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DEVELOPMENT AND LABORATORY EVALUATION OF A FIVE-STAGE CYCLONE SYSTEM

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DEVELOPMENT AND LABORATORY EVALUATION OF A FIVE-STAGE CYCLONE SYSTEM

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ABSTRACT

This report describes the development and calibration of a Five-Stage Cyclone System designed and fabricated by Southern Research Institute under EPA Contract Number 68-02-2131. The cyclone system was calibrated using a vibrating orifice aerosol generator to generate monodisperse particles of dye of large diameter for use at ambient and higher temperatures, and a pressurized Collison nebulizer to disperse monodisperse latex particles of small diameter for use at ambient temperature. Results from calibrating the cyclones at several conditions of flow, temperature, and particle density suggest that the D_{50} cut points are proportional to the flow rate of the gas raised to a negative exponent which is between -0.63 and -1.11, linearly proportional to the viscosity of the gas, and proportional to the reciprocal of the square root of the particle density. At 25°C (77°F), 28.3 ℓ/min (1.0 ft^3/min) and for a particle density of 1.0 gm/cm^3, the D_{50} cut points of the cyclone system were 5.4 μm, 2.1 μm, 1.4 μm, 0.65 μm, and 0.32 μm for Cyclones I-V, respectively.

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ACKNOWLEDGMENT

The concept of the cyclone system was formed during discussions with Bruce Harris of EPA and Kenneth Cushing and J. D. McCain of Southern Research Institute. The mechanical design was done by David Hussey and part of the experimental data was taken by Don Johnson.

SECTION 1

INTRODUCTION

The majority of measurements to determine the particle-size distribution in process streams are made with cascade impactors. Impactors, however, have several limitations:

- There is not enough mass collected for chemical analysis of the particles in each size fraction.
- Frequently there is not enough mass collected on some stages to be weighed accurately.
- Particle bounce and reentrainment cause an unpredictable, but significant, error in the stage and backup filter catches.[1]
- When the mass concentration is high, the sampling time may be undesirably short.
- Impactors are used with lightweight collection substrates which are often unstable in mass when exposed to the process stream.[2]

A series of cyclones with progressively decreasing cut points will perform similarly to impactors, but without many of the associated problems.

Cyclones, however, also have limitations to their applicability:

- There is no general theory to describe the performance of small cyclones under field test conditions.
- Sampling times may be undesirably long at sources where the mass concentration is low.

An experimental study is described in this report that was undertaken to develop and evaluate a system containing five cyclones and a backup filter in series. The cyclones were calibrated, using monodisperse aerosols, over a range in temperature, flow rate, and particle density similar to that expected for field sampling. In addition to demonstrating the utility of cyclones for in-situ particle-size analysis, it is intended that the experimental data obtained will supplement that already avail able to serve as the basis for the development of a more accurate theory of cyclone performance.

Section 2 contains a brief summary of previous work related to this study. Section 3 describes the design and evaluation of the Environmental Protection Agency-Southern Research Institute cyclone system. Section 4 is a summary of the important experimental results and Section 5 contains shop drawings for the new system.

SECTION 2

BACKGROUND

Several theories have been suggested that attempt to predict cyclone behavior. Typically, the theories are based on the classical equation for centripetal force (mv^2/r) and include additional terms to describe effects such as viscosity drag and turbulent flow of the gas in the cyclone. The final equation usually gives the cyclone's collection efficiency in terms of the cyclone's dimensions and various parameters of the test aerosol. The dimensions of the cyclone are frequently expressed as ratios. For example, the height (h) of a cyclone, the inlet diameter (d_{in}), and the exit tube diameter (d_{ex}), might be expressed as fractions of the diameter of the cyclone body, D; h/D, d_{in}/D, and d_{ex}/D, respectively. Cyclone performance also depends upon the particle diameter, the particle density, the gas flowrate, and the gas viscosity.

Cyclone behavior may conveniently be expressed in terms of a "D_{50}" cut point, which is the diameter of the particle which is collected with 50 percent efficiency. The conventional theory of Lapple gives the cyclone D_{50} cut point as a square root function of several parameters:[3]

$$D_{50} = \sqrt{\frac{9\ H_c B_c{}^2 \mu}{2\pi N_e\ \rho\ Q}} \tag{1}$$

where D_{50} is the diameter of particles which will be collected with 50 percent efficiency,
N_e is the "effective" number of turns made by the gas stream in the cyclone,
Q is the flowrate of the gas through the cyclone,
B_c is the width of the cyclone inlet,
H_c is the height of the cyclone inlet,
ρ is the density of the particles, and
μ is the gas viscosity.

For most conditions of cyclone experimentation, the gas viscosity is solely a function of temperature and gas composition, so that Lapple's theory gives the D_{50} cut point in terms of easily measured variables: gas temperature, cyclone inlet dimensions, gas flowrate, and particle density. Unfortunately, because of the complicated flow patterns in cyclones, N_e is difficult to predict.

Leith and Licht[4] proposed a somewhat different, semiempirical, equation for cyclone D_{50}'s:

$$D_{50} = \left[\left(\frac{18DB_cH_c}{C(n+1)}\right)\left(\frac{\mu}{Q\rho}\right)\left(\ln\sqrt{2}\right)^{2n+2}\right]^{\frac{1}{2}} \tag{2}$$

where C is a cyclone geometry coefficient dependent on the cyclone's dimension ratios only,
D is the diameter of the cyclone body, and
n is a parameter that depends on the cyclone diameter and the gas temperature.

This equation includes the same $\sqrt{\mu/Q\rho}$ term as did Lapple's equation, but it also contains the variable n which is dependent on the gas temperature. Thus, as the gas temperature changes, the D_{50} will not be a simple square root function of the gas viscosity.

The theories of Lapple, and Leith and Licht provide a basis for comparison of recent experimental data. Other cyclone theories are discussed by Leith and Mehta[5] and by Chan and Lippmann.[6]

Previous experimental work by Smith, et al[7] on small cyclones has shown that small cyclones perform comparably to impactors. Figure 1 compares data from the study of Smith, et al,[7] with impactor calibration data reported by Cushing, et al.[8]

Work reported by Cushing, Felix, and Smith[9] on the calibration of the middle cyclone of the EPA Source Assessment Sampling System (SASS) included data taken at two particle densities and three values of gas viscosities. The cyclone is approximately four inches in diameter and ten inches in height, including the collection cup. Figure 2 shows collection efficiency versus particle diameter curves for particle densities of 1.35 gm/cm^3 and 2.04 gm/cm^3. These data support the hypothesis that a cyclone D_{50} is inversely proportional to the square root of the particle density. Figure 3 shows that the experimental relationship between D_{50} and gas viscosity (or temperature) is not a square root, but a linear relationship. An earlier calibration by Cushing et al [9] also indicated the D_{50} vs. flowrate relationship is not a square root relationship.

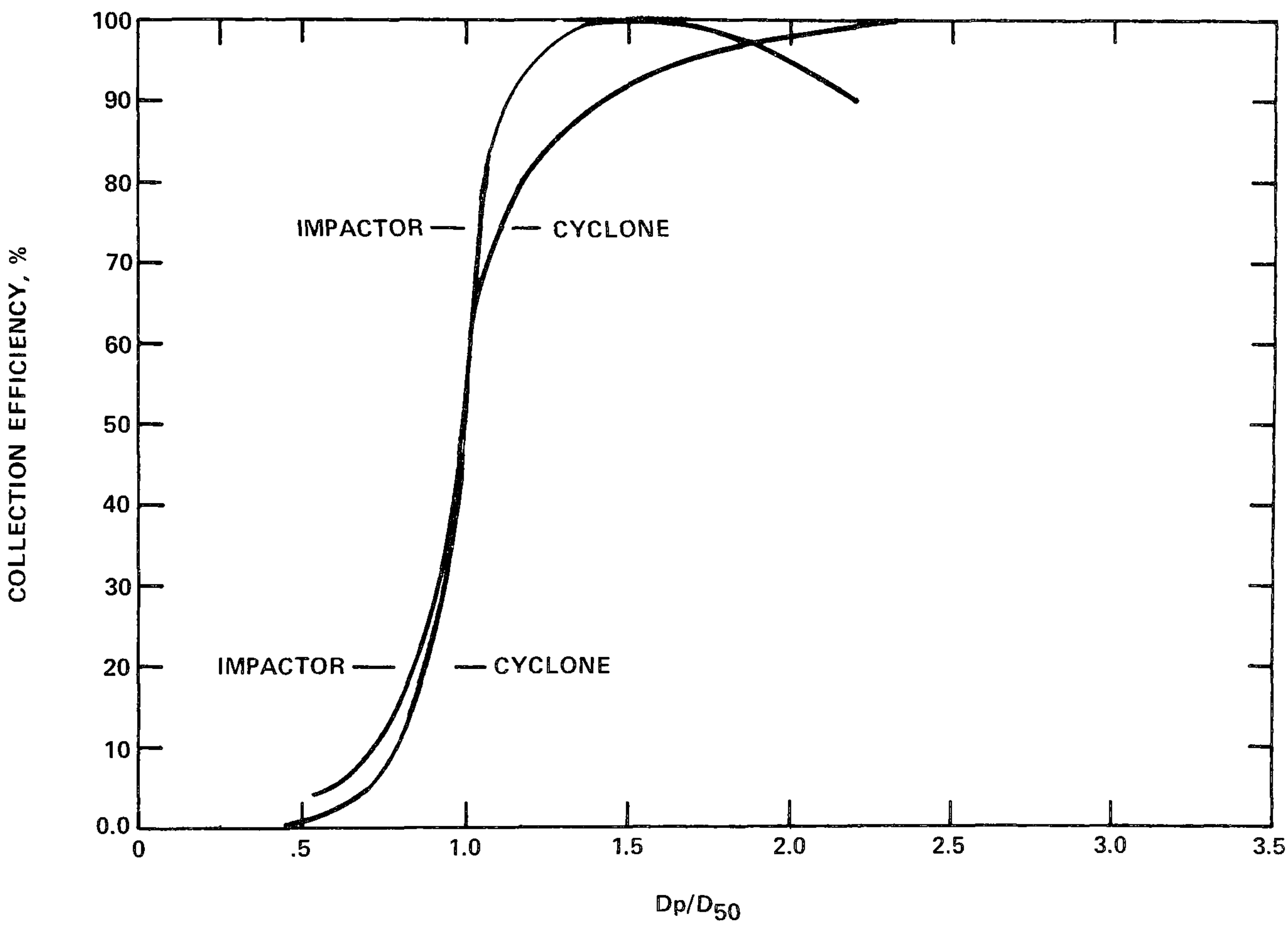

Figure 1. Comparison of cascade impactor stage with cyclone collection efficiency curve.

Cyclone: S.R.I. 1 Cyclone
28.3 ℓ/min, 22°C, 752 mm Hg
From Smith, et. al.[7]

Impactor: Modified Brink BMS-11 Cascade Impactor
Greased Collection Plate, Stage 4
Corrected for wall losses
0.85 ℓ/min, 22°C, 749 mm Hg
From Cushing, et. al.[8]

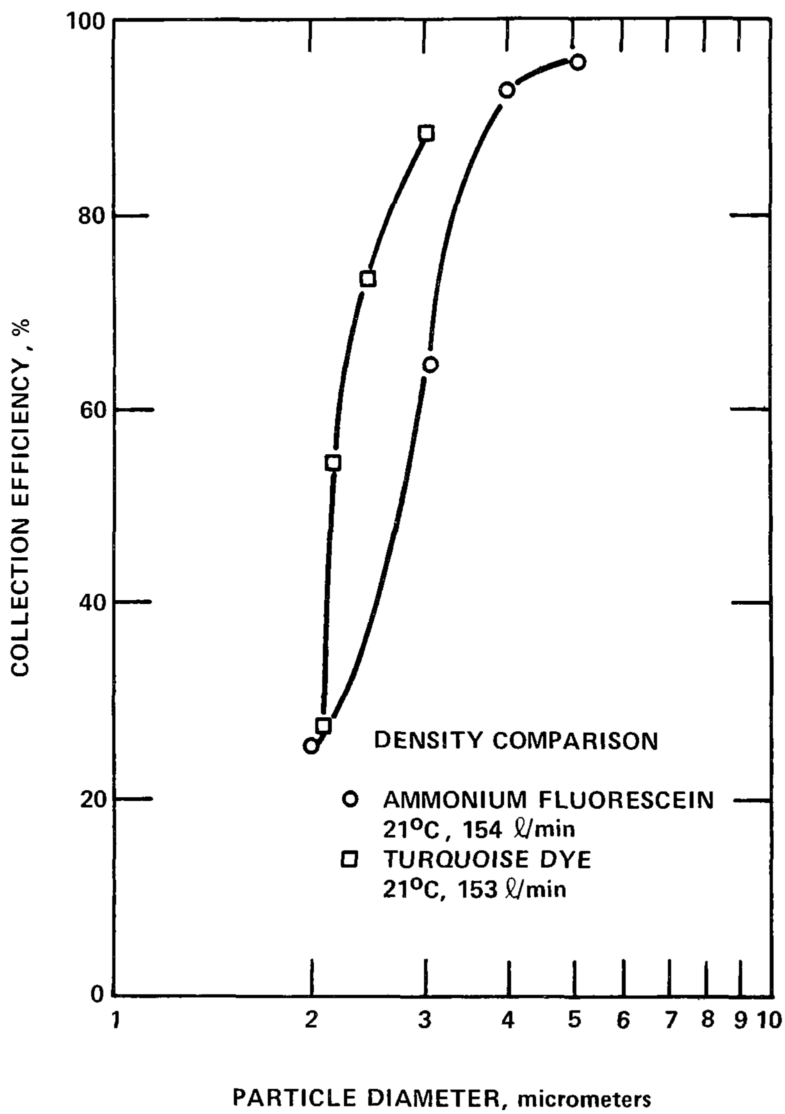

Figure 2. Collection efficiency-particle density relationship
SASS Middle Cyclone
Ammonium fluorescein particle density = 1.35 gm/cm^3
Turquoise dye particle density = 2.04 gm/cm^3
From Cushing, et. al.[9]

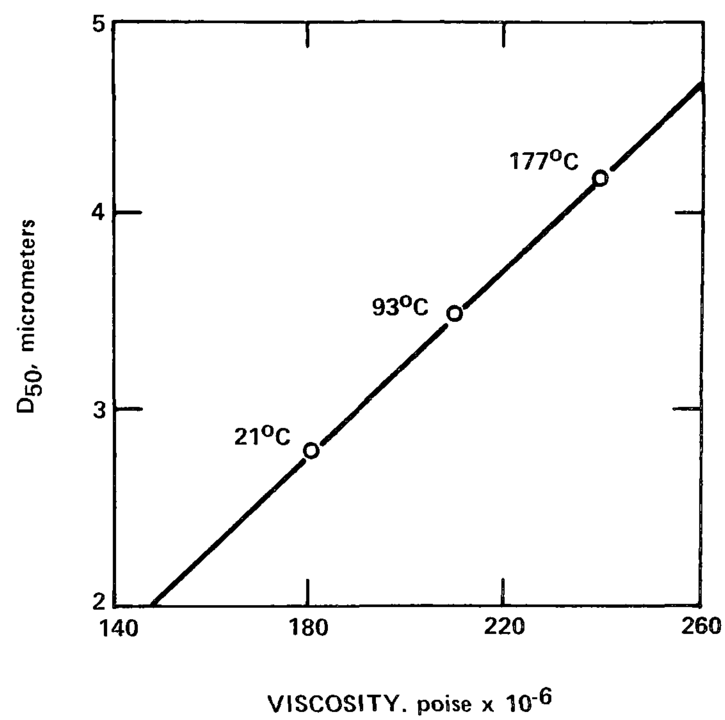

Figure 3. D_{50}-viscosity relationship
SASS Middle Cyclone
Ammonium fluorescein
Particle density = 1.35 gm/cm^3
From Cushing, et. al.[9]

Chan and Lippmann,[6] in their development of an empirical theory, also observed that the D_{50} of cyclones does not have an inverse square root dependence on the sample flowrate.

In fitting an equation of the form, $D_{50} = KQ^n$, to their experimental data, n was found to be between -0.636 and -2.13 for calibration data from several cyclones. Figure 4 is the data of Chan and Lippmann showing the experimental D_{50} vs. flowrate relationship for several cyclones. Notice that one set of data has two lines fitted to it, presumably due to an abrupt change in the gas flow pattern in the cyclone at higher flowrates. Figure 5 shows additional data from a study by Blachman and Lippmann that also suggests a discontinuity in the D_{50} vs. flowrate relationship.[10]

In summary, there does not yet seem to be a theory which can accurately predict small cyclone D_{50} cut points for varying aerosol flowrates and viscosities. Nevertheless, conventional theories, semi-empirical theory, and experimental data agree that the D_{50}'s of small cyclones are inversely proportional to the square root of the particle density. However, experimental data indicate that the D_{50}'s of small cyclones are not inversely proportional to the square root of the flowrate nor directly proportional to the square root of the gas viscosity, as some theories predict.

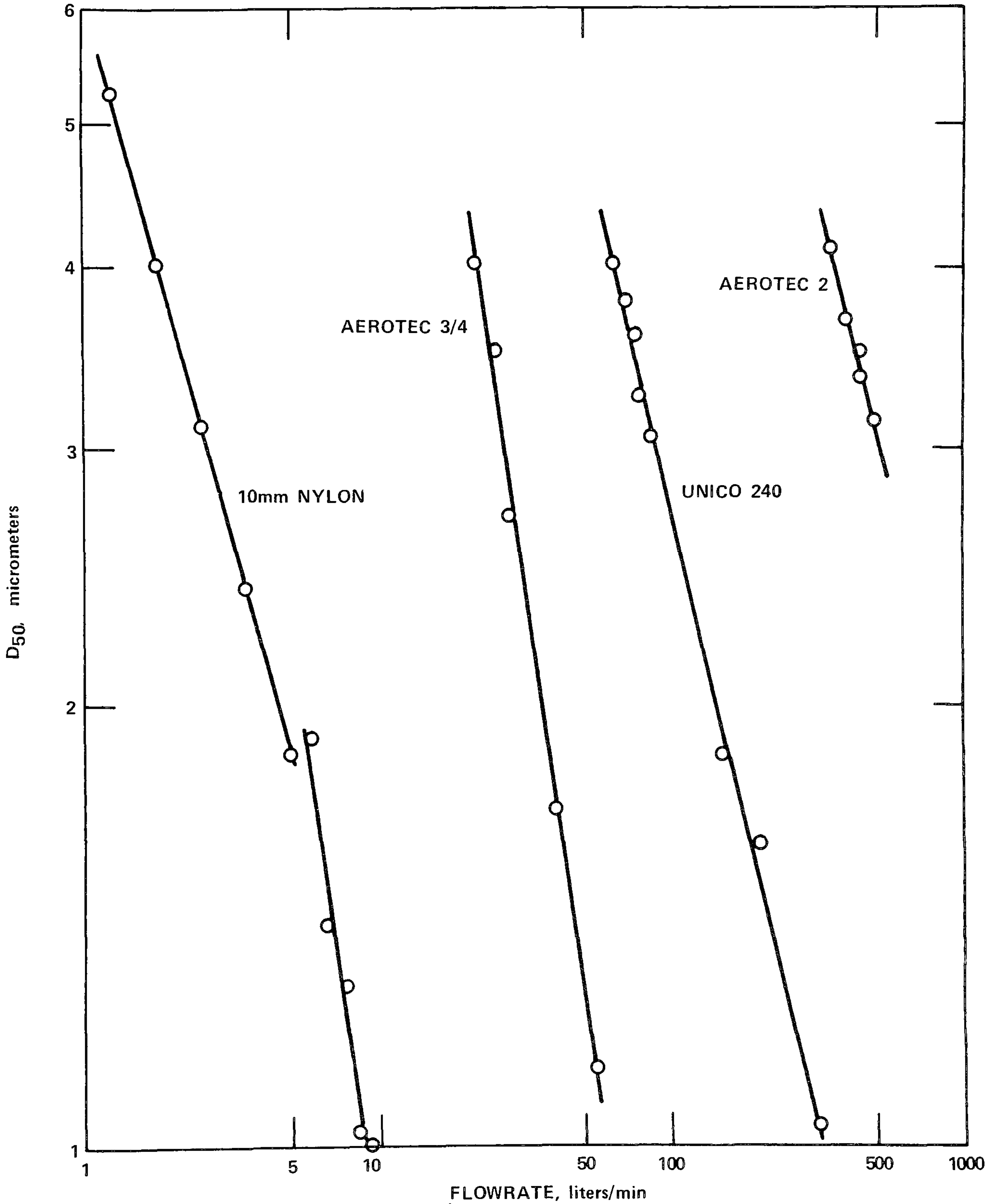

Figure 4. Dependence of particle cut size on flow rate for four cyclones. After Chan and Lippmann.[6]

