/DIRECTOR<br>CHEMICAL SYSTEMS LABORATORY | |
| Safety Office | |
| Attn: DRDAR-CLF | 1 |
| Planning & Technology Office | |
| Attn: DRDAR-CLR-L | 4 |
| Attn: DRDAR-CLR-T | 1 |
| CB Detection & Alarms Division | |
| Attn: DRDAR-CLC-B | 2 |
| Attn: DRDAR-CLC-E | 1 |
| Research Division | |
| Attn: DRDAR-CLB | 1 |
| Attn: DRDAR-CLB-D | 1 |
| Systems Assessment Office | |
| Attn: DRDAR-CLY-R | 1 |
| ABERDEEN PROVING GROUND, MD 21010 | |
| DEPARTMENT OF THE ARMY | |
| US Army Research and Standardization Group (Europe) | |
| Attn: Chief, Chemistry Branch | 1 |
| Box 65<br>FPO New York 09510 | |
| US ARMY MATERIEL DEVELOPMENT AND READINESS COMMAND | |
| Commander<br>US Army Materiel Development and Readiness Command | |
| Attn: DRCLDC | 1 |
| 5001 Eisenhower Avenue<br>Alexandria, VA 22333 | |

| ADDRESSEES | COPIES |
|---|---|
| **US ARMY MATERIEL DEVELOPMENT AND READINESS COMMAND** (cont'd) | |
| Chief, Human Engineering Laboratory<br>Attn: DRXHE-EA<br>Aberdeen Proving Ground, MD 21010 | 1 |
| Commander<br>US Army Foreign Science & Technology Center<br>Attn: DRXST-CXZ<br>220 Seventh Street, NE<br>Charlottesville, VA 22901 | 1 |
| **US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND** | |
| Commander<br>US Army Armament Research and Development Command<br>Attn: DRDAR-AC<br>Attn: DRDAR-TSS<br>Dover, NJ 07801 | 1<br>2 |
| **US ARMY ARMAMENT MATERIEL READINESS COMMAND** | |
| Cdr, APG<br>USA ARRCOM<br>Attn: DRSAR-MAS-C<br>Aberdeen Proving Ground, MD 21010 | 1 |
| **US ARMY TRAINING & DOCTRINE COMMAND** | |
| Commandant<br>US Army Ordnance & Chemical Center & School<br>Attn: ATSL-CL-CD<br>Aberdeen Proving Ground, MD 21005 | 1 |
| **US ARMY TEST AND EVALUATION COMMAND** | |
| Commander<br>US Army Test and Evaluation Command<br>Attn: DRSTE-FA<br>Aberdeen Proving Ground, MD 21005 | 1 |
| **DEPARTMENT OF THE NAVY** | |
| Chief of Naval Research<br>Attn: Code 443<br>800 N. Quincy Street<br>Arlington, VA 22217 | 1 |

| ADDRESSEES | COPIES |
|---|---|
| **DEPARTMENT OF THE AIR FORCE** | |
| Air University Library<br>Attn: AUL/LSE-8879<br>Maxwell AFB, AL 36112 | 1 |
| **OUTSIDE AGENCIES** | |
| Batelle Columbus Laboratories<br>Attn: TACTEC<br>505 King Avenue<br>Columbus, OH 43201 | 1 |
| **ADDITIONAL ADDRESSEES** | |
| US Public Health Service<br>Center for Disease Control<br>Attn: Lewis Webb, Jr.<br>Building 4, Room 232<br>Atlanta, GA 30333 | 1 |
| Administrator<br>Defense Documentation Center<br>Attn: Document Processing Division (DDC-DD)<br>Cameron Station<br>Alexandria, VA 22314 | 12 |
| Commanding Director, Chemical Systems Laboratory | |
| Attn: DRDAR-CLJ-L | 3 |
| Attn: DRDAR-CLJ-R | 2 |
| Aberdeen Proving Ground, MD 21010 | |