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INTERIM REPORT

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July 10, 1979

Mr. Donald E. Solberg
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US Nuclear Regulatory Commission
Washington, DC 20555

Dear Don:

SUBJECT: R-295 QUARTERLY PROGRESS LETTER (JANUARY 1 - MARCH 31, 1979)

This quarter, our investigations have included the following three areas:

A. interpretation of clean High Efficiency Particulate Air (HEPA) filter structural test data,

B. construction of an apparatus that will load 24- by 24-in. (0.62- by 0.62-m) HEPA filters with aerosol particles, and

C. planning of the HEPA filter medium strength test program.

This letter will summarize our results in each of these work areas. Detailed information for each area is included in the appendixes.

I. RESULTS

A. Interpretation of Clean HEPA Filter Structural Test Data

We have structurally tested about 125 24- by 24-in. (0.62- by 0.62-m) HEPA filters as of March 31, 1979. The methodology we used is explained in Appendix A. Except for tests of HEPA filters with face-guards, the clean HEPA filter tests are complete. Therefore, we have started the data reduction and analysis. We statistically analyzed

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the test data using a code supplied by a LASL statistics group. The detailed results of the statistical analysis are presented in Appendix B. The application of this statistical analysis to parameter results will be discussed in this section.

The testing program was a parametric study. The dependent variable was the static air pressure drop across the filter when its medium failed. Our analysis reveals that, of the parameters analyzed so far, the filter manufacturer is the only significant parameter.

We found that each manufacturer's filters failed at pressure values that followed a normal frequency distribution (see Appendix B). The statistical results are summarized in Table I.

TABLE I
BREAK PRESSURE STATISTICS

Manufacturer	$\overline{P}_B$	$S_{\overline{P}_B}$	S	$\overline{P}_B$-S	$\overline{P}_B$-2S
American Air Filter	2.5	0.12	0.56	1.9	1.38
Cambridge Filter	2.91	0.14	0.46	2.45	1.99
Flanders Filter	1.32	0.06	0.22	1.10	0.88
Mine Safety Appliance (MSA)	2.66	0.11	0.32	2.34	2.02
All	2.37	0.10	0.71	1.66	0.95

where

$\overline{P}_B$ = Mean HEPA filter break pressure (psi)

$S_{\overline{P}_B}$ = Standard error of the mean (psi)

S = Standard deviation (psi)

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Flanders filters have a low mean break pressure, but are the most consistent. American air filters have a reasonably high mean break pressure, but wide data scatter. The Cambridge and MSA HEPA filters have the highest mean break pressures and little data scatter.

We did both a correlation analysis and a multiple linear regression analysis of the four data sets (one set for each manufacturer). We tried to determine the functional relationship of pressurization rate, time to break, number of medium folds, rated dioctyphthalate (DOP) penetration, and rated flow resistance to break pressure. The correlation analysis (Appendix B) shows the degree of correlation between any two variables. The multiple linear regression analysis (Appendix B) shows the correlation of linear combinations of the variables to the break pressure. Tables II and III show, respectively, the major results of the correlation and multiple linear regression analyses. There is no consistency between data sets in either case.

TABLE II

CORRELATION ANALYSIS RESULTS

Data Set	Relative Correlation				
	High				Low
	1	2	3	4	5
American Air Filter	T	D	Δ	R	N
Cambridge Filter	R	N	D	Δ	T
Flanders Filter	T	Δ	D	R	N
Mine Safety Appliance	D	T	Δ	R	N

Variables correlated to break pressure:

T = time to break
N = number of medium folds
D = rated DOP penetration
R = rated flow resistance
Δ = pressurization rate

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TABLE III

MULTIPLE LINEAR REGRESSION ANALYSIS RESULTS

Data Set	Regression Step				
	1	2	3	4	5
American Air Filter	T	Δ	R	N	D
Cambridge Filter	R	D	N	T	Δ
Flanders Filter	T	D	N	Δ	—
Mine Safety Appliance	D	N	R	Δ	T

Dependent variable = break pressure:

T = time to break
N = number of medium folds
D = rated DOP penetration
R = rated flow resistance
Δ = pressurization rate

Also, earlier test results established that the following parameters had no effect on the filter break pressure:

- flow direction,
- duration of maximum pressure,
- aluminum separator,
- test air temperature, and
- test air relative humidity.