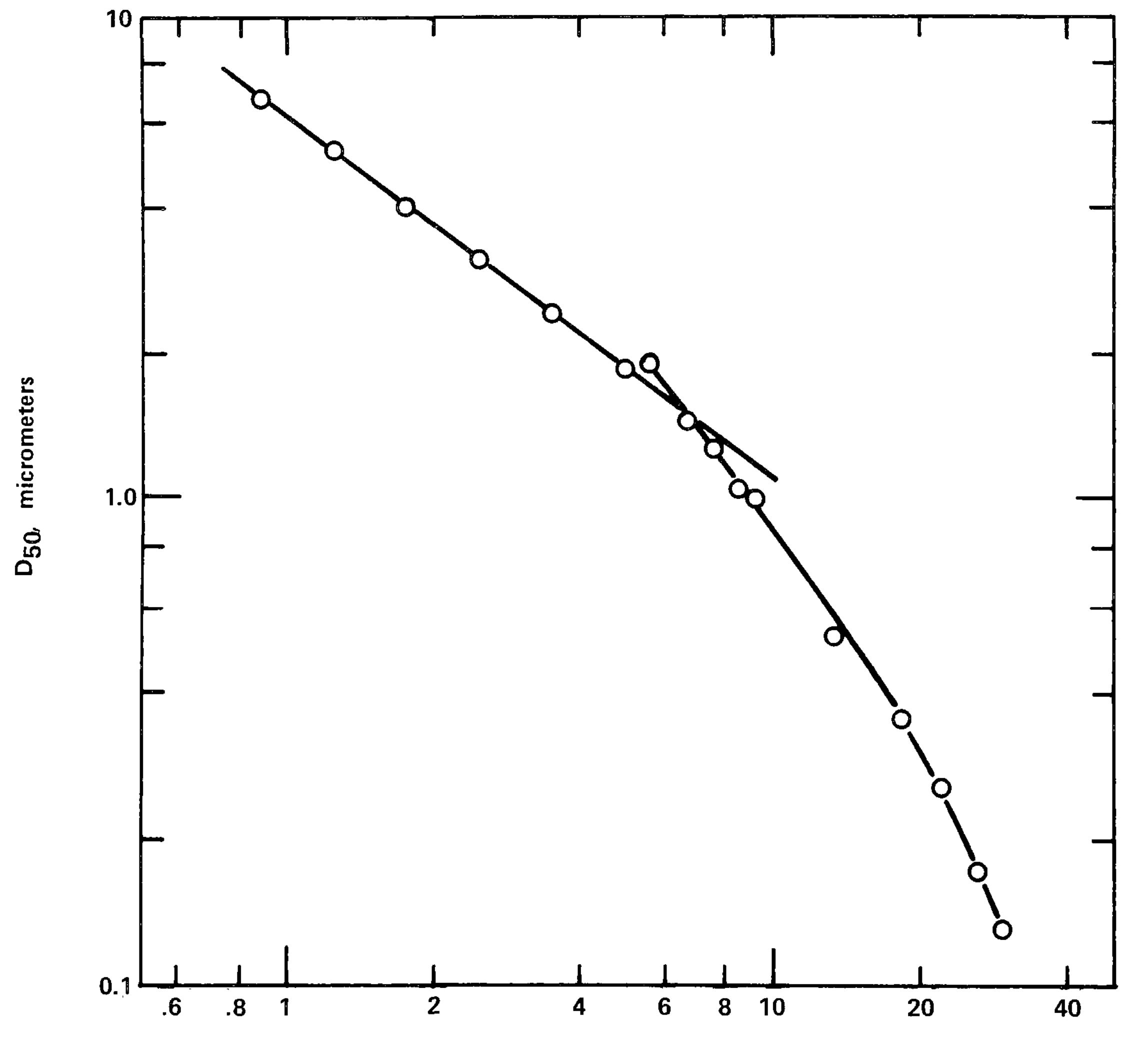

Figure 5. Dependence of particle cut size on flow rate for a 10 mm nylon cyclone. After Blachman and Lippmann.[11]

SECTION 3

TECHNICAL DISCUSSION

A. Cyclone Design

Figure 6 shows the EPA-Southern Research Institute cyclone system. One prototype system is made of aluminum, with silicone rubber o-rings, and a second prototype system is made of titanium, with metal o-rings. The system is designed to operate instack, at a sample flowrate of 28.3 ℓ/min, and is compact enough to fit through a 10 cm diameter port. The objective was to obtain five cut points equally spaced on a logarithmic scale within the range of 0.1-10 μm. Since there is no theory that is sufficiently accurate to serve as a basis for small cyclone design, the individual cyclones of the system were designed empirically. The dimensions were selected to be identical or related to those of cyclones that had been previously evaluated in our laboratories.[7] Lapple's equation was used to obtain extrapolated cyclone dimensions for cutpoints between those observed previously, and some redesign based upon trial and error was required to achieve the final designs.

The cyclones are numbered sequentially as I through V, starting with the largest. Cyclones II-V are of conventional design, as shown in Figure 7. Cyclone I is somewhat different, with the gas exit tube passing through the collection cup as shown in Figure 8.

B. Experimental Procedures

Two aerosol generator systems were used to calibrate the cyclones. A vibrating orifice aerosol generator was used to produce dye particles 1.2-8 μm in diameter. A Collison nebulizer system was employed to disperse latex spheres of 0.3-2.0 μm diameter.

The vibrating orifice aerosol generator (VOAG) is shown in Figure 9. This system is similar to that developed by Berglund and Liu[11] and has been described previously by Cushing _et al_.[8] The two types of dye particles were ammonium fluorescein (density 1.35 gm/cm^3) and du Pont Pontamine Fast Turquoise 8GLP dye (density 2.04 gm/cm^3). The VOAG system was used to calibrate Cyclones I, II, and III at flowrates of 14.2 and 28.3 ℓ/min (0.50 and 1.00 ft^3/min) and temperatures of 25

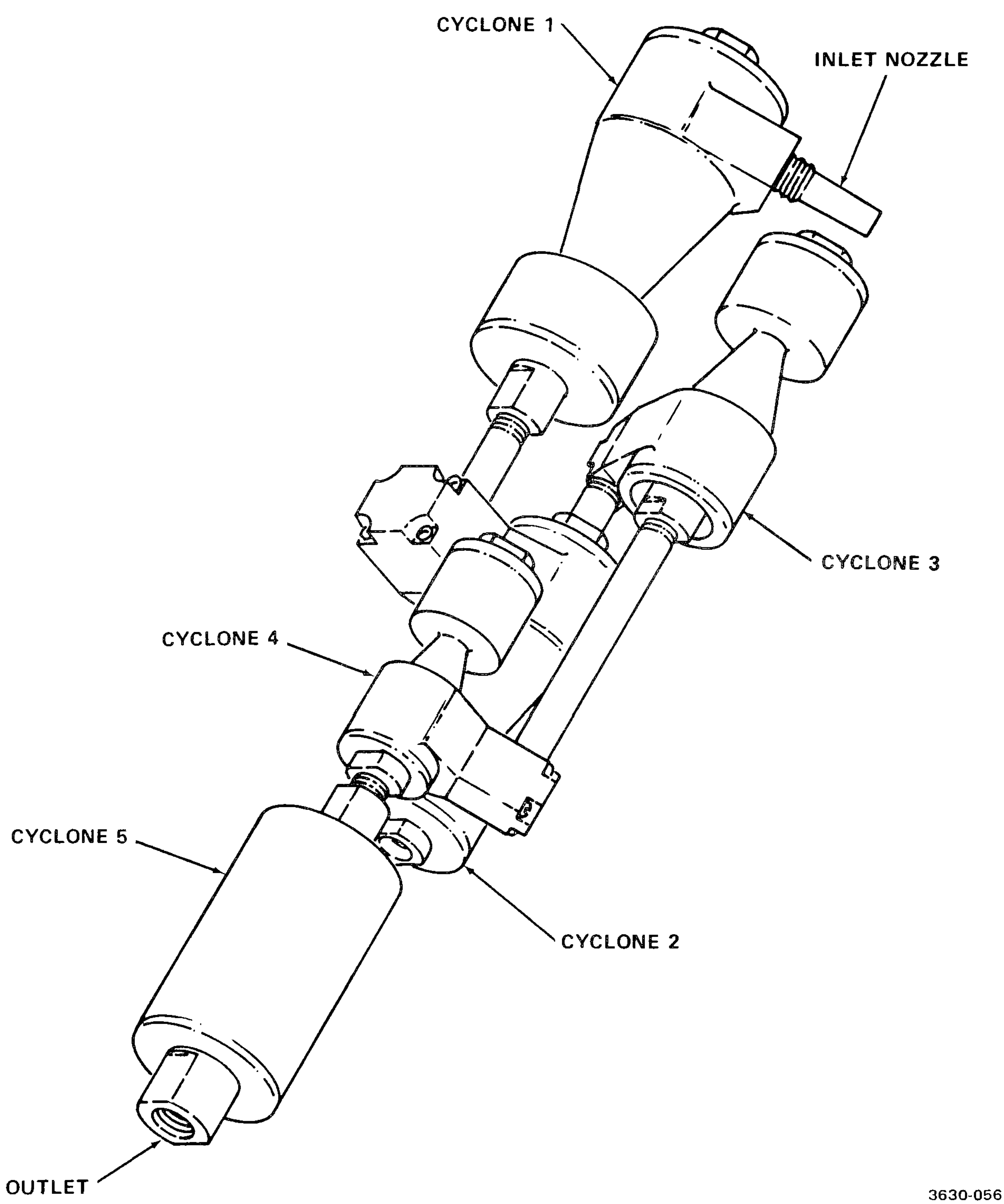

Figure 6. Environmental Protection Agency-Southern Research Institute Five-Stage Cyclone.

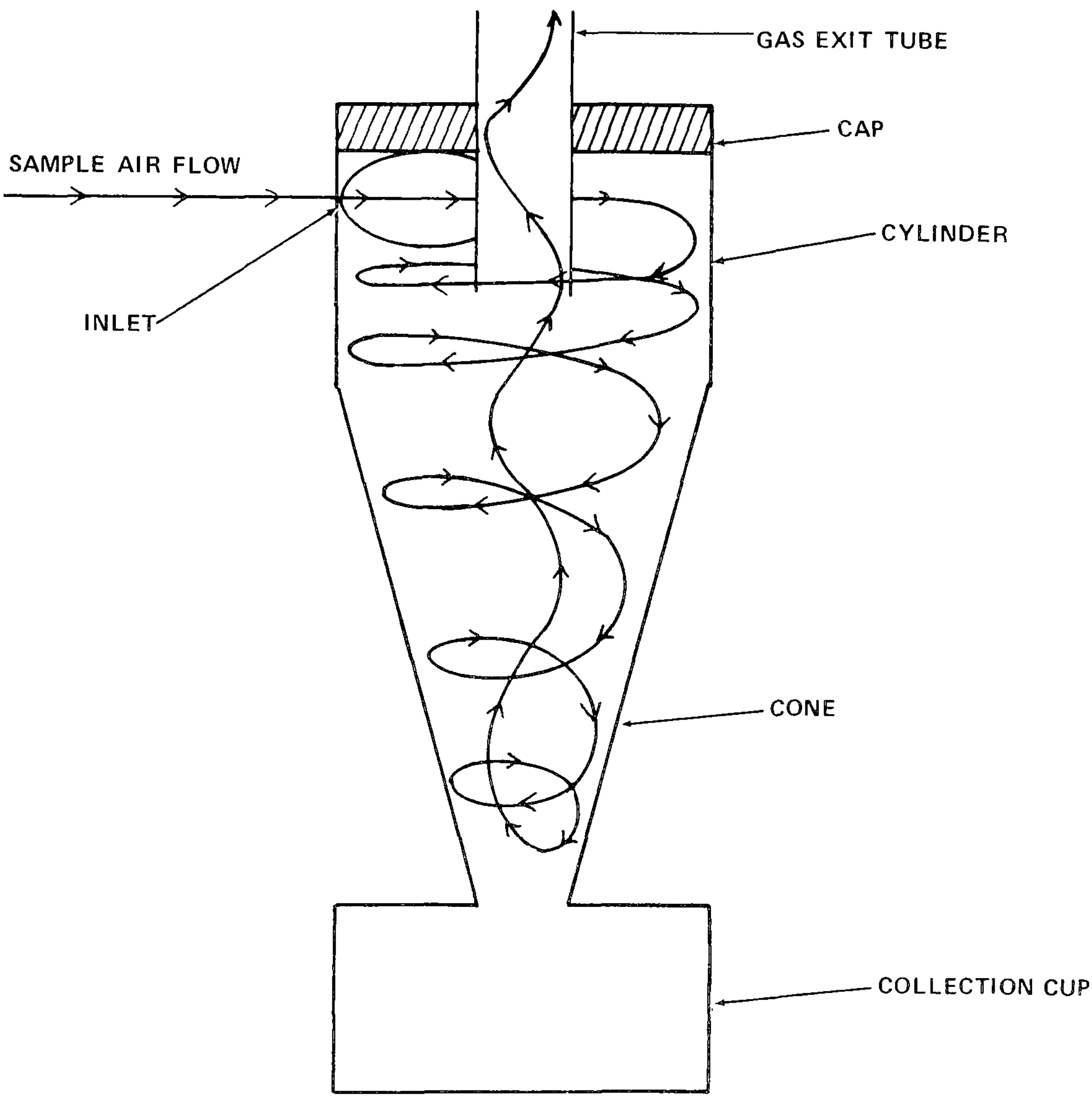

Figure. 7. Hypothetical flow through a cyclone of conventional design.

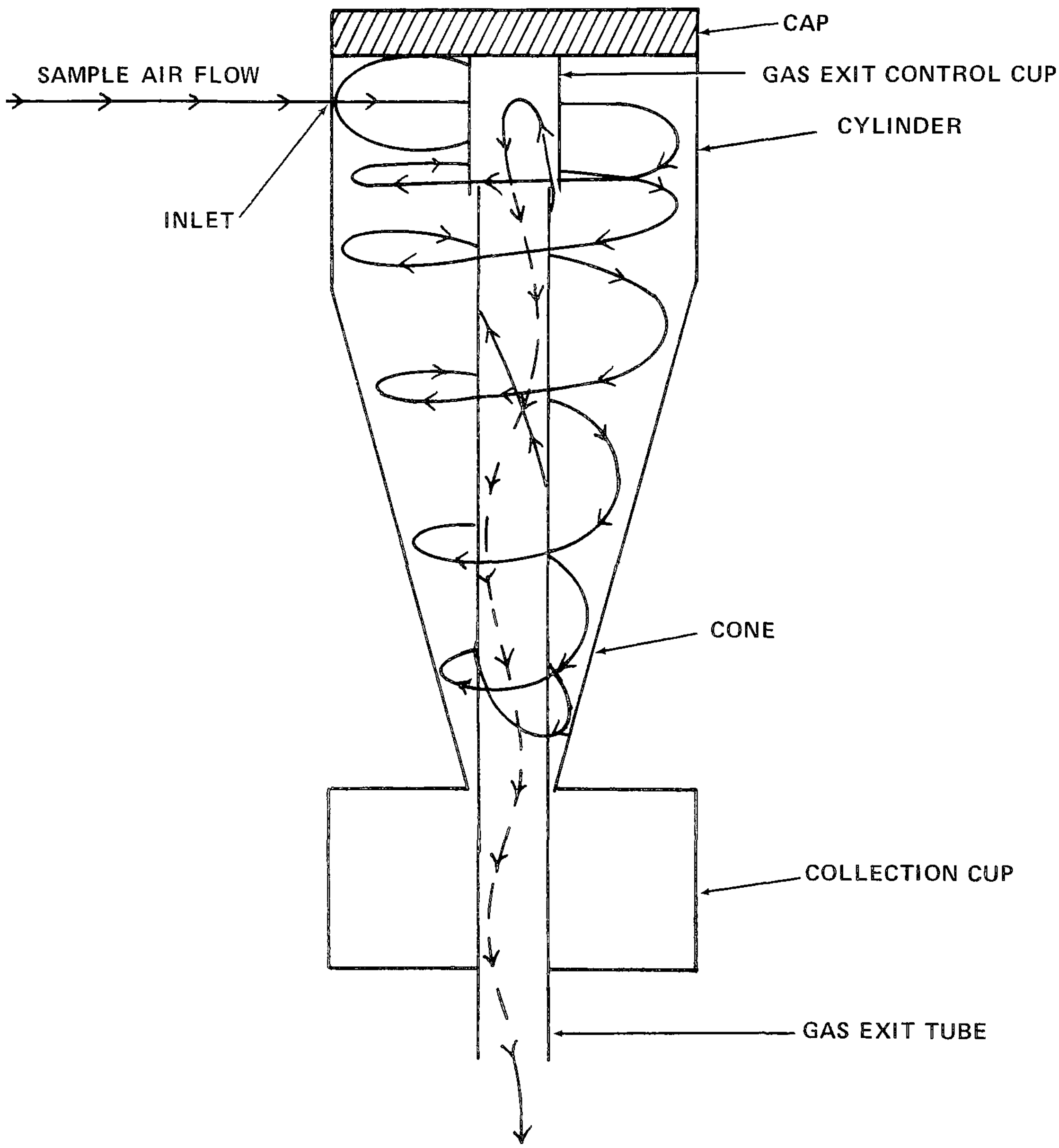

Figure 8. Hypothetical flow through a cyclone of modified design (Cyclone I).

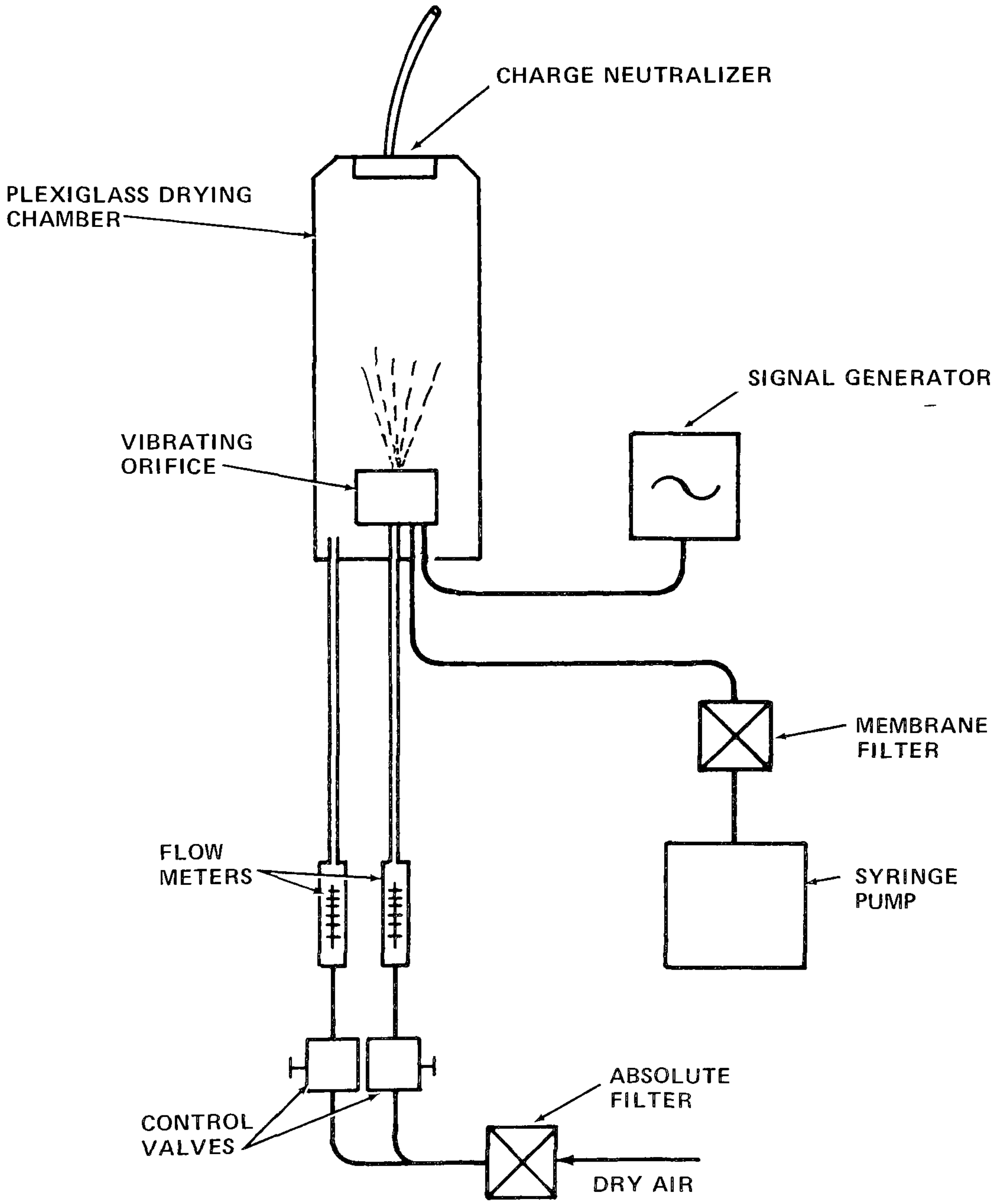

Figure 9. Vibrating orifice aerosol generating system.

93, and 204°C (77, 200 and 400°F); and Cyclone IV at 7.1 ℓ/min (0.25 ft^3/min) and 25°C (77°F). All of the internal surfaces of the cyclones were washed after sampling, and the mass collected on each surface was determined by absorption spectroscopy.

The apparatus used to heat the turquoise dye aerosol to the desired temperatures is shown in Figure 10. A pump was used to obtain the desired air flow through the cyclones. In general the cyclones were calibrated individually with a 47 mm Gelman Filter holder connected to the cyclone gas exit tube 8 cm from the cap. For tests in which the flowrate of the aerosol stream from the VOAG was greater than the desired flowrate through the cyclone, the bleed valve was opened to allow the excess air to escape. For tests in which the flowrate from the VOAG was less than the desired flow through the cyclone, makeup air was supplied through the absolute filter. The aerosol stream to the cyclone passed through a heated copper tube and the temperature was measured at the inlet of the cyclone. The sampling port was used to collect and examine heated particles for correct size, color, shape, and general integrity. The cyclone to be tested, and a glass fiber back-up filter, were kept heated in an oven at the same temperature as the aerosol stream. The air exiting the filter entered a heat exchanger which allowed the air to come to room temperature. The flowrate was measured with a calibrated orifice located just upstream from the pump. A valving arrangement on the pump was used to adjust the air flow to the desired rate.

The second aerosol generator, shown in Figure 11, was a pressurized Collison nebulizer which was used to disperse polystyrene latex (PSL) particles with diameters from 0.312 μm to 1.099 μm and with a density of 1.05 gm/cm^3 and polyvinyltoluene particles with diameters of 2.01 μm with a density of 1.027 gm/cm^3. A general description of the system was given by Calvert,[12] and a more specific description by Cushing, et al.[9] The Collison system was used to calibrate Cyclones IV and V at three flowrates: 7.1, 14.2, and 28.3 ℓ/min (0.25, 0.50, and 1.00 ft^3/min). Due to the low melting point of the latex spheres, cyclones IV and V were calibrated at 25°C (77°F) only.

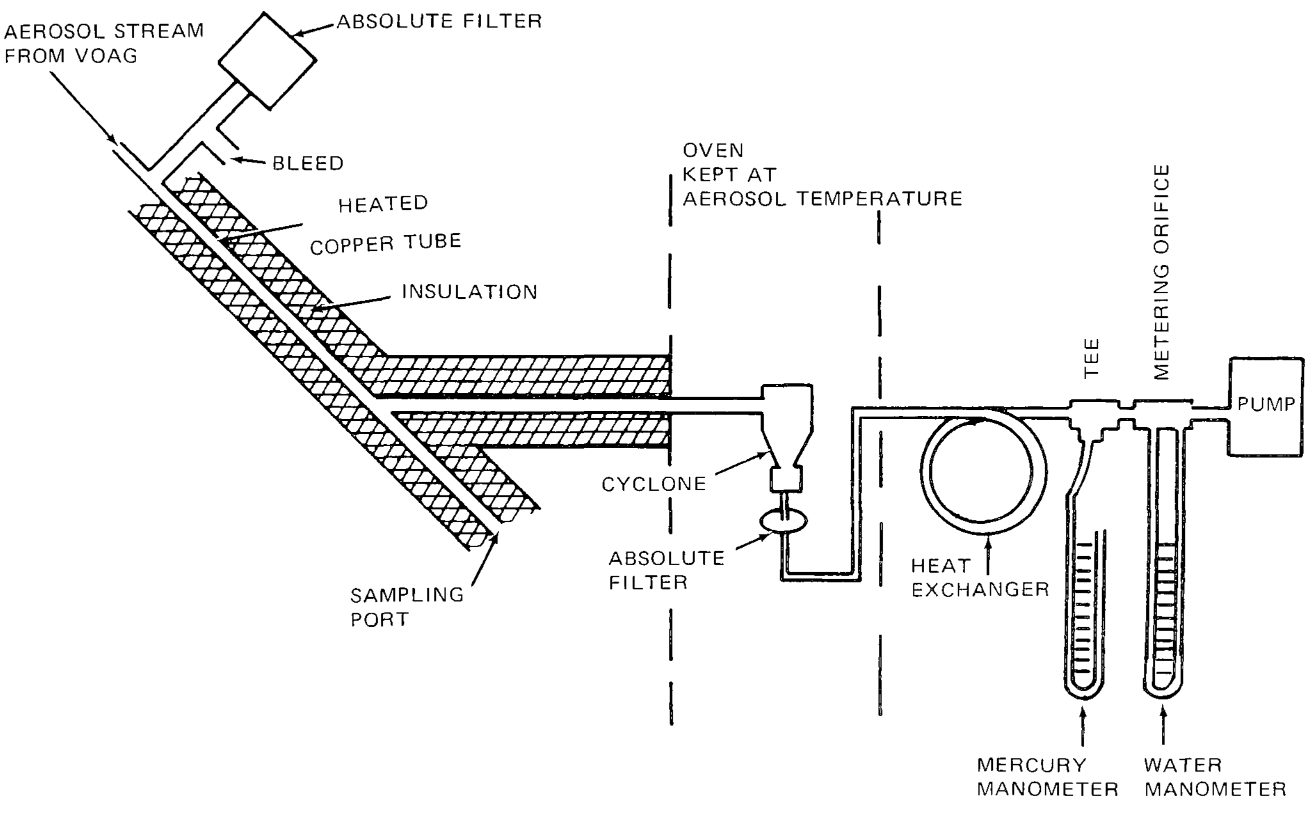

Figure 10. Calibration system for heated aerosols.

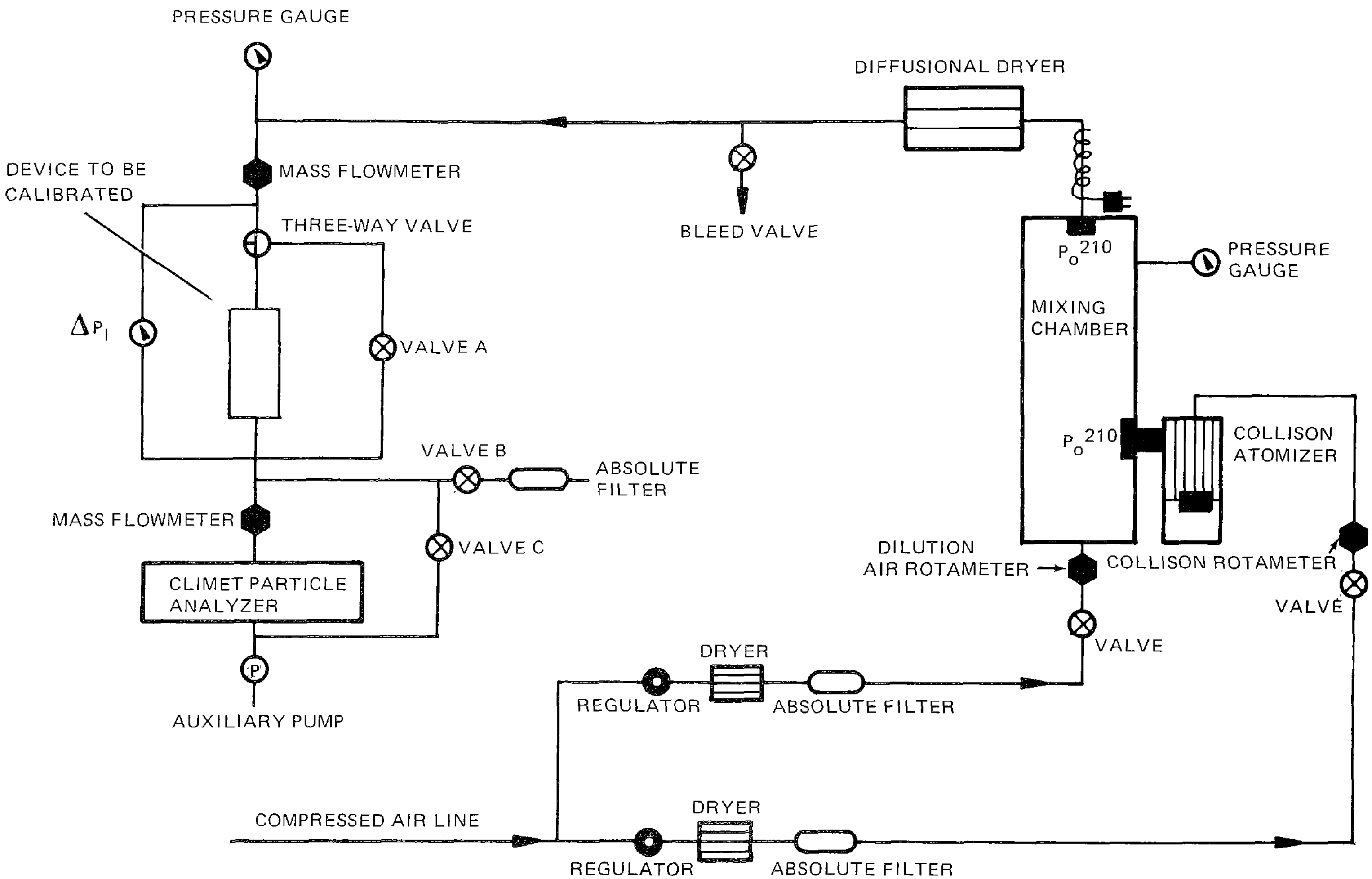

Figure 11. Collison aerosol generator system.

SECTION 4

EXPERIMENTAL RESULTS

Table 1 lists the experimental parameters for the laboratory calibration study. As previously stated, three values each of flowrate, particle density, and gas temperature were used to simulate a range of conditions that might be expected in field use. The object of the experiments was to accurately determine the D_{50} cut points of the cyclones by measuring the collection efficiency of the cyclones for particle diameters near the D_{50}.

Table 1

Laboratory Calibration of Five Stage Cyclone System
Test Conditions

Flowrate ℓ/min.	Temperature degrees C	Cyclone I	II	III	IV	V
7.1	25				T/P	P
14.2	25	T	T	T/A	P	P
28.3	25	T	T	T/P	P	P
28.3	93	T	T	T		
28.3	204	T	T	T		

T is turquoise dye particles
A is ammonium fluorescein particles
P is polystyrene latex or polyvinyltoluene particles

In tests conducted with particles generated by the VOAG, each point on the collection efficiency graphs represents the entrance of a very large number (over 10^7) monodisperse particles into the cyclone inlet. Thus, each data point was found to be reproducible to within one or two percent of the initial value of the collection efficiency, except for particle diameters very close to the D_{50} cut point where the efficiency curve is almost vertical.

The sample flowrate, as measured by the metering orifice, was accurate to within 1 ℓ/min. The temperature of the dye aerosol was accurate to within 3°C of the true value. The density of the dye particles was accurate to within 0.05 gm/cm^3 and the reported size is estimated to be within 1% of the true size.

For tests conducted with the Collison system, the aerosol concentration was approximately 10-40 $particles/cm^3$. One minute samples were run alternately through the cyclone and the bypass line. At least five sets of inlet/bypass data were averaged to calculate each point shown in the graphs of collection efficiency vs. particle diameter. The flowrate was measured by an electronic mass flowmeter that is accurate to within ±1 ℓ/min of the true value. The temperature was stable to within 1°C. The density of the latex particles is reported to be accurate to three significant digits. Particle size standard deviations were less than 0.0082 micrometers for sizes smaller than 2 micrometers in diameter and 0.0135 micrometers for the 2.020 micrometer diameter particles.[13] The average standard deviation of the collection efficiency was 5% except for particle diameters very close to the D_{50} cut point.

The collection efficiency curves for Cyclones I, II, and III, calibrated at 28.3 ℓ/min with turquoise dye particles (particle density 2.04 gm/cm^3) at temperatures of 25, 93, and 204°C (77, 200, and 400°F), are shown in Figures 12 and 13. The steepness of the curves indicate the extent to which the cyclones will have ideal behavior at these conditions. In Figure 13, the solid symbols represent collection efficiencies measured using latex particles and the Collison system and are called derived data. Derived data are values of collection efficiency and D_{50} which were measured using particles of a different density than that listed on the graph and were then transposed to particle diameters of equivalent aerodynamic behavior and the same density as those listed, by means of Stokes law. Application of Stokes law yields:

$$D_2 = \left(\frac{\rho_1 C_1}{\rho_2 C_2}\right)^{\frac{1}{2}} D_1 \quad , \qquad (3)$$

where D_1 and D_2 are the diameters of particles of densities ρ_1 and ρ_2, respectively, which have the same aerodynamic behavior, and

C_1 and C_2 are the slip correction factors for particles of diameters D_1 and D_2, respectively.

Equation (3) must be solved by iteration to yield D_2 and C_2 from an initial value of D_1 and C_1.

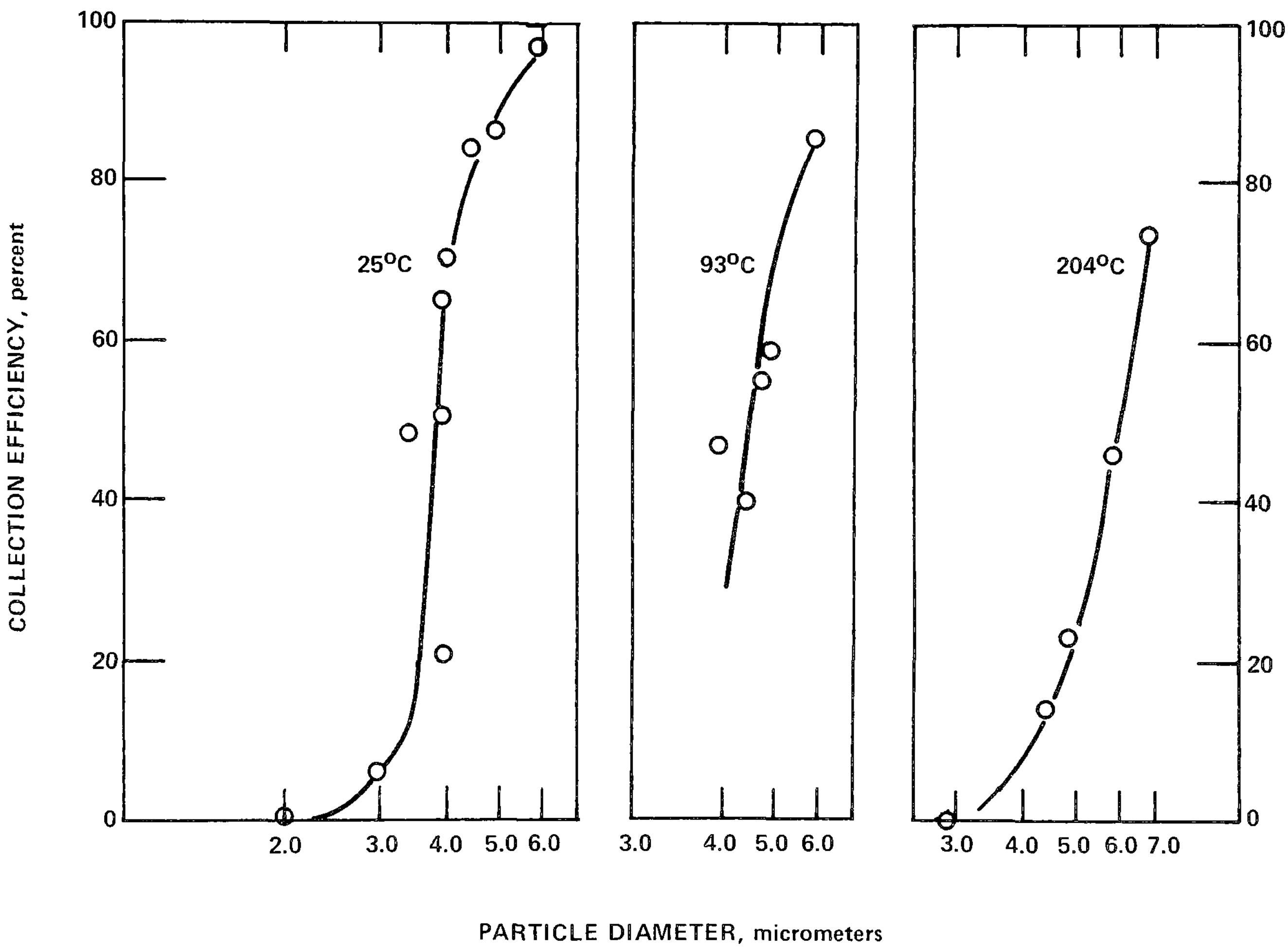

Figure 12. Collection efficiency of EPA-S.R.I. Cyclone I at a flow of 28.3 ℓ/min, temperatures of 25, 93, and 204°C, and for a particle density of 2.04 gm/cm³.

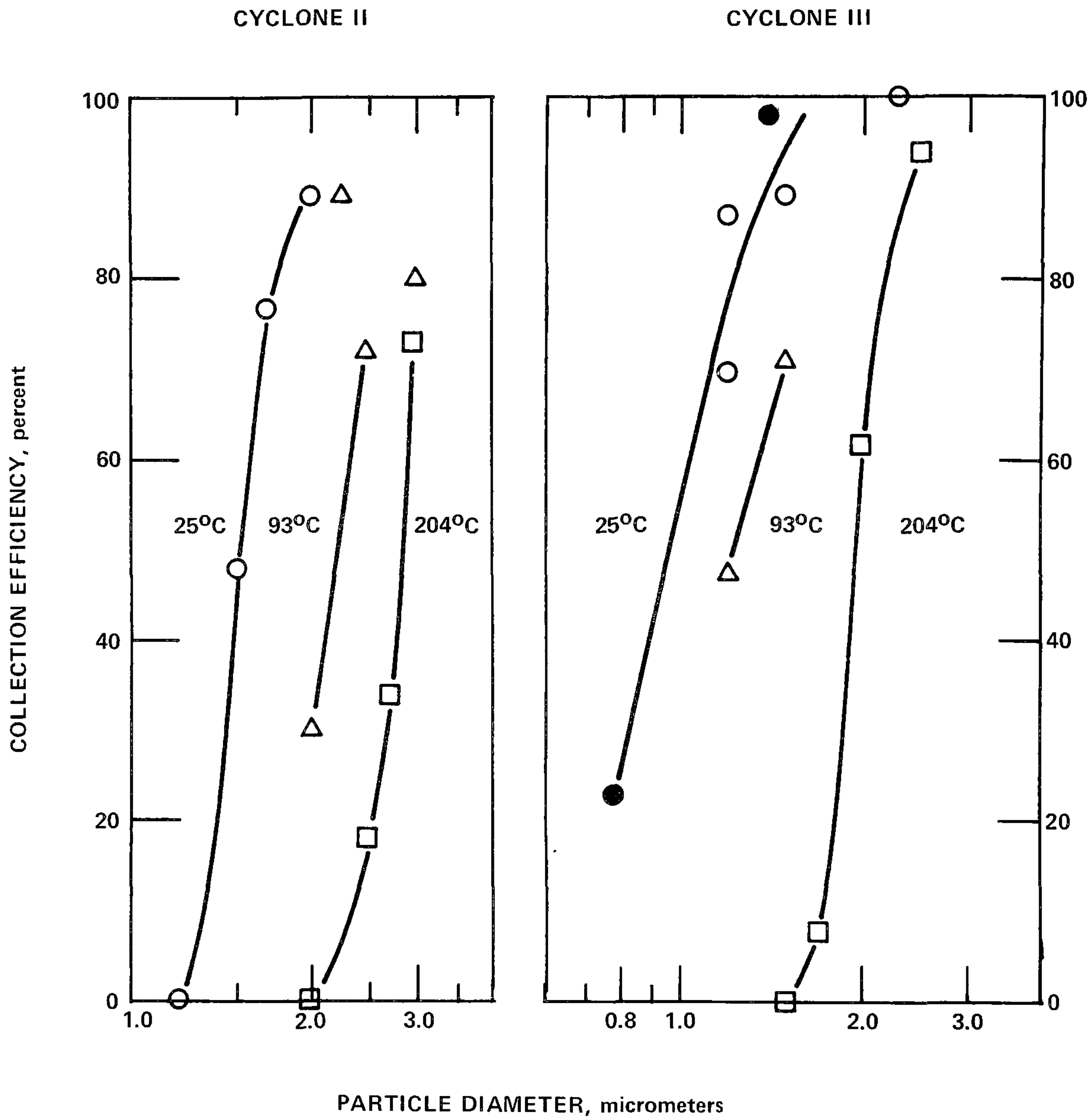

Figure 13. Collection efficiency of EPA-S.R.I. Cyclones II and III at a flow of 28.3 ℓ/min, temperatures of 25, 93, and 204°C, and for a particle density of 2.04 gm/cm³. Solid symbols: Derived from data taken at a particle density of 1.05 gm/cm³.