Therefore, at this time, the only apparent determinant of the filter break pressure for a clean HEPA filter is its manufacturer.

B. Construction of an Apparatus that Will Load Large HEPA Filters with Aerosol Particles

The large-scale filter loading apparatus is now complete. We will load 24- by 24-in. (0.62- by 0.62-m) HEPA filters with 0.5 μm aerosol particles. It will take about a week to load a filter to a resistance of 6 in. w.g. (1.5 kPa) at the rated flow. Figure 1 is a drawing of the apparatus. Its operation is explained in Appendix C.

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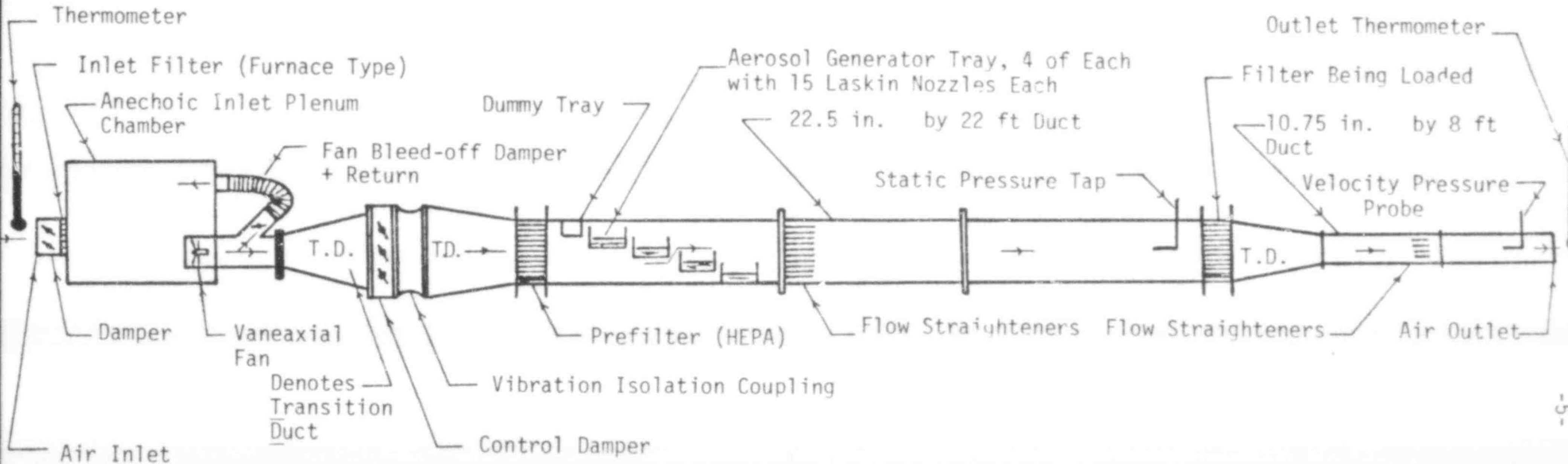

Fig. 1.

Filter-loading device.

C. Determination of the HEPA Filter Medium Strength Test Program

We will be testing HEPA filter medium strength to determine any correlation between medium strength and break pressure. We will establish this correlation by testing media removed from HEPA filters that have failed in our tornado simulator. The medium tests will consist of the standard medium tests performed at Rocky Flats Filter Acceptance Laboratory and a special impact test that we have designed (See Appendix D).

This quarter we contacted the Institute of Paper Chemistry, the Technical Association of the Pulp and Paper Industry, and Rocky Flats Filter Acceptance Laboratory to obtain information on medium testing. Only Rocky Flats personnel gave us useful information and will help us test our medium samples at their laboratory. We have started taking samples from our filters and have planned our tests (See Appendix D).

II. SUMMARY

We have made significant advances toward completion of the structural portion of the HEPA filter tornado response program. We can now load full-size HEPA filters with particulate for structural testing.

Cordially,

Henry L. Horak

W. S. Gregory

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APPENDIX A

STRUCTURAL TEST METHODOLOGY

The Nuclear Regulatory Commission (NRC) defines design basis tornadoes in Regulatory Guide 1.76 by windspeed, pressurization rate, and maximum pressure drop. We have transmuted this into a pressure-vs-time definition. Therefore, our goal in the HEPA filter structural test portion of our overall test program has been to determine the time and pressure at which a HEPA filter will fail for many types of tornadoes and to identify any test or filter parameters that effect the failure time or pressure. During a test, the pressure across the filter along with several other parameters was recorded as a function of time. The logic for analyzing each parameter follows.

1. Manufacturer. HEPA filters from four major manufacturers are installed in US nuclear facilities. Thus any variations between filters from different manufacturers is important.
2. Pressurization rate. The faster the pressure rise, the stronger the impulse.
3. Flow direction. The asymmetric gluing of the medium edges might cause the filter strength to be sensitive to flow direction.
4. Time at maximum pressure. These tests were run to determine if the medium fails because of material fatigue.
5. Time to failure. All parameters are synchronized to time, and therefore the time of failure is important.
6. Number of folds. This number varies from filter to filter (from 60 to 70 folds for one manufacturer) and might be structurally significant.

7. Aluminum separator effect. Asbestos separators, common now, are being banned by the Occupational Safety and Health Administration. Aluminum separators are a possible replacement.
8. Test air relative humidity. Static tests of medium handsheets indicate that high relative humidity weakens the media.
9. Test air temperature. We recorded this variable even though it did not seem, in advance, to be a significant determinant of medium strength. However, the density of the airflow can be calculated using temperature and relative humidity.
10. Filter pressure drop at rated flow. We suspected a correlation to filter strength at high flow.
11. DOP penetration. There is some correlation between medium DOP penetration and tensile strength under quasi-steady loading.
12. Location of the initial break. Consistency would help identify the failure mechanism.
13. Medium area destroyed. This may also help identify the failure mechanism. Safety analysis reviewers are interested in this parameter.
14. Medium tensile strength. This may correlate with filter strength at high airflow.
15. Medium impact strength. This may correlate with filter strength under transient airflow loading.
16. Medium DOP penetration. This may correlate with filter strength under high airflow conditions.

These parameters are measured before, during, or after the transient test as appropriate. Tests 10, 11, 14, 15, and 16 are done at Rocky Flats HEPA Filter Acceptance Laboratory. The others are measured at the LASL test facility at New Mexico State University. All parameters recorded during the test are time-synchronized to a high-speed movie of the downstream face of the test filter during the test.

APPENDIX B

STATISTICAL ANALYSIS OF CLEAN HEPA FILTER STRUCTURAL TEST DATA

Three statistical analysis techniques were used:

1. Frequency distribution
2. Correlation between parameters
3. Multiple linear regression.

Results of these techniques are presented in this appendix.

1. Frequency distribution

   The break pressure of all standard HEPA filters was plotted on probability paper by manufacturers. These plots are Figs. B-1 thru B-4. The closeness of the data to a straight line in each case shows that the distribution is close to normal (Gaussian). From the data, the mean, standard deviation, and standard error of the mean for the break pressure were calculated for each manufacturer's filters. These are presented in the text of the letter as Table I. (Standard error of the mean gives an indication of the variation of the mean of another sample of the data from the mean of this sample.)

2. Correlation between parameters

   Using the statistics code, we have determined the degree of correlation between any two of the parameters we input. In the tables that follow, the correlation coefficients between parameters range from 0 (no correlation) to 1 (perfect correlation). Negative values represent anticorrelation, which means the amount of change in each variable set correlates, but the order is opposite.