As an example, in Figure 13, the collection efficiency of Cyclone III was 23% for PSL particles, 1.099 μm in diameter and with a density of 1.05 gm/cm³. Using these values in equation (3), we find an equivalent diameter for particles of density 2.04 gm/cm³.

$$D_2 = \left[\frac{(1.05)(1.152)}{(2.04)(C_2)}\right]^{\frac{1}{2}} (1.1) = .75 \ \mu m.$$

Therefore, in Figure 13, the 23% collection efficiency for Cyclone III is plotted at .75 μm. Similarly, the 99% collection efficiency is plotted at 1.4 μm for a particle density of 2.04 gm/cm³ instead of the actual 2.0 μm diameter for the polyvinyltoluene particle density of 1.027 gm/cm³.

Figure 14 shows the collection efficiency curves for Cyclones I, II, and III, calibrated at a flowrate of 14.2 ℓ/min and temperature of 25°C with turquoise dye particles (particle density 2.04 gm/cm³). The two derived data points were obtained using ammonium fluorescein (particle density 1.35 gm/cm³). Again the steepness of the collection efficiency curves indicates that the cyclones have nearly ideal collection characteristics at the reduced flowrate of 14.2 ℓpm.

In the collection efficiency curves for Cyclone III in Figure 14, the transposed data taken using the ammonium fluorescein dye and the turquoise dye lie close to a single smooth curve as would be expected according to Stokes' law.

Figure 15 shows the collection efficiency curves for Cyclones IV and V for a temperature of 25°C and flowrates of 7.1, 14.2, and 28.3 ℓ/min. The open symbols indicate data taken using either polystyrene latex particles (density 1.05 gm/cm³) or polyvinyltoluene particles (density 1.027 gm/cm³). The darkened symbols represent data taken using turquoise dye particles (density 2.04 gm/cm³) and translated to a density of 1.05 gm/cm³ using Stokes' law. The limitation in the particle sizes available in the range 1.0 μm to 2.8 μm is quite evident and the uncertainty in the values of the D_{50} cut point that are in this size range is greater than for those cut points that lie outside this size range.

The data cited above were for each of the cyclones sampling at the same actual inlet flows. However, when operating the cyclones as a series train, the inlet flowrate to each cyclone will be slightly different due to the pressure drops across the cyclones preceding it. In order to allow more accurate calculations of the cyclone D_{50} cut points in field operation, the pressure drop was measured across each cyclone at the same mass flow with the inlet of the large cyclone operating at ambient pressure and temperature and at 28.3 ℓ/min. The results of this measurement are listed below:

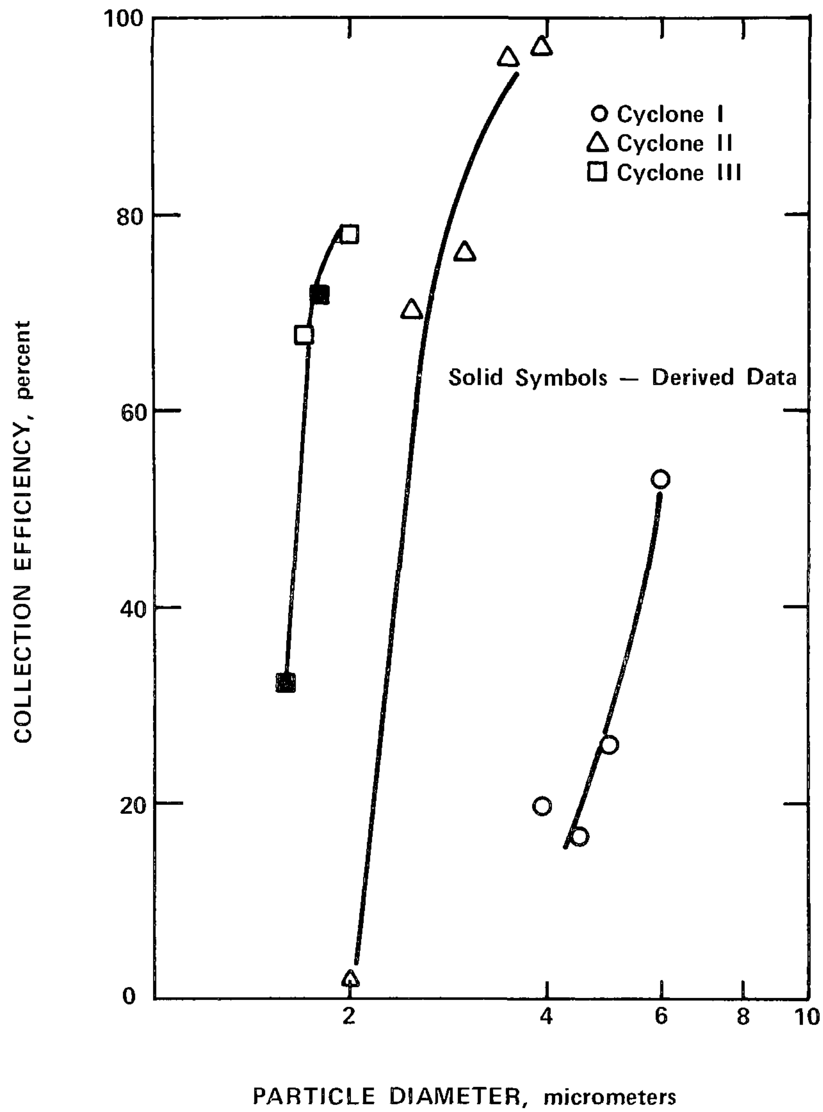

Figure 14. Collection efficiency of EPA-S.R.I. Cyclones I, II, and III at a flow rate of 14.2 ℓ/min, a temperature of 25°C, and for a particle density of 2.04 gm/cm^3. Solid symbols: Derived from data taken at a particle density of 1.35 gm/cm^3.

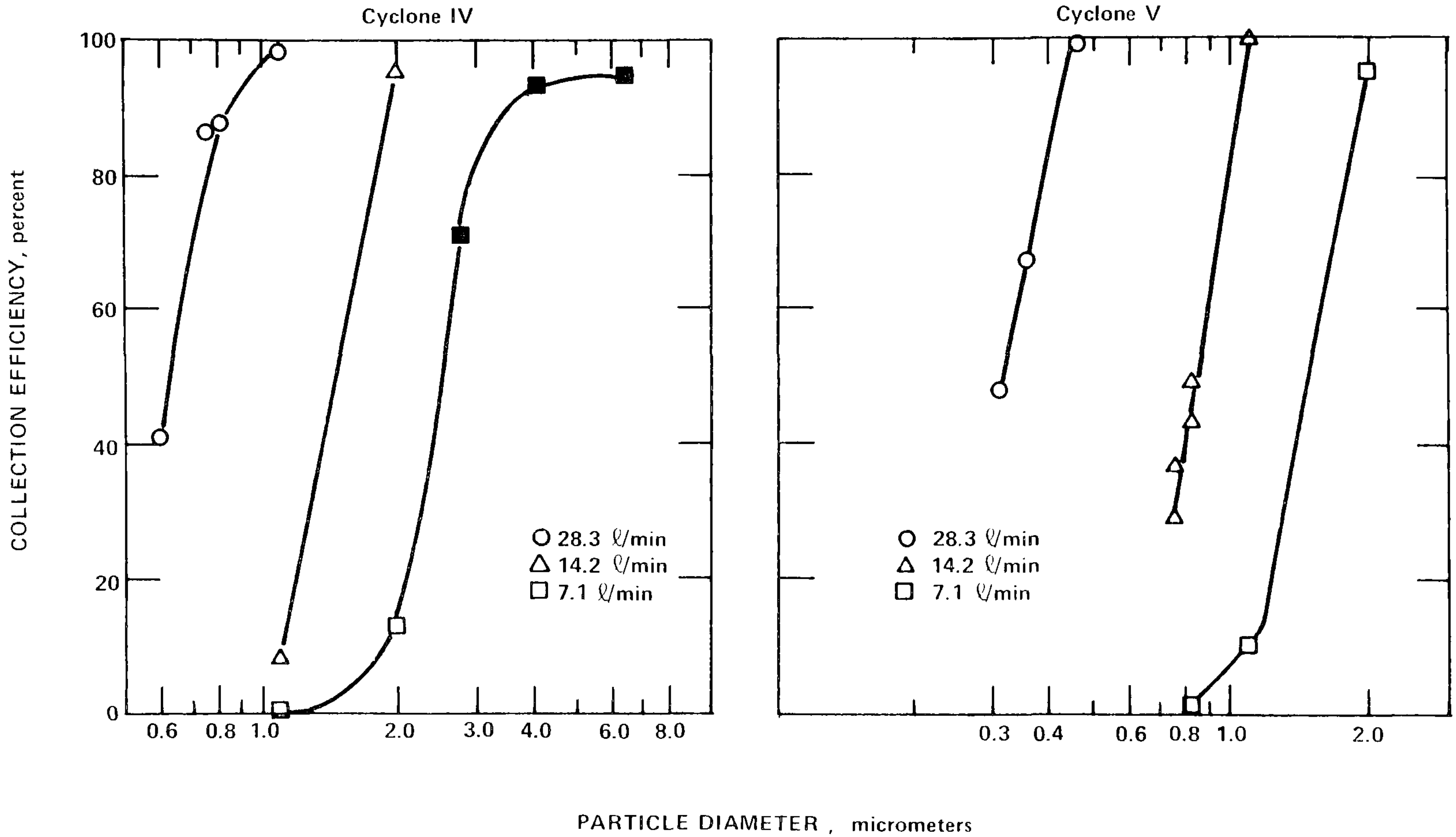

Figure 15. Collection efficiency of EPA-S.R.I. Cyclones IV and V at flow rates of 7.1, 14.2, and 28.3 ℓ/min, a temperature of 25°C, and for a particle density of 1.05 gm/cm^3 Solid symbols: Derived from data taken at a particle density of 2.04 gm/cm^3

Barometric Pressure = 747 mm Hg   Ambient Temperature = 25°C

Cyclone	Pressure Drop Across Cyclone	% of Total Pressure Drop	Inlet Flow ℓ/min
I	5.1 mm H_2O	0.22	28.3
II	40.6 mm H_2O	1.76	28.8
III	71.1 mm H_2O	3.07	28.9
IV	332.7 mm H_2O	14.37	29.1
V	137.2 mm Hg	80.58	30.1
Total	170.2 mm Hg	100.00	

These pressure drops were measured without a backup fiber downstream of Cyclone V. If a back-up filter is used, its pressure drop should be measured separately and subtracted from the total pressure drop to yield just the pressure drop across the cyclones. Then the above percentages can be used to determine the flow at the inlet of each cyclone.

A study of particulate deposition in a cyclone during its operation yielded some interesting results. Deposition data were taken from tests on three cyclones at two flow-rates and two particle densities. The aerosol particles collected were turquoise dye and ammonium fluorescein. The particulate concentrations were low and thus no data were obtained under conditions where there was a large amount of material on the surfaces. The analysis was performed by rinsing the various parts of the cyclone separately after each test and measuring the absorbance of each wash with a spectrophotometer. The data on deposition are listed in Table 2, with a short explanation, and plotted in a bar graph format in Figure 16. In each cyclone, the largest deposition occurred in tne cone. The next largest depositions occurred in the cup.

For each of the cyclones, the material collected inside the exit tube was considered part of the catch of the next stage. It was questioned whether a similar procedure should be used for the gas exit control cup of Cyclone I. During the calibration procedure, particulate matter collected in the gas exit control cup was measured separately from that collected in the rest of the cyclone. Figure 17 shows the results of these measurements. Since the cup's collection efficiency is zero for particles slightly larger than the D_{50} of Cyclone II, for data reduction the catch of the control cup was considered to be part of the Cyclone II catch, and not part of the Cyclone I catch.

TABLE 2

DEPOSITION STUDY

Cyclone I at 14.2 ℓ/min, ambient temperature, 6 μm dye particles

Collection Efficiency - Cyclone	53.3%
Deposition - Cylinder and inlet	21.3%
Cone and top of cup	55.6
Cup and outside of exit tube	23.1
Total in cyclone	100.0%

Cyclone II at 28.3 ℓ/min, ambient temperature, 2 μm dye particles

Collection Efficiency	93.3%
Deposition - Cylinder and inlet	2.4%
Cone and top of cup	51.0
Collection cup	46.0
Top of cyclone and outside of gas exit tube	0.6
	100.0%

Cyclone III at 14.2 ℓ/min, ambient temperature, 2 μm ammonium fluorescein particles

Collection Efficiency	32.5%
Deposition - Cylinder and inlet	0.0
Cone and top of collection cup	72.1
Collection cup	27.9
Top of cyclone and outside of gas exit tube	0.0
	100.0%

Note: Inside of gas exit tube was not considered part of the cyclone catch.

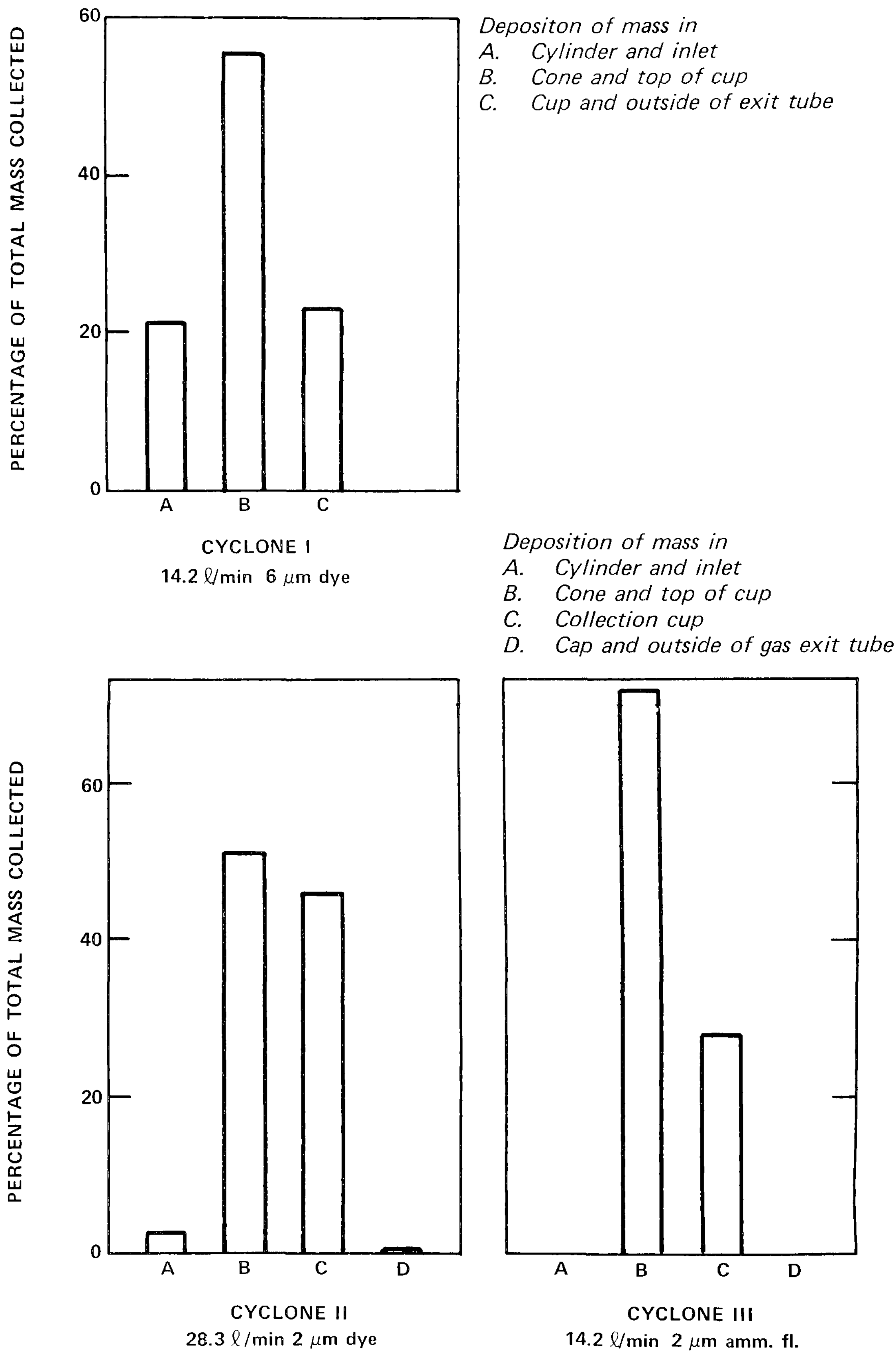

Figure 16. Deposition of particulate mass in EPA-S.R.I. Cyclones I, II, and III.

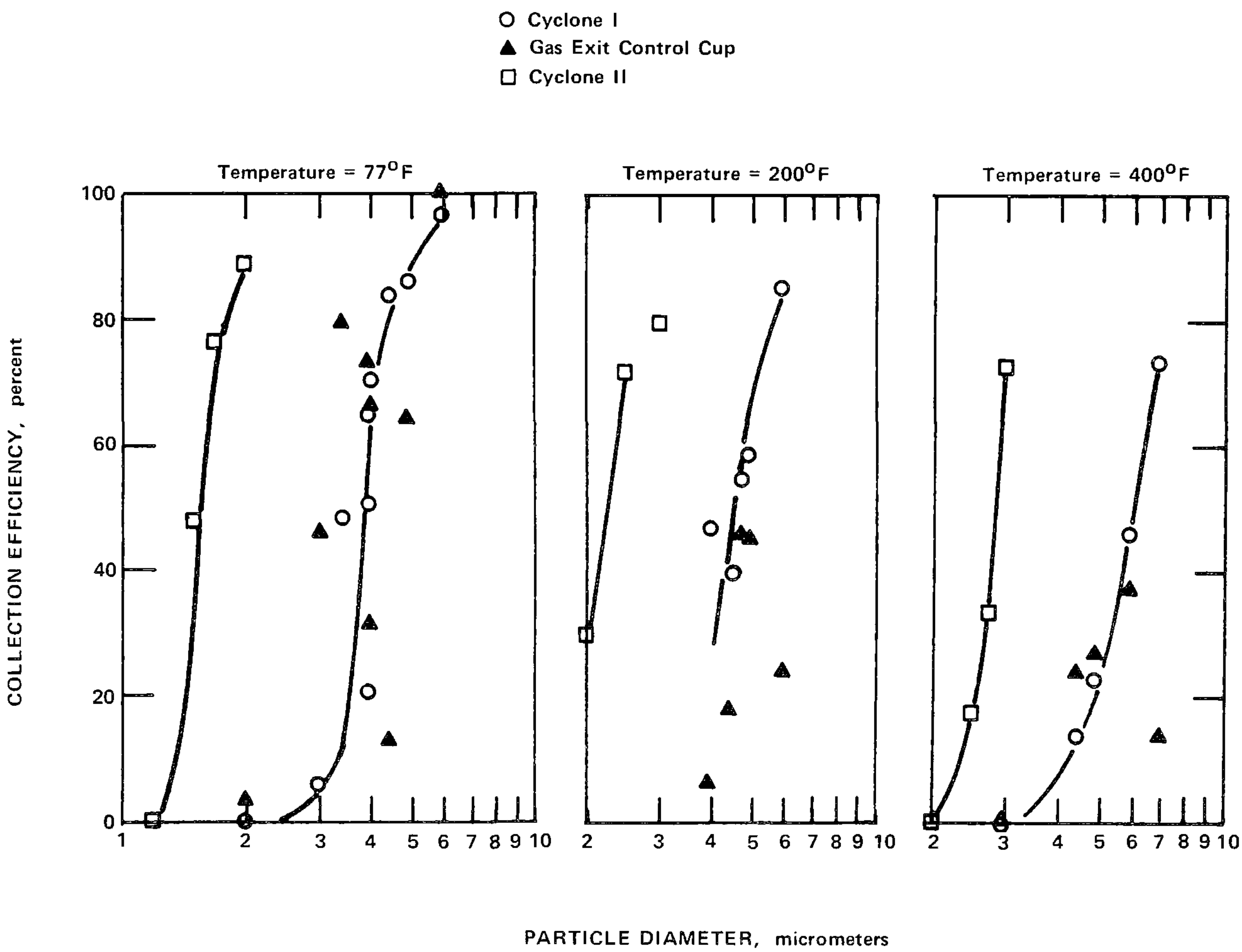

Figure 17. Collection efficiency of EPA-S.R.I. Cyclones I, II, and the Cyclone I gas exit control cup at a flow rate of 28.3 ℓ/min, temperatures of 25, 93, and 204°C, and for a particle density of 2.04 gm/cm³.