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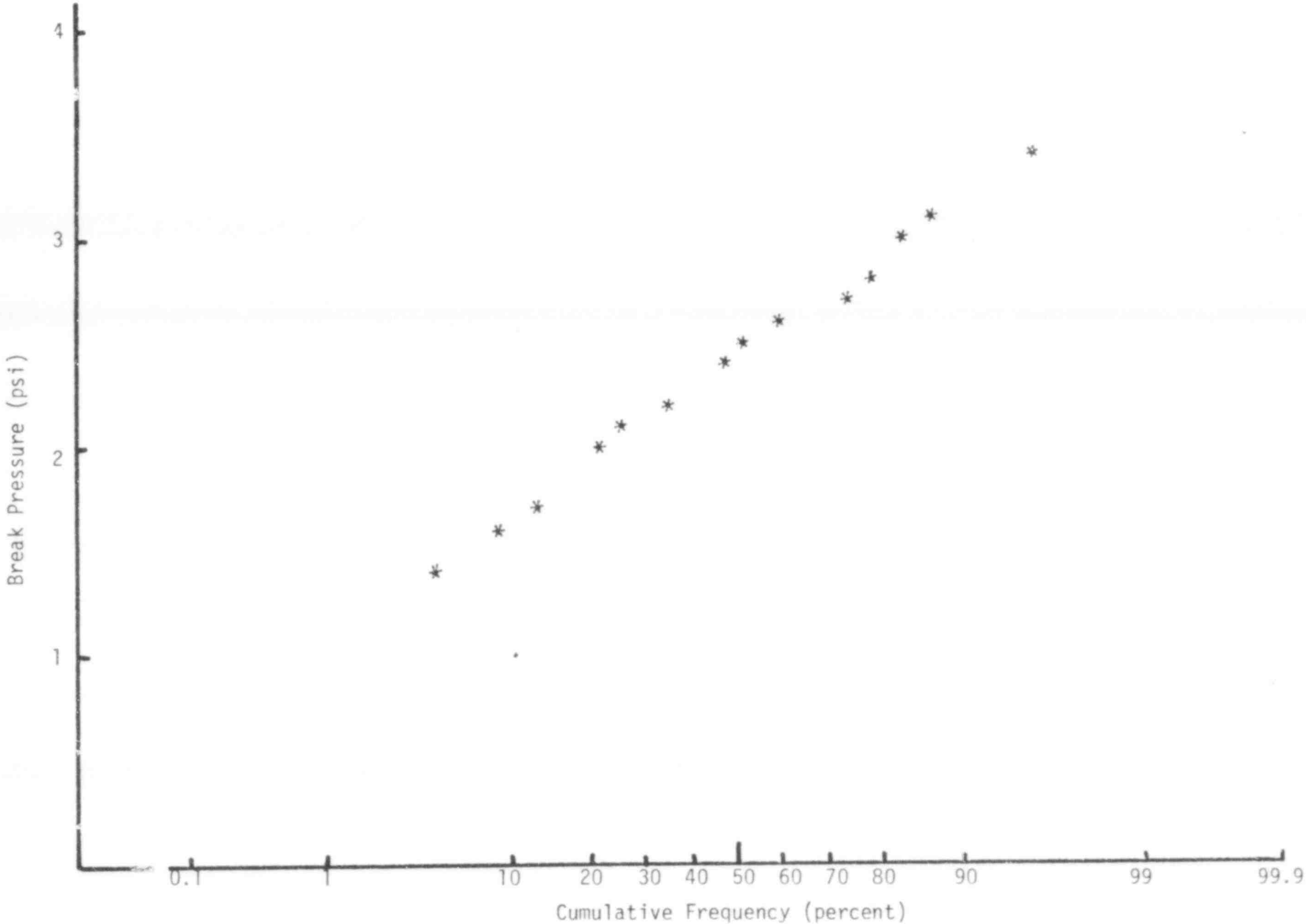

Fig. B-1.
Break pressure vs cumulative frequency, AAF 1000-cfm HEPA filters.

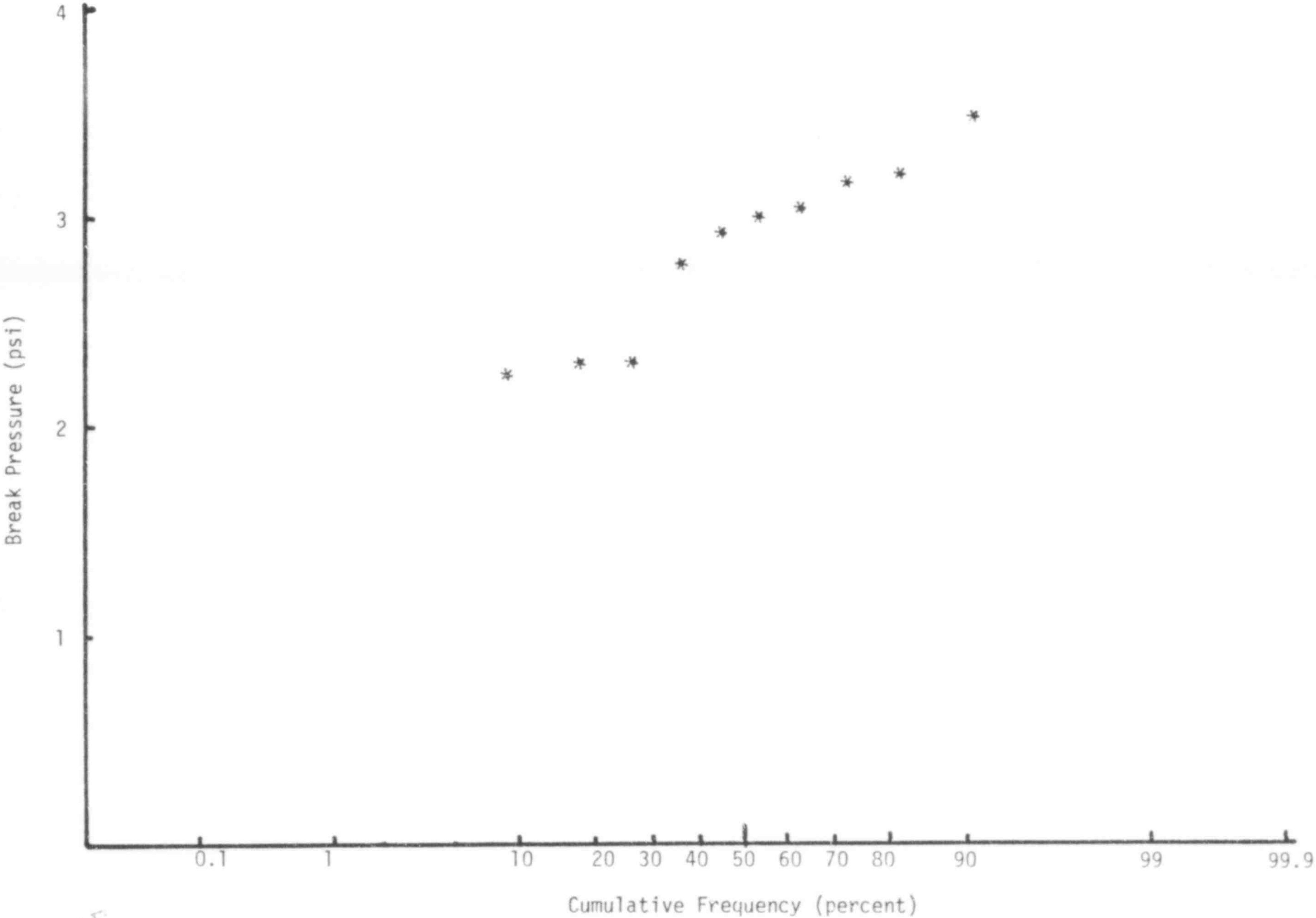

Fig. B-2.
Break pressure vs cumulative frequency, Cambridge 1000-cfm HEPA filters.