Figure 18 shows the change in D_{50} cut point due to the change in gas viscosity for Cyclones I, II, and III. Viscosity is dependent only on temperature for our calibration conditions, and the viscosity values 183, 214, and 259 micropoise correspond to 25°C, 93°C, and 204°C respectively. These values of viscosity were calculated from the equation

$$\mu = \frac{T^{3/2}}{.068T + 7.8} \qquad (4)$$

where μ is the viscosity in micropoise and T is the temperature in degrees Kelvin. Equation 4 is a curve fit to data given in the Chemical Rubber Handbook for the viscosity of air.[14] For each cyclone, a linear regression has been performed on the three data points to give the best straight line. Although a search of the literature has not revealed a theory which suggests a linear dependence of D_{50} on viscosity, a straight line was suggested by the lack of a consistent trend in curvature of the data and by the linear fit made on earlier data shown in Figure 3.[9] The coefficient of determination is near to unity for each set of data. The curves have been extrapolated to 316°C for each cyclone and replotted for a particle density of 1.00 gm/cm^3 in Figure 19. This facilitates the determination of the D_{50} cut points at actual test conditions.

Figure 20 indicates the change in D_{50} cut point due to the change in gas flow for Cyclones IV and V. A power curve was fitted to both sets of data points to yield the following equations:

For Cyclone IV: $D_{50} = 17.6\ Q^{-0.98}$ (5)
where $r^2 = 0.981$

For Cyclone V: $D_{50} = 14.0\ Q^{-1.11}$ (6)
where $r^2 = 0.974$

and r^2 is the coefficient of determination.

In their April 1977 work as discussed above, Chan and Lippmann suggested that the relationship between D_{50} cut point and gas flowrate (Q) was $D_{50} = KQ^n$ where K and n are experimentally determined constants.[6] From our data, the values of n and K for Cyclones I-V are:

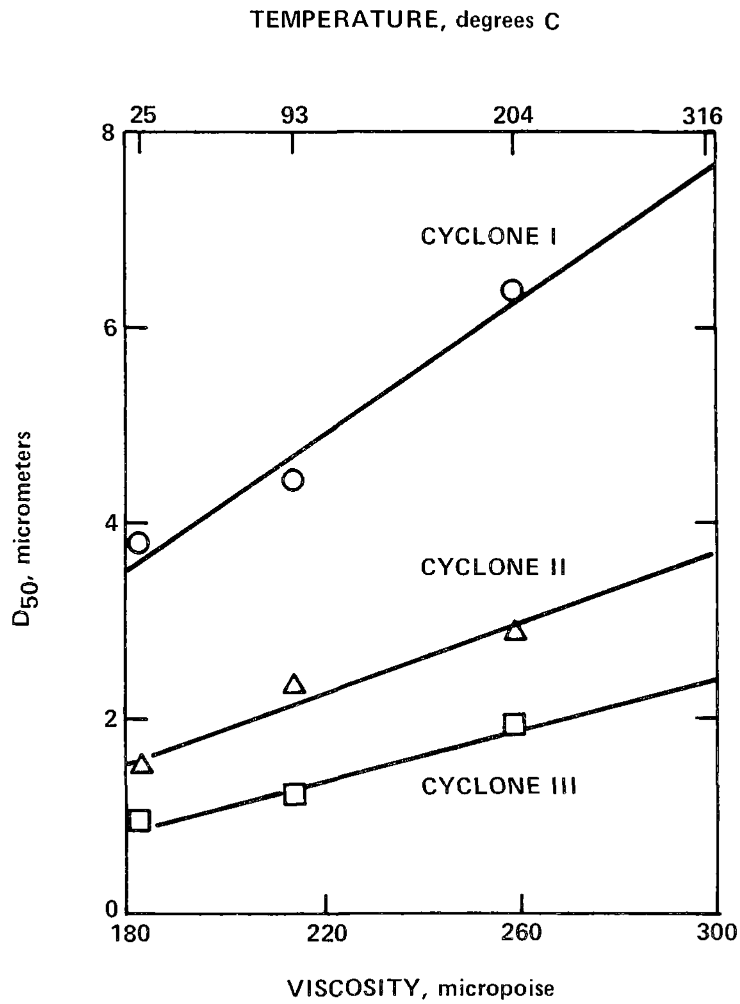

Figure 18. *D_{50} cut point versus viscosity for EPA-S.R.I. Cyclones I, II, and III at a flow rate of 28.3 ℓ/min, temperatures of 25, 93, and 204°C, and for a particle density of 2.04 gm/cm^3*

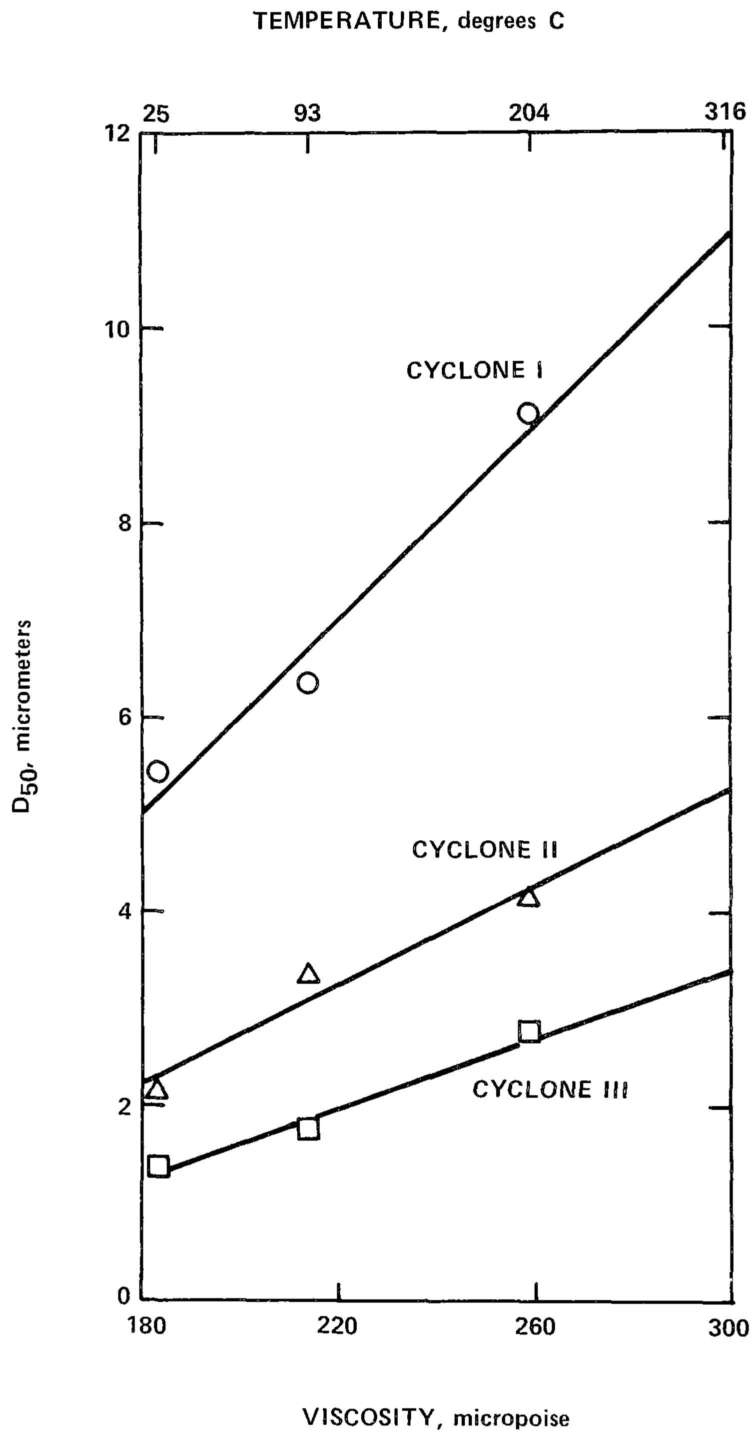

Figure 19. *D_{50} cut point versus viscosity for EPA-S.R.I. Cyclones I, II and III at a flow rate of 28.3 ℓ/min, temperatures of 25, 93, and 204°C, and for a particle density of 1.00 gm/cm³*

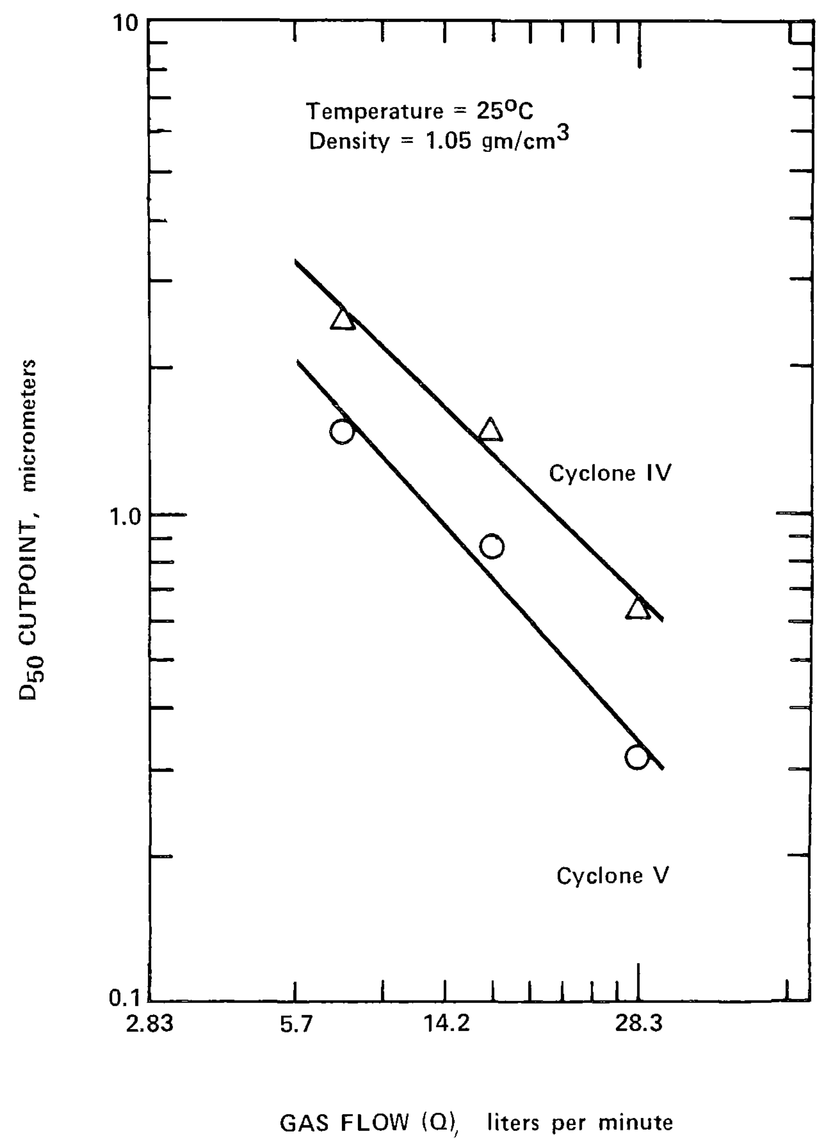

Figure 20. *D_{50} cut point versus flow rate for EPA-S.R.I. Cyclones IV and V at flow rates of 7.1, 14.2, and 28.3 ℓ/min, a temperature of 25°C, and for a particle density of 1.05 gm/cm^3.*

Cyclone	I	II	III	IV	V
n	-.63	-.70	-.84	-.98	-1.11
K	44.6	22.2	22.7	17.6	14.0

Note that only two data points were available to determine the constants n and K for Cyclones I, II, and III. The range in values for n reported by Chan and Lippmann was -0.636 to -2.13, the reported magnitudes of K were from 6.17 to 4591, and the diameters of the cyclones range from 10 to 152 mm. Also, the geometries and relative dimensions of the cyclones used by Chan and Lippmann may not have been identical to each other, or to the ones used in this study.[15]

SECTION 5

SUMMARY

The EPA-S.R.I. cyclone system is an inertial particle sizing device that is designed for in-situ sampling of industrial process streams. It will fit through a 10 cm diameter port and is equipped with nozzles of different diameters to allow isokinetic sampling at the nominal sample flowrate of 28.3 ℓ/min.

In this study, the individual cyclones of the system were tested and calibrated in the laboratory under conditions similar to those frequently encountered in field tests: gas temperatures of 25, 93, and 204°C, flowrates of 7.1, 14.2, and 28.3 ℓ/min, and particle densities of 1.05, 1.35, and 2.04 gm/cm^3.

The D_{50} cut points for the cyclone system at various operating conditions are given in Table 3. For laboratory test conditions (25°C, 28.3 ℓ/min, particle density 1.0 gm/cm^3) the cut points are 5.4, 2.1, 1.4, 0.65, and 0.32 μm. Figures 21 and 22 show some of the calibration curves that were obtained. Figure 21 has efficiency vs. aerodynamic (particle density = 1.0 gm/cm^3) particle diameter plots at a sampling rate of 28.3 ℓ/min and Figure 22 shows similar data where the flowrate is 14 ℓ/min. These two figures illustrate that the small cyclones have "sharp" efficiency curves and indicate that the system should function adequately as a particle sizing device. At the test conditions for Figure 21, the pressure drop across the cyclone system was 170 mm Hg.

Data from this study wherein different particle densities (ρ) were used tend to support the D_{50} vs. $\rho^{-\frac{1}{2}}$ relationship suggested by several theories.[3,17,18] On the other hand, the experimental results indicated that the cut points were directly proportional to the gas viscosity which is in opposition to most theories.[3,4,16,17] Also, it was found in this study and by Chan and Lippmann[6] that the D_{50}'s of small cyclones are not inversely proportional to the square root of the flowrate as some theories predict.

TABLE 3

LABORATORY CALIBRATION OF THE FIVE-STAGE CYCLONES
D_{50} Cut Points

Cyclone		I		II		III			IV		V	
Particle Density (gm/cm^3)		2.04	1.00	2.04	1.00	2.04	1.35	1.00	1.05	1.00	1.05	1.00
Flow ℓ/min	Temperature °C	Cyclone D_{50} cut points micrometers										
7.1	25								2.5	(2.5)	1.5	(1.5)
14.2	25	5.9	(8.4)	2.4	(3.5)	(1.7)	2.1	(2.4)	1.5	(1.5)	.85	(.87)
28.3	25	3.8	(5.4)	1.5	(2.1)	.95	-	(1.4)	.64	(.65)	.32	(.32)
28.3	93	4.4	(6.3)	2.3	(3.3)	1.2	-	(1.8)				
28.3	204	6.4	(9.1)	2.9	(4.1)	1.9	-	(2.8)				

D_{50} cut points enclosed in parentheses are derived from the experimental data using Stoke's law.

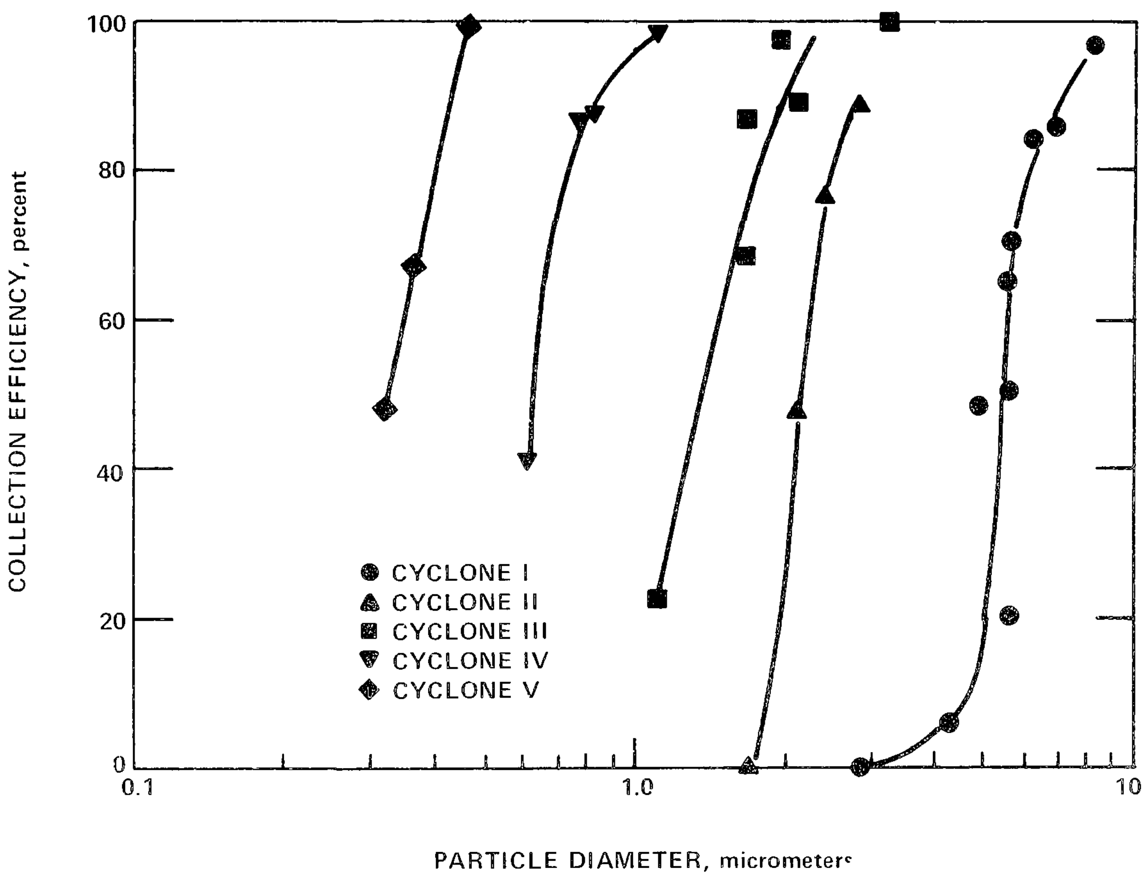

Figure 21. Collection efficiency of the EPA-S.R.I. Cyclones at a flow rate of 28.3 ℓ/min, a temperature of 25°C, and for a particle density of 1.00 gm/cm³.

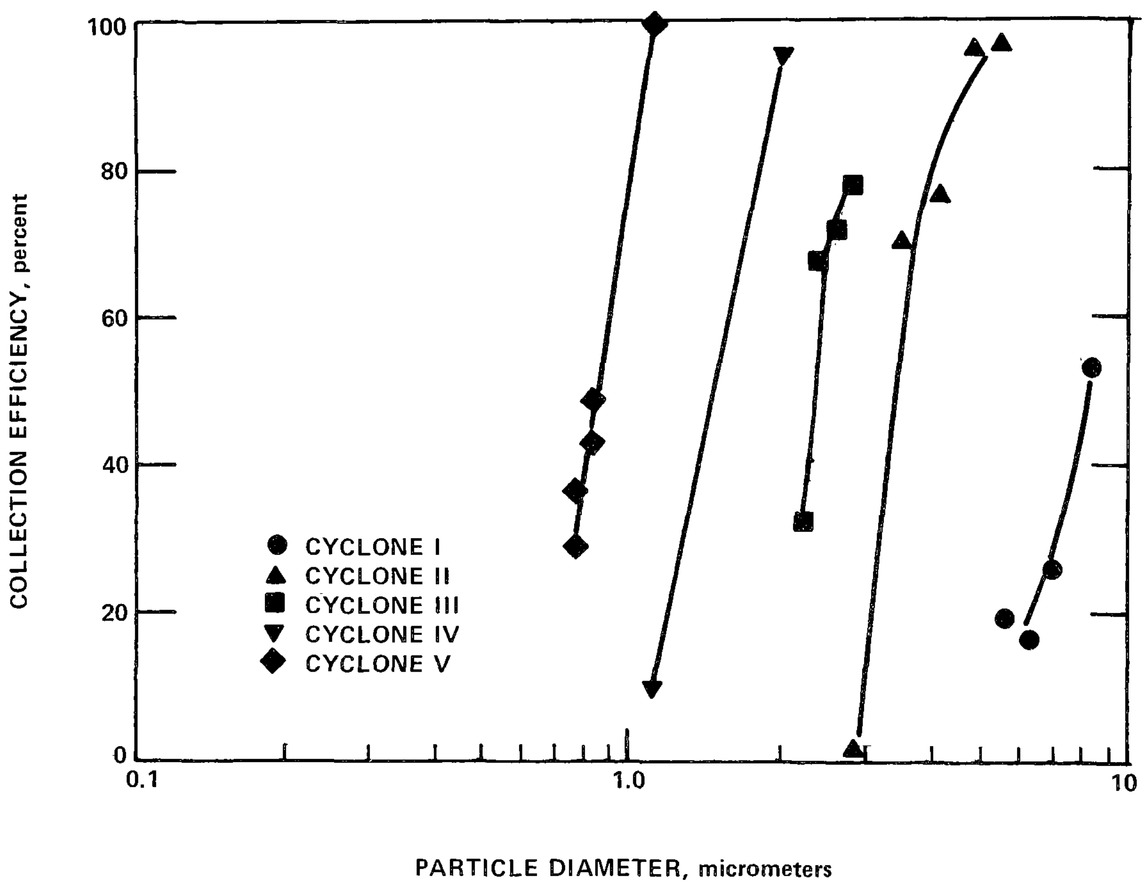

Figure 22. Collection efficiency of the EPA-S.R.I. Cyclones at a flow rate of 14.2 ℓ/min, a temperature of 25°C, and for a particle density of 1.00 gm/cm³.