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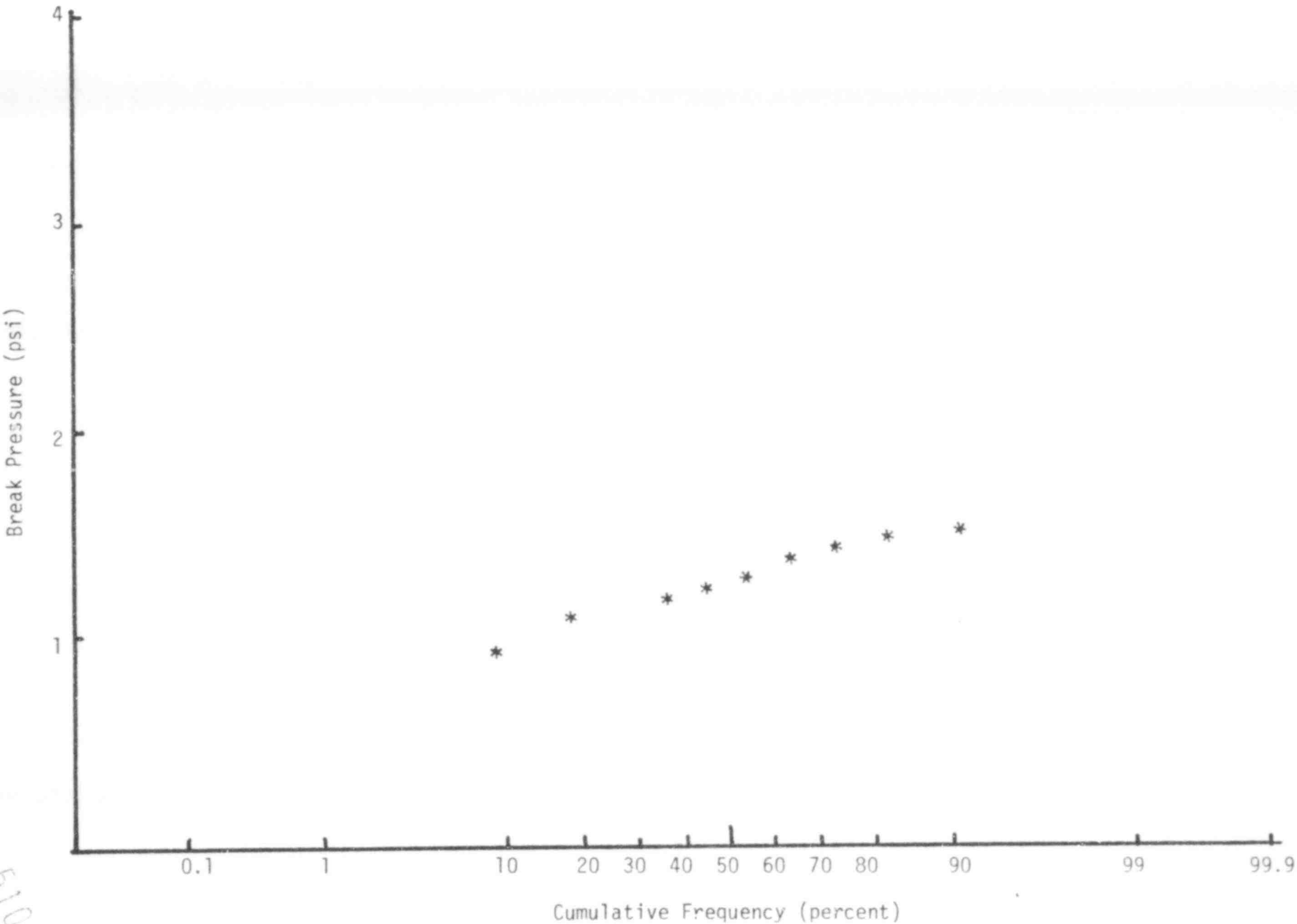

Fig. B-3.
Break pressure vs cumulative frequency, Flanders 1000-cfm HEPA filters.

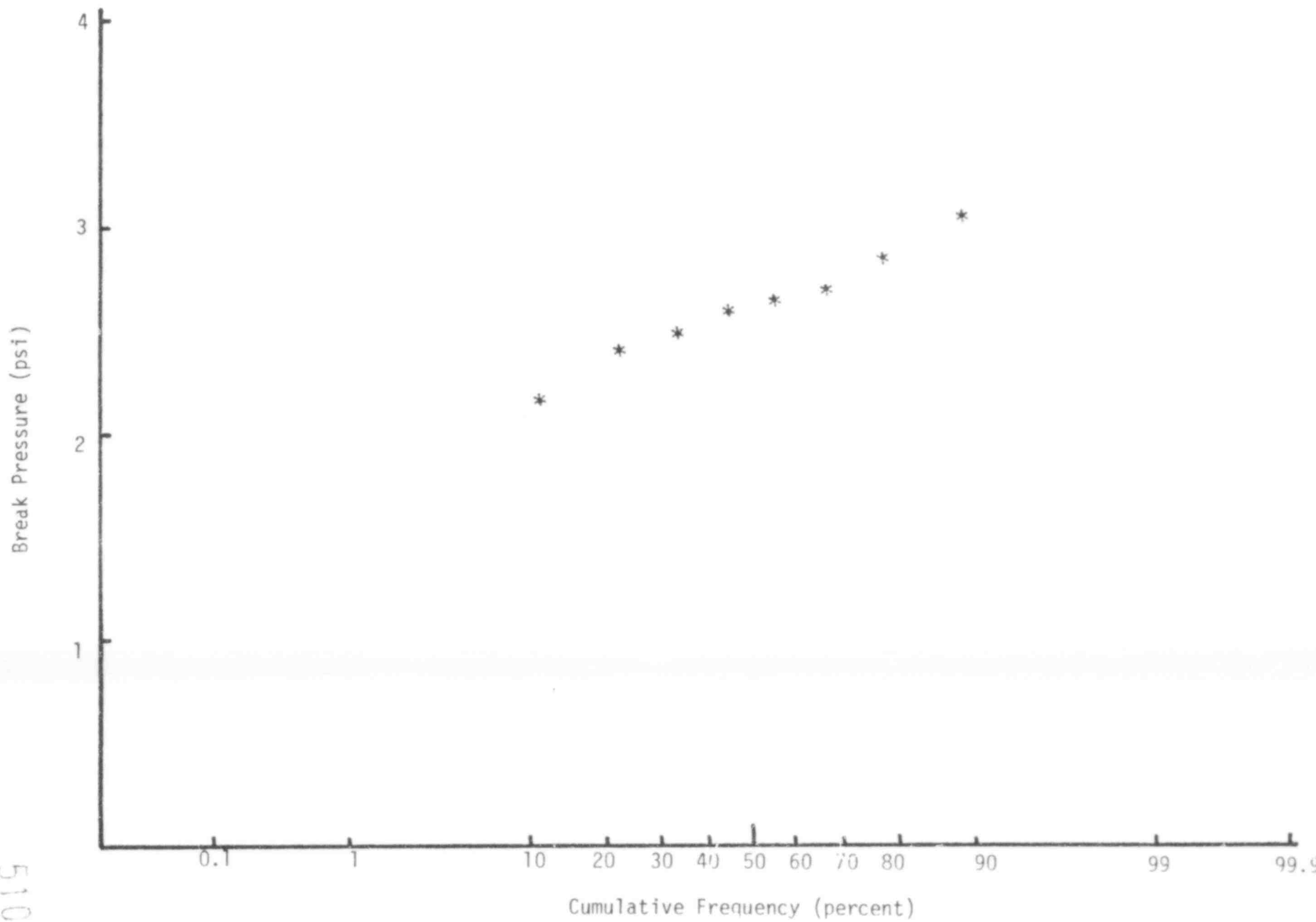

Fig. B-4.
Break pressure vs cumulative frequency, MSA 1000-cfm HEPA filters.

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NFOLD = Number of medium folds

PRATE = Pressurization rate

PBREAK = Break pressure

TBREAK = Break time

RESIST = Pressure drop at rated airflow

RDOP = DOP penetration at rated airflow

a. American Air Filter

	NFOLD	PBREAK	PRATE	TBREAK	RESIST
PBREAK	.03537				
PRATE	.01951	-.23535			
TBREAK	-.04945	.77528	-.68914		
RESIST	-.65427	.07913	.08930	-.12259	
RDOP	-.57920	-.31366	-.22872	-.02569	.34130

b. Cambridge Filter

	NFOLD	PBREAK	PRATE	TBREAK	RESIST
PBREAK	-.41041				
PRATE	.12454	.20423			
TBREAK	-.19954	.16045	-.91161		
RESIST	.48558	-.60491	.06774	-.31705	
RDOP	.19230	.26354	.58972	-.47353	.03573

c. Flanders Filter

	NFOLD	PBREAK	PRATE	TBREAK	RESIST
PBREAK	-.07329				
PRATE	.21138	-.47409			
TBREAK	-.37688	.52097	-.96978		
RESIST	-.72932	-.18029	-.17718	.26239	
RDOP	-.01738	.19169	.35579	-.31001	-.47988

d. MSA

	NFOLD	PBREAK	PRATE	TBREAK	RESIST
PBREAK	.34356				
PRATE	-.81165	-.40358			
TBREAK	.65472	.57647	-.93997		
RESIST	-.47194	-.37596	.37746	-.34343	
RDOP	.43386	-.60484	-.30496	.03330	.29251