Work is continuing in an effort to identify or develop an adequate theory for the prediction of cyclone performance under a range of test conditions.

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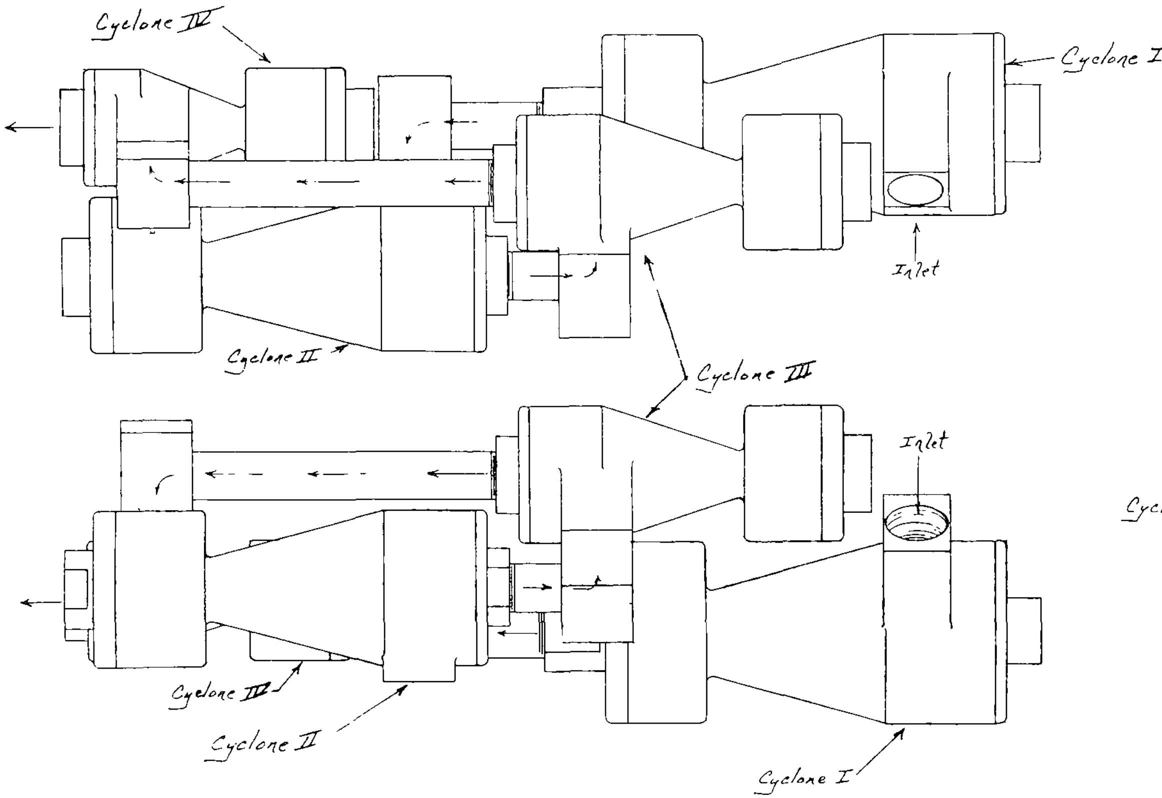
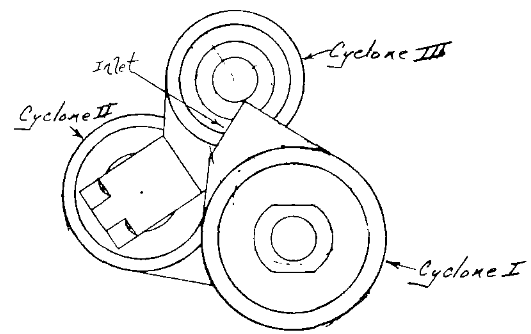
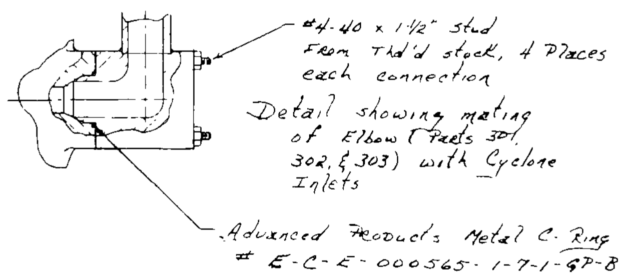
APPENDIX

SHOP DRAWINGS FOR THE EPA-S.R.I. CYCLONE SYSTEM







Detail showing mating of Elbow (Parts 301, 302, & 303) with Cyclone Inlets

DATE	REVISIONS	ZONE	NO.

TOLERANCES UNLESS OTHERWISE NOTED		
FRACTIONS	± 1/32	N/A
DECIMALS	± .010	N/A
ANGLES	± 1°	N/A
FINISH		
APPROVED		
CHECKED		
DRAWN	DWH	

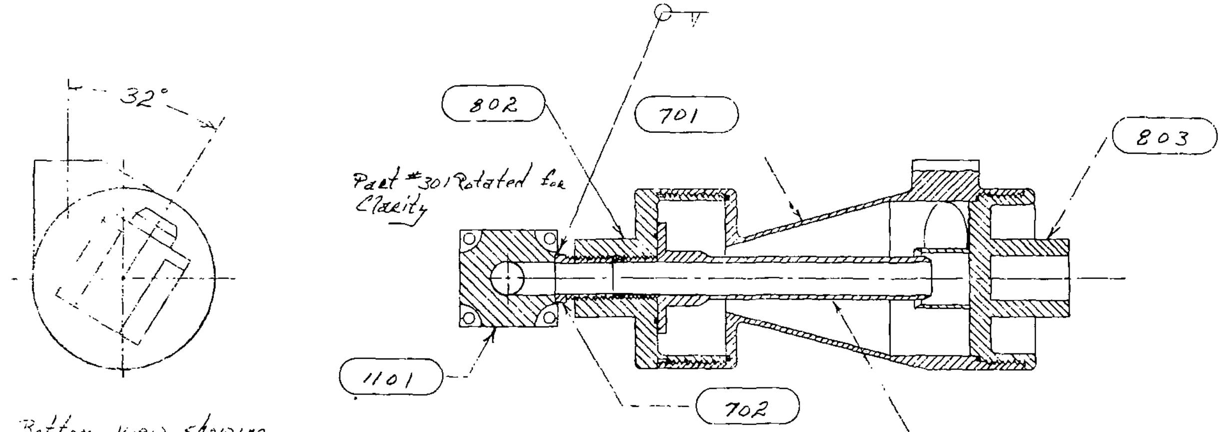
SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205

TITLE: Four Stage Series Cyclone

Cyclone Ensemble Assembly

SCALE: Full
DATE: 6/23/76
DWG NO. 3630-1-C-4

ASSY.	ITEM	QUAN.	NAME	DESCRIPTION	MATERIAL
	701	1	Cyclone I		
	702	1	Outlet Tube 'B'		
	801	1	Outlet Tube 'A'		
	802	1	Collection Cup		
	803	1	Vortex Tube		
	1101	1	Elbow		



Bottom view showing orientation of Part #301 with respect to Cyclone Inlet.

Thread Part #702 Into Part #802 until Chamfered edges 'seal'. Orient Part #702 with Respect to Cyclone Inlet & weld Part #702 to Part #1101

Note. Part #702 Not shown to scale

DATE	REVISIONS	ZONE	NO.

SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205

TOLERANCES UNLESS OTHERWISE NOTED		
FRACTIONS	± 1/32	N/A
DECIMALS	± .010	N/A
ANGLES	±	± 1/4
FINISH		
APPROVED		
CHECKED		
DRAWN	DHH	

TITLE: Four Stage Series Cyclone

Cyclone I Assembly A

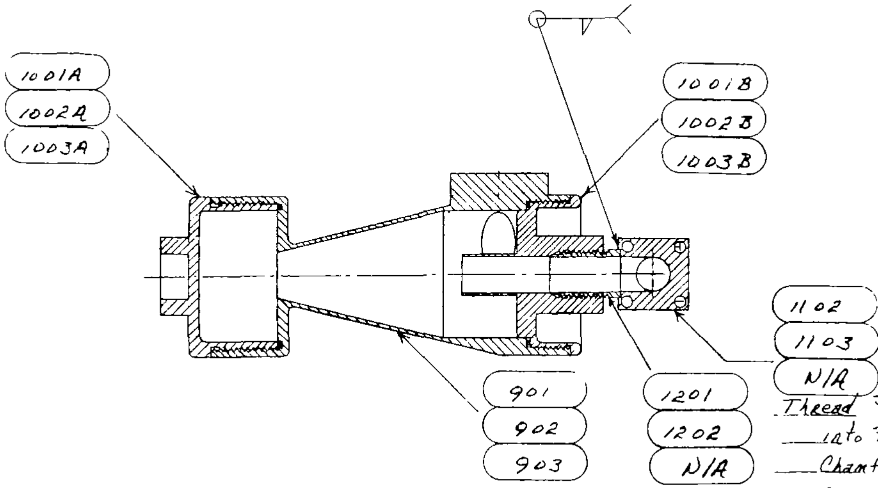
SCALE: Full
DATE: 6/21/76
DWG. NO. 2630-1-C-5

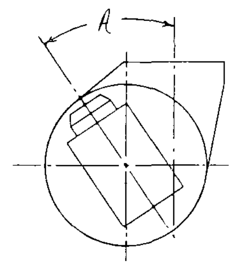
ASSY.	ITEM	QUAN.	NAME DESCRIPTION MATERIAL
	1102	1	Elbow
	1103	1	Elbow
	1001A	1	Collection Cup, Cyclone II
	1001B	1	Vortex Tube, Cyclone II
	1002A	1	Collection Cup, Cyclone III
	1002B	1	Vortex Tube, Cyclone III
	1003A	1	Collection Cup, Cyclone IV
	1003B	1	Vortex Tube, Cyclone IV
	901	1	Cyclone II
	902	1	Cyclone III
	903	1	Cyclone IV
	1201	1	Connector (Short)
	1202	1	Connector (Long)

Note.

Upper Part No.'s associated with Cyclone II
Center Part No.'s associated with Cyclone III
Lower Part No.'s associated with Cyclone IV

For Part #1102 & Cyclone II Angle "A" = 34°;
For Part #1103 & Cyclone III Angle "A" = 294° (66° to other side of Inlet ℄)





Top View, For orientation of Part with Respect to Cyclone Inlet

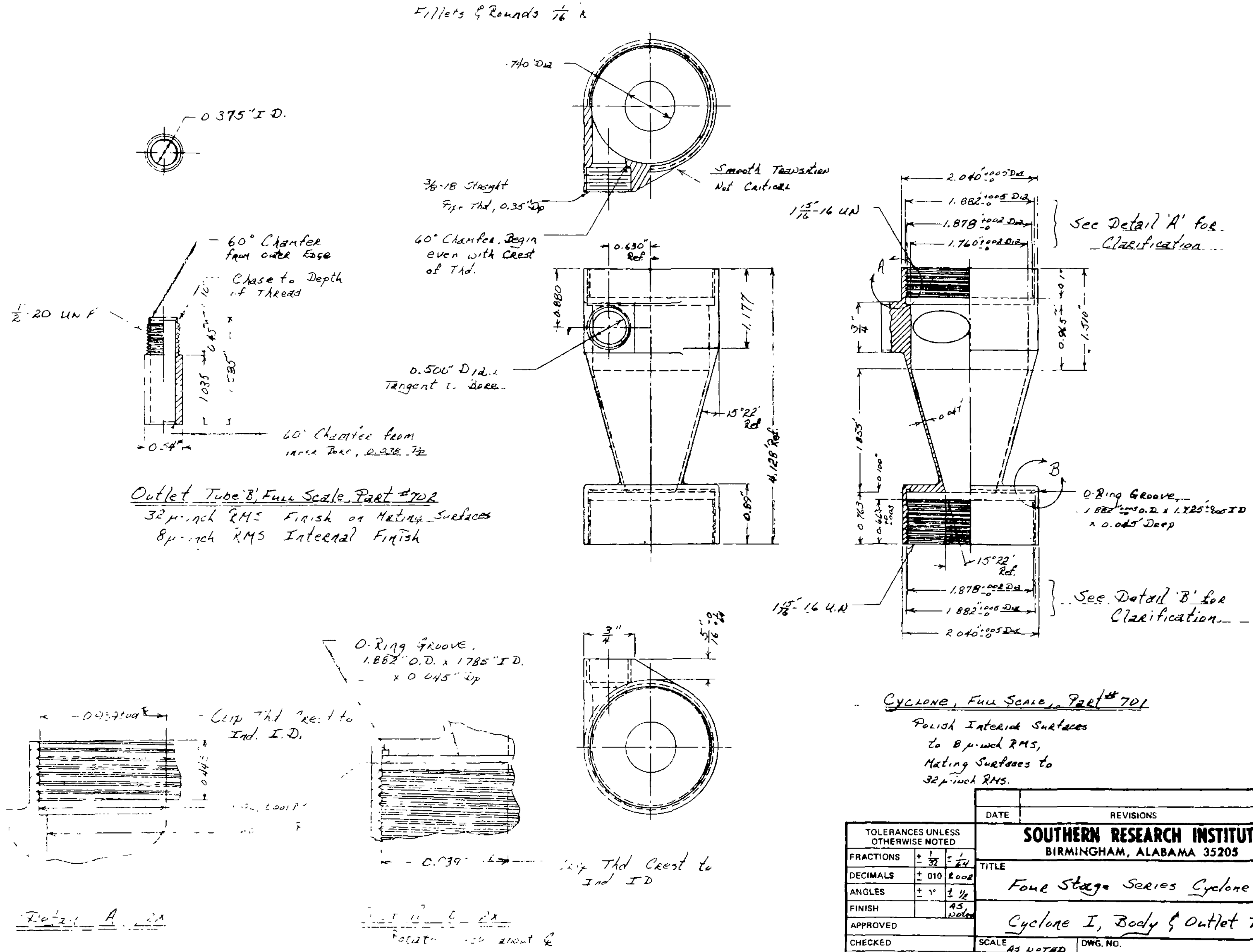
Thread Part #1201/1202 into Part #1001/1002 until Chamfered edges 'seal'. Orient Part #1102/1103 with Respect to Cyclone Inlet & weld Part #1102/1103 to Part #1201/1202

Note. Parts 302 & 303 Rotated for Clarity; Parts 601 & 602 Not shown to Scale

DATE	REVISIONS	ZONE	NO.
			A

TOLERANCES UNLESS OTHERWISE NOTED	SOUTHERN RESEARCH INSTITUTE, BIRMINGHAM, ALABAMA 35205
FRACTIONS ± 1/32 N/A	TITLE Four Stage Series Cyclone
DECIMALS ± .010 ±1/16	
ANGLES ± 1° ±1/4°	
FINISH N/A	Cyclones II, III, & IV, Assembly B
APPROVED	
CHECKED	SCALE Full — DWG. NO. 3630-1-C-6
DRAWN DHH	DATE 6/22/76

ASSY.	ITEM	QUAN.	NAME	DESCRIPTION	MATERIAL
	701	1ea	Cyclone I, ≈ 2¾" O.D. x 4.13" L,		Titanium
	702	1ea	Outlet Tube 'B', 0.54" O.D. x 0.397" I.D. x 1.20" L,	(1/4" Sched. 40 Pipe Size),	316 S.S.
			Note: Titanium = 6AL-4V Titanium Alloy		



TOLERANCES UNLESS OTHERWISE NOTED		
FRACTIONS	± 1/32	± 1/64
DECIMALS	± .010	± .002
ANGLES	± 1°	± 1/2
FINISH		As Noted
APPROVED		
CHECKED		
DRAWN	DHH	

DATE	REVISIONS	ZONE	NO.

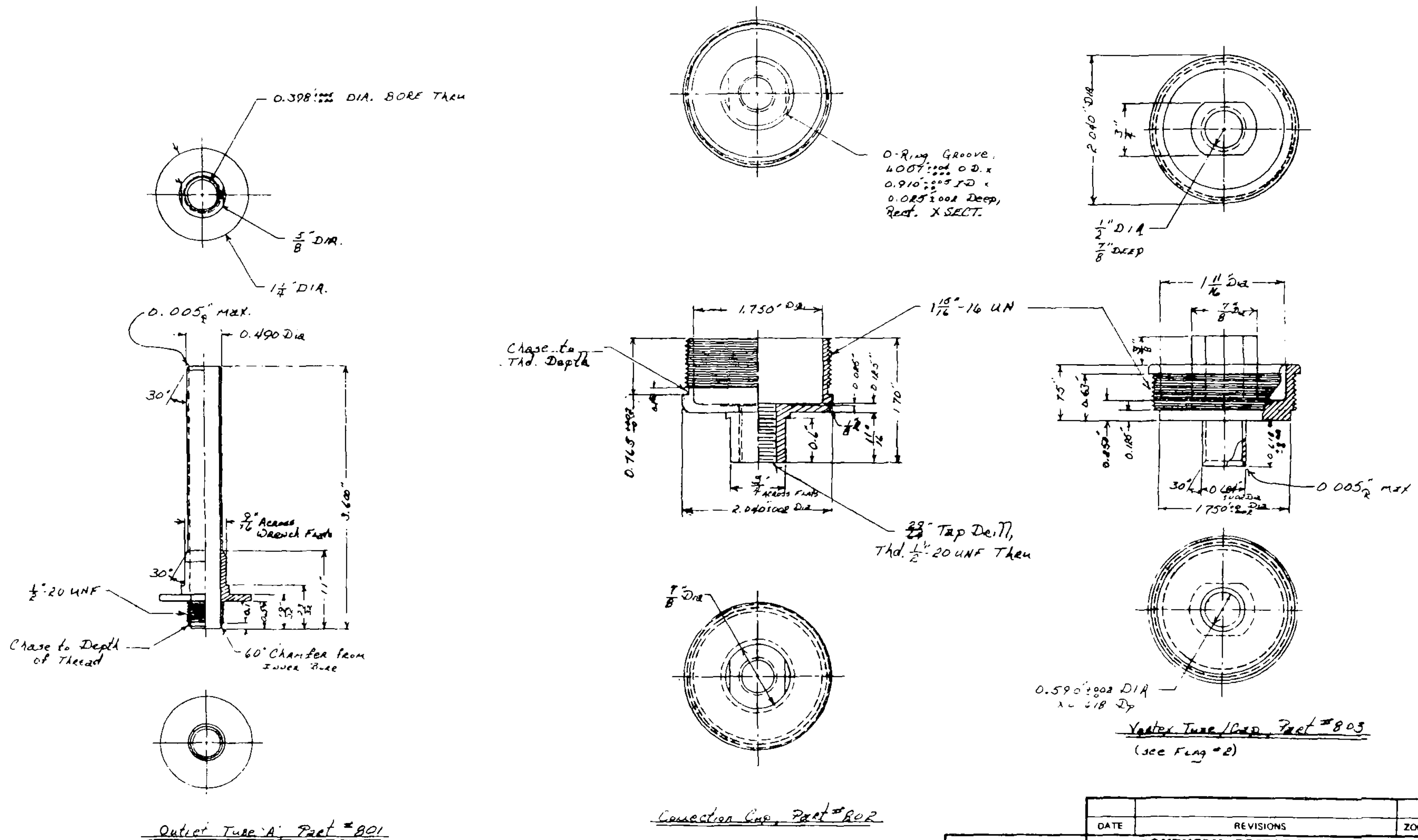
SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205

TITLE: Four Stage Series Cyclone
Cyclone I, Body & Outlet Tube 'B'

SCALE: As Noted | DATE: 6/11/76 | DWG. NO. 3630-1-C-7

ASSY.	ITEM	QUAN.	NAME	DESCRIPTION	MATERIAL
	801	1	Outlet Tube 'A', 1¼" O.D. x 0.398" I.D. x 3.6" L., 6Al-4V Titanium		
	802	1	Collection Cup, 2.04" OD x 1.7" L., 6Al-4V Titanium		
	803	1	Vortex Tube/Cap, 2.04" O.D. x 1¾" L., 6Al-4V Titanium		

All Fillets & Rounds 1/16" R unless Noted



Outlet Tube 'A', Part #801

Collection Cup, Part #802

Vortex Tube/Cap, Part #803 (see Fig. #2)

1. Finish exterior surfaces & Bore to 8 µ inch RMS. Threads & Mating Surfaces to 32 µ inch RMS

2. Finish Interior Surfaces to 8 µ inch RMS, Threads to 32 µ inch RMS

DATE	REVISIONS	ZONE	NO.

TOLERANCES UNLESS OTHERWISE NOTED		
FRACTIONS	± 1/32	± 1/64
DECIMALS	± .010	± .005
ANGLES	± 1°	± ½°
FINISH		As Noted
APPROVED		
CHECKED		
DRAWN	DHH	

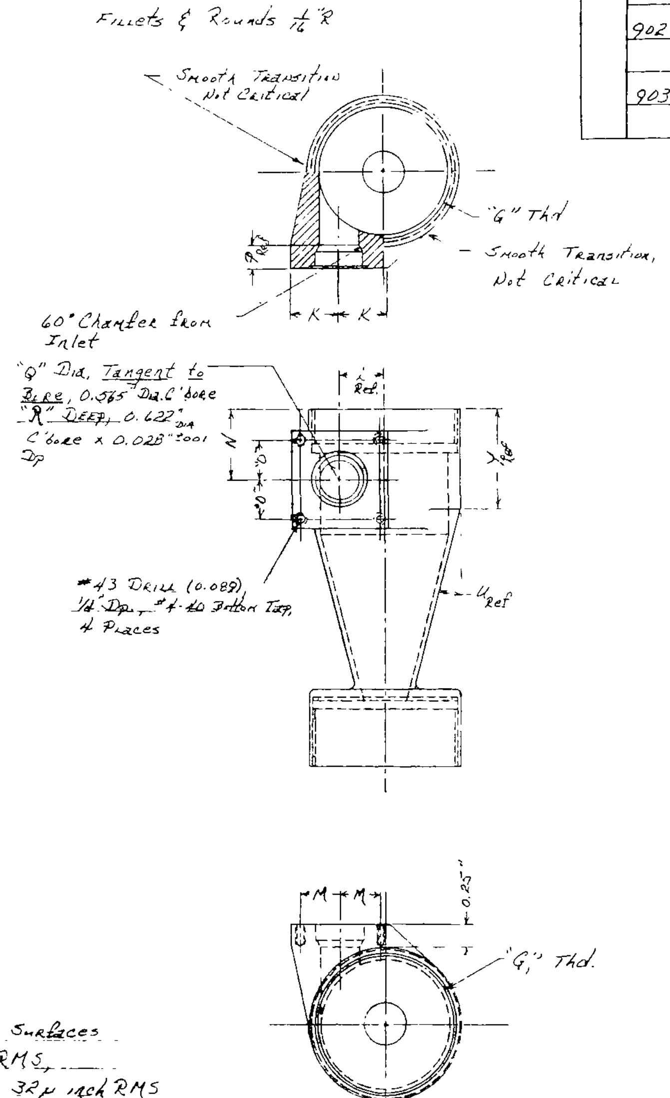
SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205

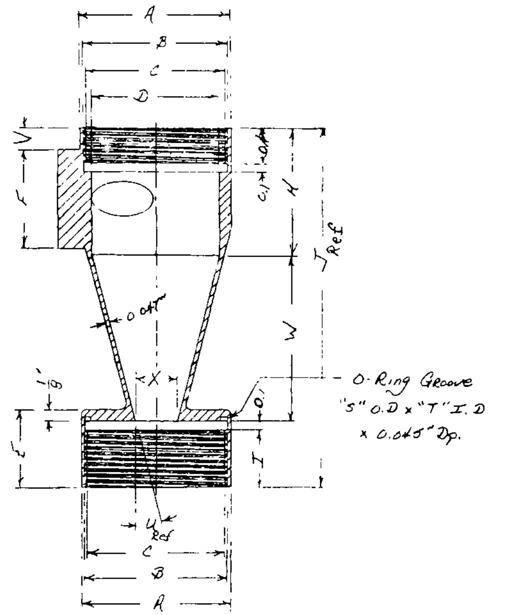
TITLE: Four Stage Series Cyclone
Collection Cup, Vortex Tube, Outlet Tube 'A'

SCALE: Full | DWG. NO. 3630-1-C-8
DATE: 6/10/76

ASSY.	ITEM	QUAN.	NAME / DESCRIPTION / MATERIAL
	901	1	Cyclone II, 2½" O.D x 4.03" L, 6Al-4V Titanium
	902	1	Cyclone III, 2¼" O.D. x 3.29" L, 6Al-4V Titanium
	903	1	Cyclone IV, 2 " O.D x 2.56" L, 6Al-4V Titanium

Designation	Dimension: Cyclone II Part 901	Cyclone III Part 902	Cyclone IV Part 903
A	1.790" ±.005	1.538" ±.005	1.350 ±.005
B	1.632 +.005 −0	1.382 +.005 −0	1.195 +.005 −0
C	1.630	1.375	1.188
D	1.440 +.001 −0	1.223 +.001 −0	1.000 +.001 −0
E	7/8	7/8"	7/8"
F	1.10"	0.800	0.800
G	1 11/16 -16 UN	1 7/16 -16 UN	1 1/4 -16 UN
H	1.430	1.150	1.006
I	0.650	0.650	0.650
J	4.035 Ref.	3.283 Ref	2.656 Ref
K	0.550	0.400	0.400
L	0.522"	0.464	0.400
M	0.450	0.300	0.300
N	0.800	0.750	0.700
O	0.450	0.300	0.300
P	0.345 Ref	0.434 Ref	0.475 Ref.
Q	0.397	0.295	0.201
R	0.200	0.200	0.160
S	1.632 +.005 −0	1.382 +.005 −0	1.195 +.005 −0
T	1.475 +0 −.005	1.225 +0 −.005	1.037 +0 −.005
U	14°5' Ref.	18°30' Ref	23°59' Ref
V	0.250"	0.350"	0.300"
W	1.855	1.383	0.900
X	0.509"	0.298	0.199
Y	0.927"	0.826"	0.722"





Finish Interior Surfaces to 8μ-inch RMS, Threads to 32μ inch RMS

Note: Clip Crest of thread 'G' to I.D. of 'C'. See Details A & B, Drawing No. 3630-1-C-7, for Qualitative clarification.

DATE	REVISIONS	ZONE	NO.

TOLERANCES UNLESS OTHERWISE NOTED		
FRACTIONS	± 1/32	± 1/64
DECIMALS	± .010	± .002
ANGLES	± 1°	± 1/2
FINISH		As Noted
APPROVED		
CHECKED		
DRAWN	DHH	

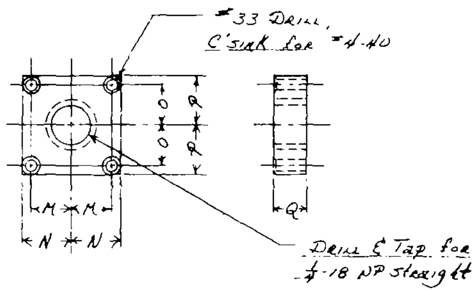
SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205

TITLE: Four Stage Series Cyclone

Cyclone II, III, IV Body

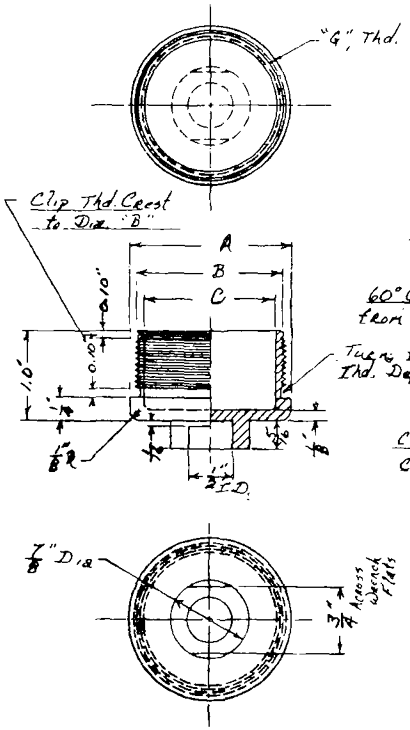
SCALE: Full
DATE: 6/17/76
DWG. NO. 3630-1-C-9

ASSY.	ITEM	QUAL.	NAME	DESCRIPTION	MATERIAL
			See Addendum		

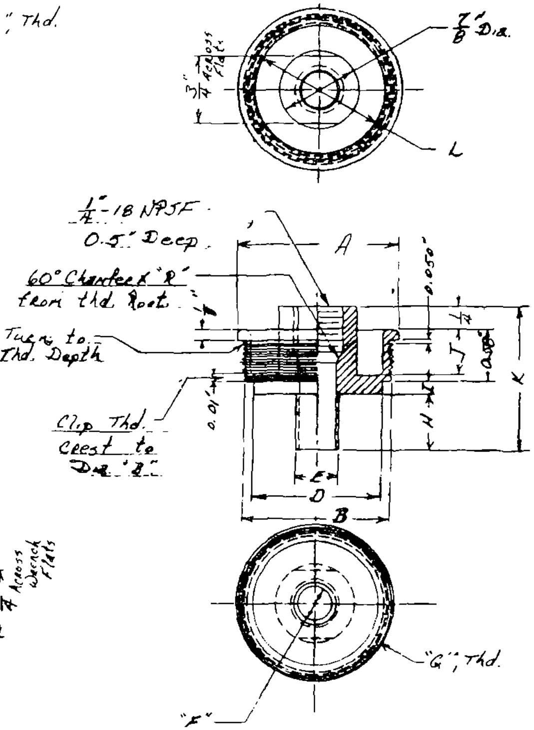


Inlet Adaptor, Part # —-C

Designation	Dimension Cyclone II Parts 1001 A, B, C	Cyclone III Parts 1002 A, B, C	Cyclone IV Parts 1003 A, B, C
A	1.790 ±.005	1.538 ±.005	1.350 ±.005
B	1.630 +0/-.001	1.380 +0/-.001	1.193 +0/-.001
C	1 15/32"	1 7/32"	1 1/32"
D	1.435 +0/-.002	1.220" +0/-.002	0.997" +0/-.002
E	0.465"	0.400"	0.300"
F	0.414" Dia	0.328" Dia	0.234" Dia
G	1 11/16"-16 UN	1 7/16"-16 UN	1 1/4"-16 UN
H	0.618"	0.425"	0.230"
I	0.145"	0.145"	0.145"
J	0.500	0.500	0.40
K	1.593" Ref	1.400" Ref.	1.205" Ref.
L	1 15/32" Dia	1 7/32" Dia	N/A
M	0.450"	0.300"	0.300"
N	0.550"	0.400"	0.400"
O	0.450"	0.300"	0.300"
P	0.550"	0.400"	0.400"
Q	3/8"	3/8"	11/32"
R	0.109"	0.184"	0.265"



Collection Cup, Part # —-A



Vortex Tube / Outlet, Part # —-B

Polish Interior Surfaces to 8 μ-inch RMS, Threads & Mating Surfaces to 32 μ-inch RMS.

DATE	REVISIONS	ZONE	NO.

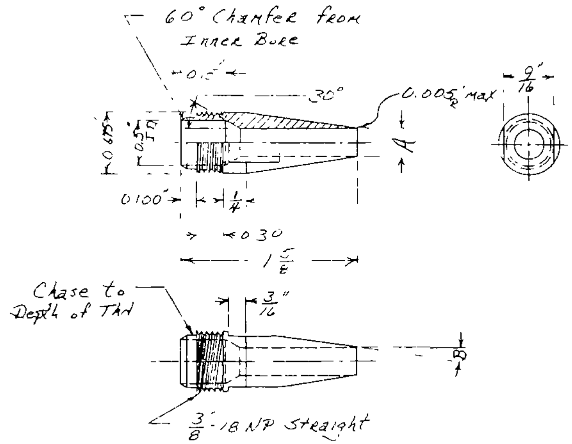
TOLERANCES UNLESS OTHERWISE NOTED		
FRACTIONS	± 1/32	± 1/64
DECIMALS	± .010	± .005
ANGLES	± 1°	± 1/2°
FINISH		63
APPROVED		
CHECKED		
DRAWN	D H H	

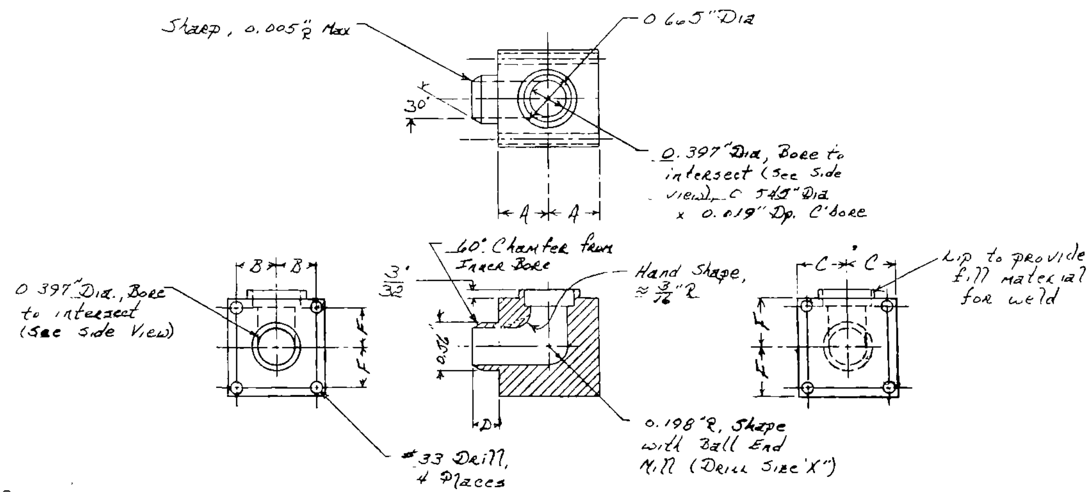
SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205

TITLE Four Stage Series Cyclone
Cyclone II, III, & IV
Inlet Adaptor, Collection Cup, Vortex Tube

SCALE Full
DATE 6/16/76
DWG. NO 3630-1-C-10

ASSY.	ITEM	QUAN.	NAME DESCRIPTION MATERIAL
A	1101	1	Elbow, 1.1"W x 1.1"H x 1.37"L, 316 S.S.
B	1102	1	Elbow, 0.80"W x 0.80"H x 1.37"L, 316 S.S.
B	1103	1	Elbow, 0.80"W x 0.80"H x 1.34"L, 316 S.S.
N/A	N/A	10	Nozzle, 0.675" O.D. x 1 5/8" L, 6Al-4V Titanium





Nozzle No.	Dimension 'A'	Dimension 'B'
1	0.177	14° 19' Ref.
2	0.196	13° 48' Ref.
3	0.213	13° 19' Ref.
4	0.238	12° 39' Ref.
5	0.277	11° 32' Ref.
6	0.316	10° 26' Ref.
7	0.358	9° 41' Ref.
8	0.397	8° 6' Ref.
9	0.435	7° 1' Ref.
10	0.475	5° 51' Ref.

Nozzle

Full Scale for Nozzle No. 6

Designation	Dimension Part #1101	Part #1102	Part #1103
A	0.558"	0.558"	0.558"
B	0.450"	0.300"	0.300"
C	0.550"	0.400"	0.400"
D	0.345"	0.345"	0.305"
E	0.450"	0.300"	0.300"
F	0.550"	0.400"	0.400"

Elbow, Full Scale

DATE	REVISIONS	ZONE	NO.

SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205

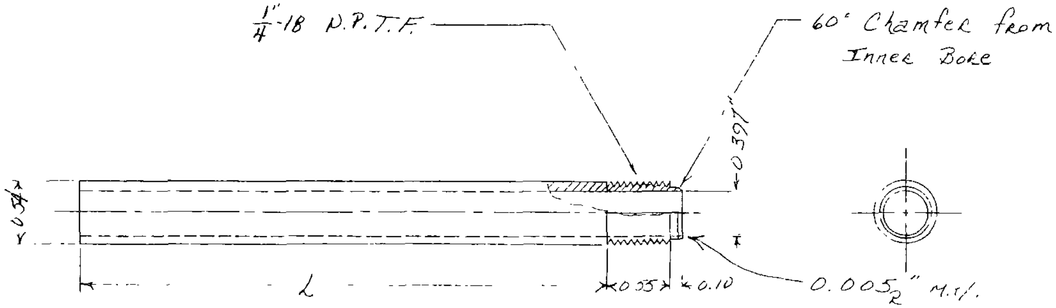
TOLERANCES UNLESS OTHERWISE NOTED		
FRACTIONS	± 1/32	± 1/64
DECIMALS	± .010	± .002
ANGLES	± 1°	± 1/2
FINISH	32μ-inch	
APPROVED		
CHECKED		
DRAWN	DKH	

TITLE: Four Stage Series Cyclone

Elbow & Nozzle

SCALE: As Noted — DATE: 6/18/76 — DWG. NO: 3630-1-C-11

ASSY.	ITEM	QUAN.	NAME DESCRIPTION MATERIAL
	1202	1ea	Connector, 0.54" O.D x 0.397 I.D. x 4.13 L (1/4" Pipe, Sched 40) 316 SS
	1201	1ea	Connector, 0.54" O.D x 0.397 I.D. x 1.22 L 316 S.S.



For Part #1201, L = 5/16"
For Part #1202, L = 3 3/8"

TOLERANCES UNLESS OTHERWISE NOTED		
FRACTIONS	± 1/32	± 1/64
DECIMALS	± .010	± .012
ANGLES	± 1°	± 1/2
FINISH	32 μ in RMS	
APPROVED		
CHECKED		
DRAWN		

DATE	REVISIONS	ZONE	NO.
			A

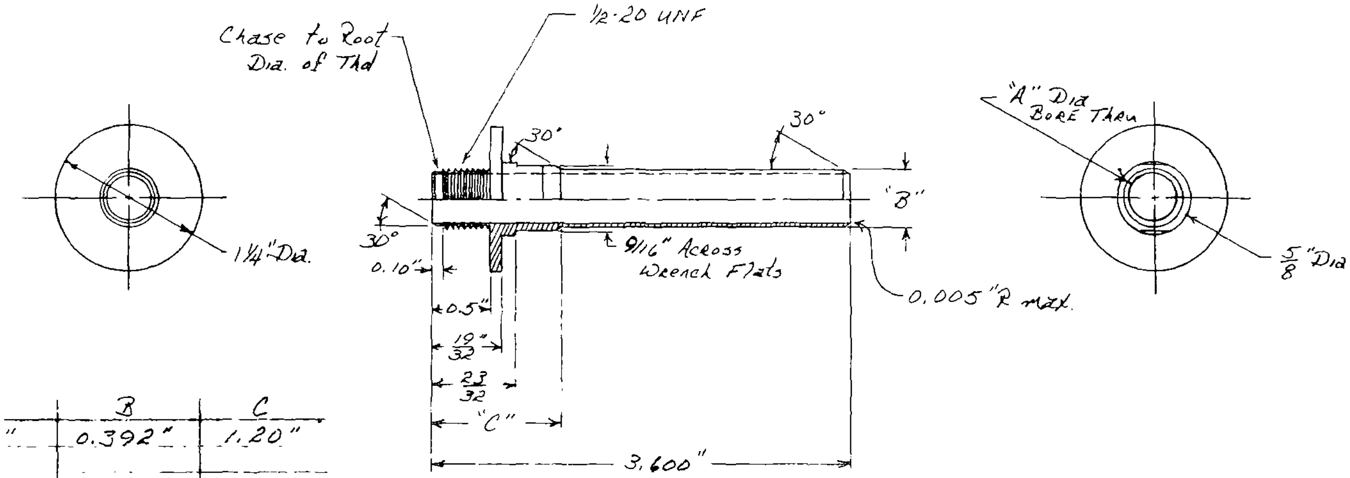
SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205

TITLE: SRI Series Cyclone Connectors

SCALE | DWG NO. -B-

REPRINT CORP 7-75

ASSY.	ITEM	QUAN.	NAME DESCRIPTION MATERIAL
	8016	1ea	Outlet Tube 1¼" O.D. x 3.6" L, Mat'l As Specified



Part No.	A	B	C
8016	0.318"	0.392"	1.20"

Finish Exterior Surface & Bore to 8 μ-inch RMS.,
Threads & Mating Surfaces to 32 μ-inch RMS.

TOLERANCES UNLESS OTHERWISE NOTED		
FRACTIONS	± 1/32	± 1/64
DECIMALS	± .010	± .002
ANGLES	± 1°	± ½°
FINISH	As Noted	
APPROVED		
CHECKED		
DRAWN		

DATE	REVISIONS	ZONE	NO

SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205

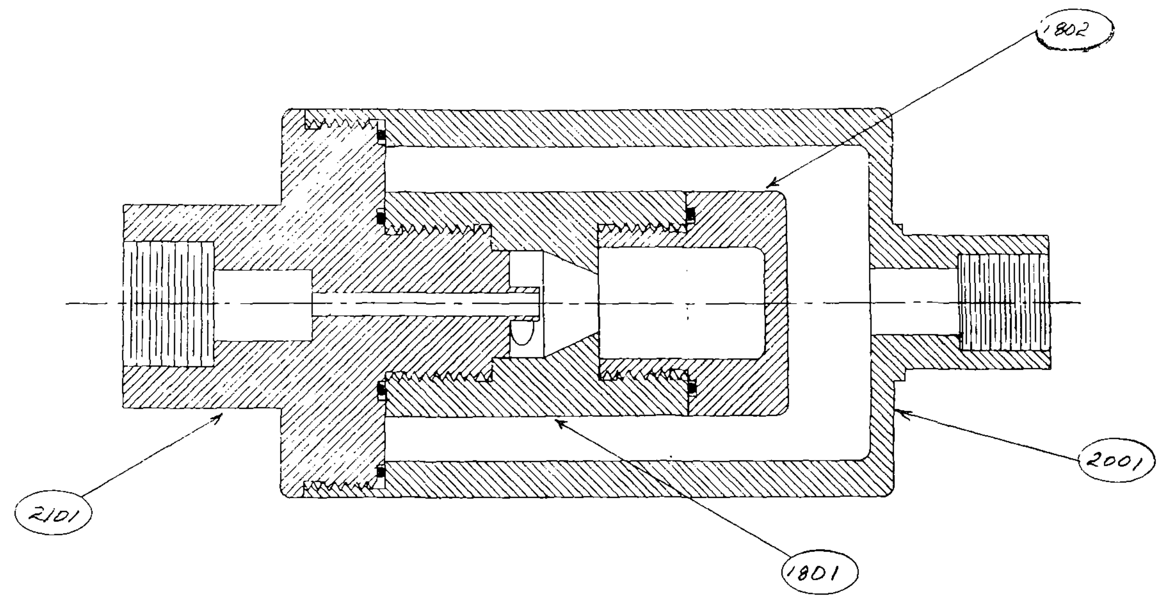
TITLE Four Stage Series Cyclone
Auxillary Outlet Tubes 'A'

SCALE Full | DWG. NO. 3630-1(4d)-B-23
DATE 11/3/76

Addendum

ASSY	ITEM	QUANT.	NAME	DESCRIPTION	MATERIAL
B	1001A	1	Collection Cup	Cyclone II, 6A7-4V	1.79" O.D. X 1 5/16" L, Titanium
B	1001B	1	Vortex Tube/Out-let	Cyclone II, 6A7-4V	1.79" O.D. x 1.6" L, Titanium
N/A	1001C	1	Inlet Adapter	Cyclone II, 6A7-4V	1.1" W x 1.1" H x 3/8" L, Titanium
B	1002A	1	Collection Cup	Cyclone III, 6A7-4V	1.54" O.D. x 1.6" L, Titanium
B	1002B	1	Vortex Tube/Out-let	Cyclone III, 6A7-4V	1.54" O.D. x 1.4" L, Titanium
B	1002C & 1003C	1 1	Inlet Adapter (402C & 403C Identical)	Cyclone III, 6A7-4V	0.8" W x 0.8" H x 3/8" L, Titanium
B	1003A	1	Collection Cup	Cyclone IV, 6A7-4V	1.35" O.D. x 1.6" L, Titanium
B	1003B	1	Vortex Tube/Out-let	Cyclone IV, 6A7-4V	1.35" O.D. x 1.21" L, Titanium

ASSY.	ITEM	QUAN.	NAME	DESCRIPTION	MATERIAL
A	1801	1 ea	Cyclone Body		
	1802	1 ea	Collector Cup		
	2001	1 ea	Outer Shell		
	2101	1 ea	Cap & Vortex Tube		



DATE	REVISIONS	ZONE	NO.

SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205

TOLERANCES UNLESS OTHERWISE NOTED	
FRACTIONS	$\pm \frac{1}{32}$
DECIMALS	$\pm$ .010
ANGLES	$\pm 1°$
FINISH	
APPROVED	
CHECKED	KMT
DRAWN	HH

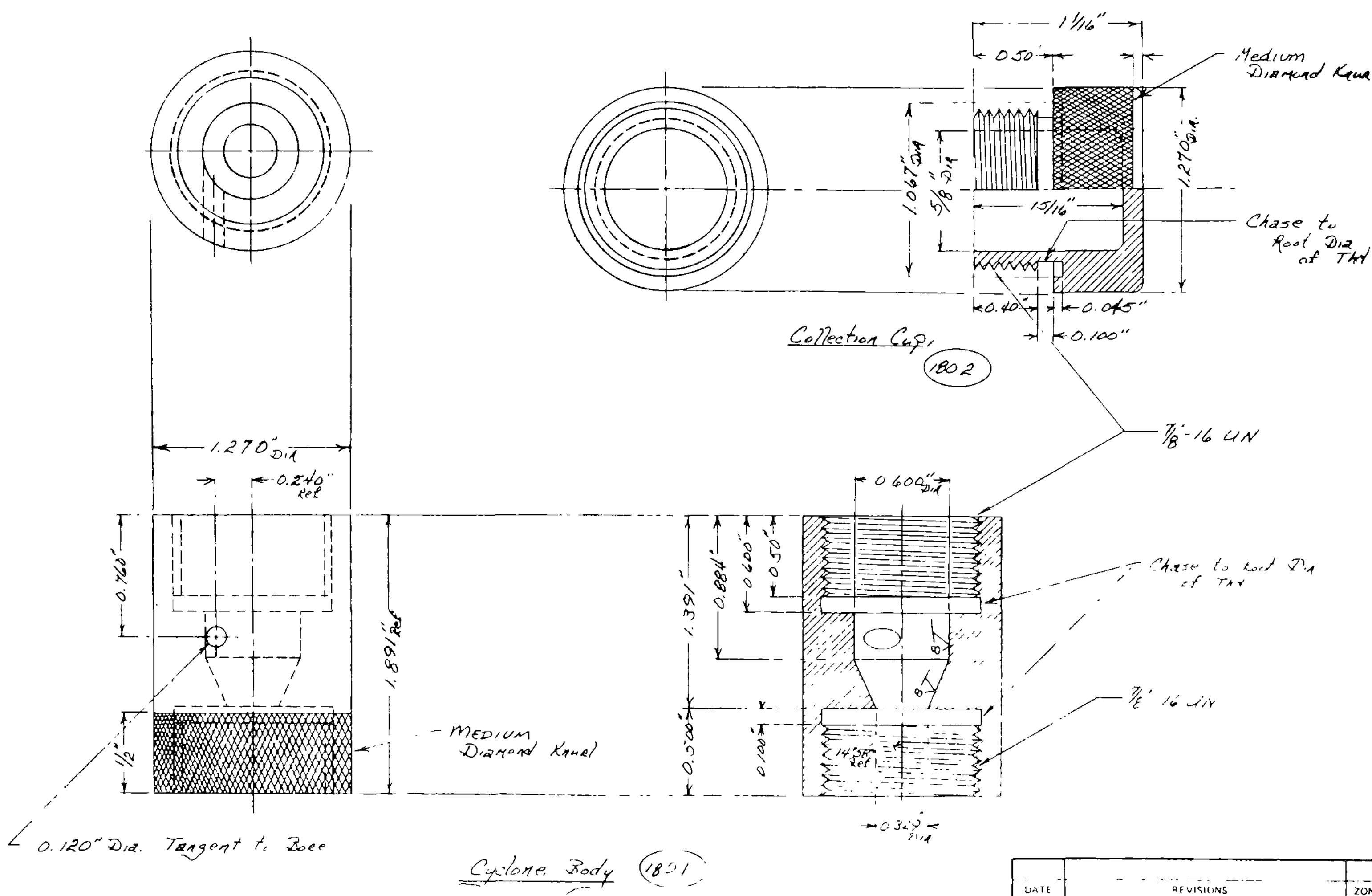
TITLE: Backup Cyclone, MK II

Assembly View

SCALE 2X
DATE 9/24/76
DWG. NO. 3630-1(4d)-C-17

ASSY.	ITEM	QUAN.	NAME / DESCRIPTION / MATERIAL
A	1801	1 ea	Cyclone Body, 1.27" O.D. x 1 1/2" L
			Mat'l as specified
	1802	1 ea	Collection Cup, 1.27" O.D. x 1 1/16" L
			Mat'l as specified

All Fillets & Rounds 1/16" R

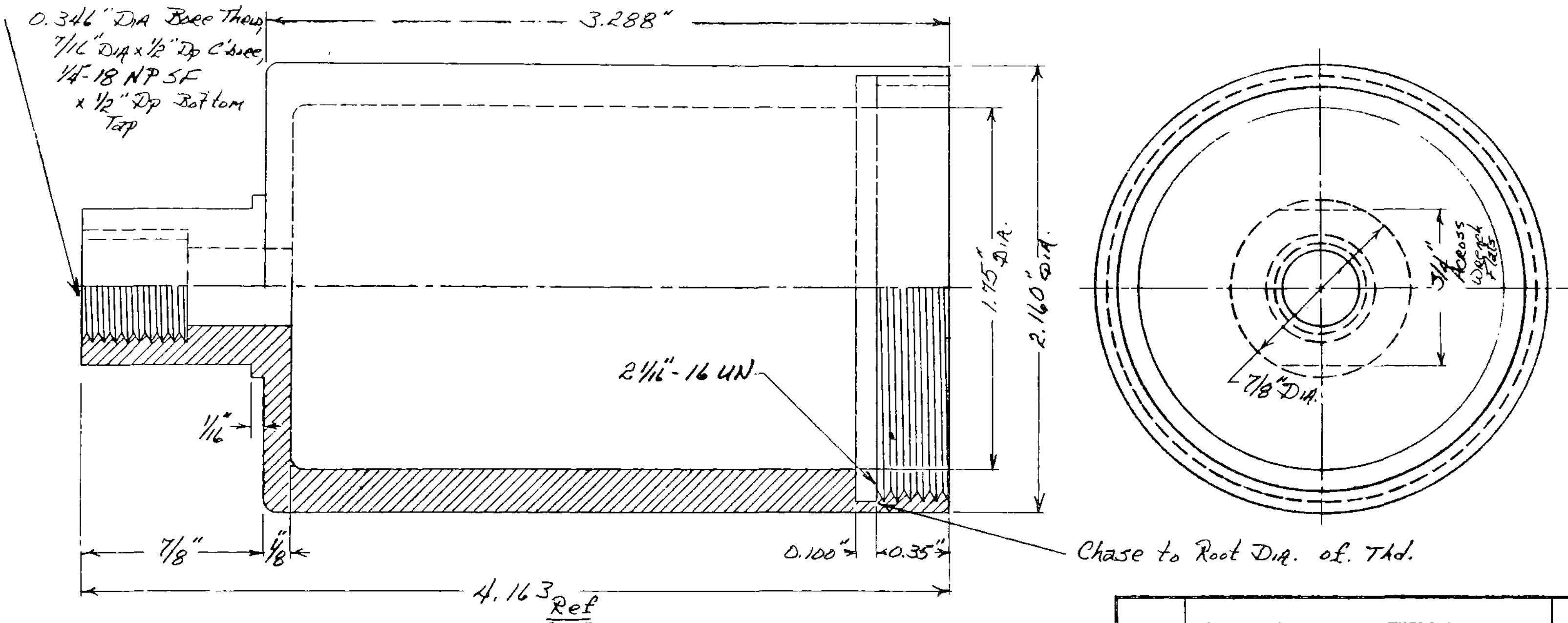


DATE	REVISIONS	ZONE	NO
			A

TOLERANCES UNLESS OTHERWISE NOTED	**SOUTHERN RESEARCH INSTITUTE** BIRMINGHAM, ALABAMA 35205
FRACTIONS 1/32	TITLE [illegible] cyclone, MK II
DECIMALS .010	[illegible] Body & Collection Cup
ANGLES	
FINISH	
APPROVED	
CHECKED [illegible]	SCALE 2X
DRAWN [illegible]	DATE [illegible] 76 — DWG NO 3630-1140-C-18

ASSY.	ITEM	QUAN.	NAME	DESCRIPTION	MATERIAL
	2001	1ea	Outer Shell, 2.16" O.D. x 4.163 Lg		
			Mat'l as specified		

All Fillets & Rounds 1/16" R



DATE	REVISIONS	ZONE	NO.
			A

SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205

TOLERANCES UNLESS OTHERWISE NOTED		
FRACTIONS	± 1/32	± 1/64
DECIMALS	± .010	± .002
ANGLES	± 1°	
FINISH	32 μ-inch	
APPROVED		
CHECKED	[signature]	
DRAWN	DHH	

TITLE Backup Cyclone, MK II

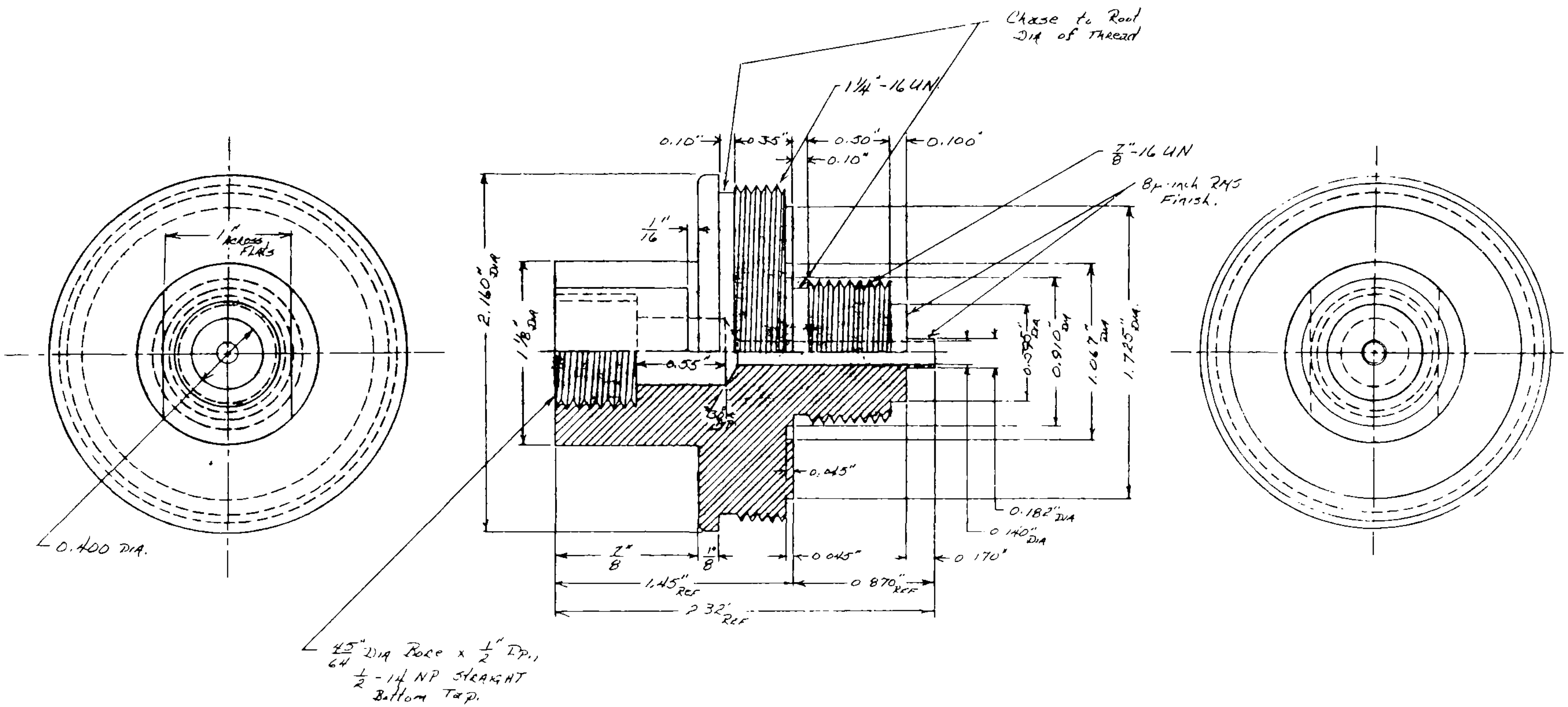
Outer Shell (2001)

SCALE 2X
DATE 9/23/76
DWG. NO. 3630-1(4d)-B-20

REPRINT CORP. 7-75

ASSY.	ITEM	QUAN.	NAME	DESCRIPTION	MATERIAL
	2131	1	Vortex Tube & Cap, 2¼" O.D. x 2⅜" L.		
			Mat'l as specified.		

All Fillets & Rounds 1/16" R.



Part 301

DATE	REVISION	ZONE	NO

TOLERANCES UNLESS OTHERWISE NOTED	**SOUTHERN RESEARCH INSTITUTE** BIRMINGHAM, ALABAMA 35205
FRACTIONS ± 1/32 ± 1/64	TITLE Backup Cyclone Mk II
DECIMALS ± .010 ± .002	
ANGLES ± 1	
FINISH	Vortex Tube & Cap
APPROVED	
CHECKED	SCALE 2X
DRAWN	DATE 12/11/76
	DWG NO 3630-114di-C-2

The following is a listing of seals required for a single set of cyclones:

Cyclone I:

1 ea. #1000-1-7, 1.000" O.D. X 0.035" Dia., Inconel X-750 Metal-O-Ring;

2 ea. #1875-2-7, 1.875" O.D. X 0.062" Dia., Inconel X-750 Metal-O-Ring, or #E-C-E-001750-5-7-1, 1.750" I.D. X 0.062" Free Height Metal-C-Ring;

Cyclone II:

2 ea. #1625-2-7, 1.625" O.D. X 0.062" Dia., Inconel X-750 Metal-O-Ring, or #E-C-E-001500-5-7-1, 1.500" I.D. X 0.062" Free Height Metal-C-Ring;

Cyclone III:

2 ea. #1375-2-7, 1.375" O.D. X 0.062" Dia., Inconel X-750 Metal-O-Ring, or #E-C-E-001250-5-7-1, 1.250" I.D. X 0.062" Free Height Metal-C-Ring;

Cyclone IV:

2 ea. #1188-2-7, 1.188" O.D. X 0.062" Dia., Inconel X-750 Metal-O-Ring, or #E-C-E-001062-5-7-1, 1.062" I.D. X 0.062" Free Height Metal-C-Ring;

Cyclone V:

2 ea. #1062-2-7, 1.062" O.D. X 0.062" Dia., Inconel X-750 Metal-O-Ring, or #E-C-E-000938-5-7-1, 0.938" I.D. X 0.062" Free Height Metal-C-Ring;

1 ea. #1938-2-7, 1.938" O.D. X 0.062" Dia., Inconel X-750 Metal-O-Ring, or #E-C-E-001812-5-7-1, 1.812" I.D. X 0.062" Free Height Metal-C-Ring.

Available from: Advanced Products Co.
Defco Park Road
North Haven, Connecticut
06473

SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205

TITLE: Five Stage Series Cyclone & Backup

SCALE: N/A
DATE: 7/14/77
DWG. NO.: 3630-1-A-24

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-78-008	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Development and Laboratory Evaluation of a Five-stage Cyclone System		5. REPORT DATE January 1978 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Wallace B. Smith and Rufus Ray Wilson, Jr.		8. PERFORMING ORGANIZATION REPORT NO. SORI-EAS-78-44
9. PERFORMING ORGANIZATION NAME AND ADDRESS Southern Research Institute 2000 Ninth Avenue, South Birmingham, Alabama 35205		10. PROGRAM ELEMENT NO. EHE624 11. CONTRACT/GRANT NO. 68-02-2131, T.D. 10602
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 4/76-6/77 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is D. Bruce Harris, Mail Drop 62, 919/541-2557.

16. ABSTRACT The report describes the development and calibration of a five-stage cyclone system, designed and fabricated by Southern Research Institute. The system was calibrated using both a vibrating-orifice aerosol generator (to generate monodisperse, large-diameter dye particles for use at ambient and higher temperatures) and a pressurized Collison nebulizer (to disperse monodisperse, small-diameter latex particles for use at ambient temperature). Results from calibrating the cyclones at several conditions of flow, temperature, and particle density suggest that the D(50) cut points are proportional to the gas flow rate raised to a negative exponent which is between -0.63 and -1.11, linearly proportional to the gas viscosity, and proportional to the reciprocal of the square root of the particle density. At 25 C, 28.3 liters/min, and for a particle density of 1.0 g/cc, the D(50) cut points were 5.4, 2.1, 1.4, 0.65, and 0.32 micrometers for cyclones I-V, respectively.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Calibrating	Air Pollution Control	13B
Cyclone Separators		Stationary Sources	07A
Development		Particulate	14B
Evaluation			
Aerosols			07D
Dust			11G

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