3. Multiple linear regression

We used the same variables for both the multiple linear regression analysis and the correlation analysis. For each data set (AAF, Cambridge, Flanders, and MSA), a linear equation for the break pressure is determined as a function of the remaining variables. The analysis equation for the break pressure is a function of the variable with the highest correlation to the break pressure. Successive steps in the analysis add one parameter per step to the linear equation. The parameter that is added is chosen because it increases the correlation between the equation and the break pressure the most that step. The results of this analysis follow.

a. American Air Filter

Step	Variable	Multiple Correlation Coefficient
1	TBREAK	0.77528
2	PRATE	0.87820
3	RESIST	0.89503
4	NFOLD	0.93326
5	RDOP	0.94052

b. Cambridge Filter

Step	Variable	Multiple Correlation Coefficient
1	RESIST	0.60491
2	RDOP	0.66883
3	NFOLD	0.69655
4	TBREAK	0.70883
5	PRATE	0.91052

c. Flanders Filter

Step	Variable	Multiple Correlation Coefficient
1	TBREAK	0.52097
2	RDOP	0.63986
3	NFOLD	0.66796
4	PRATE	0.70610

d. Mine Safety Appliance

Step	Variable	Multiple Correlation Coefficient
1	RDOP	0.60484
2	NFOLD	0.90454
3	RESIST	0.97381
4	PRATE	0.97982
5	TBREAK	0.98569

APPENDIX C

OPERATION OF THE LARGE SCALE AEROSOL LOADER

During operation, ambient air is drawn into the anechoic inlet plenum chamber through an inlet damper and filter (see Fig. 1). The air is discharged by the vaneaxial fan through both a bleed-off and control damper. The bleed off air is returned to the fan inlet by way of the plenum chamber allowing fan operation within its stable flow rate region with minimized nois and pulsing. Air leaving the control damper passes through a fan vibration isolation coupling, a HEPA prefilter, and into the aerosol generation duct.

The positioning of one dummy and four generator trays in the aerosol generation duct directs the airstream up and over each generator tray where wet particles are entrained in the flow. The 15 Laskin generator nozzles in each tray are driven in parallel by compressed air. The aerosol fluid is fed in cascade to each tray by a recirculating pump from a storage sump, with the fluid level of each tray established by an overflow weir (not shown in figure).

The aerosol-laden air passes through flow straighteners and 14 ft of duct (allowing aerosol drying and uniform mixing) on the way to the loading filter. The filter traps the aerosol and discharges the air through a transition duct into a smaller cross sectional area duct. The smaller duct increases the air velocity allowing accurate flow measurement with a pitot tube and oil fluid manometer.

Loading parameters of interest include static pressure across and air flow rate through the loading filter, inlet and outlet wet and dry bulb temperatures, ambient barometric pressure, and amount of aerosol solution added to sump. These are recorded approximately every 12 hours.

APPENDIX D

MEDIUM STRENGTH TEST PROGRAM

The strength tests will be performed on the medium samples taken from HEPA filters previously subjected to tornado simulation tests. The strength tests can be divided into two classes: standard medium strength tests and impact strength tests. Medium samples will be removed from 12 filters, three filters from each manufacturer. Twelve samples (8- by 8-in., 0.2- by 0.2-m) will be removed from each filter:

4 interior for standard tests,
4 folded for standard tests,
2 interior for impact tests, and
2 folded for impact tests.

Thus a total of the 144 samples will be taken.

1. The standard tests will be performed at Rocky Flats HEPA Filter Acceptance Laboratory. These tests are done to sample media from each shipment of HEPA filters tested at Rocky Flats. These tests are:

tensile strength along machine direction,
tensile strength across machine direction,
DOP penetration at 20% and 100% flow, and
resistance at rated flow.

2. Impact Tests

Paper is not normally impact-tested, so we designed our own medium impact test. Fig. D-1 shows the apparatus. A medium identical to those used in the tensile tests is clamped between the two guides. The pendulum is released and swings down against one clamp. This instantaneously loads the medium sample longitudinally, causing it to break. The pendulum continues to swing, and its maximum height after the impact is recorded. The amount of energy absorbed by the medium is a function of difference in heights of the end of the pendulum at the initial and final positions. We will then compare these results to the standard medium tests and the tornado simulation tests to determine if there are any correlations.

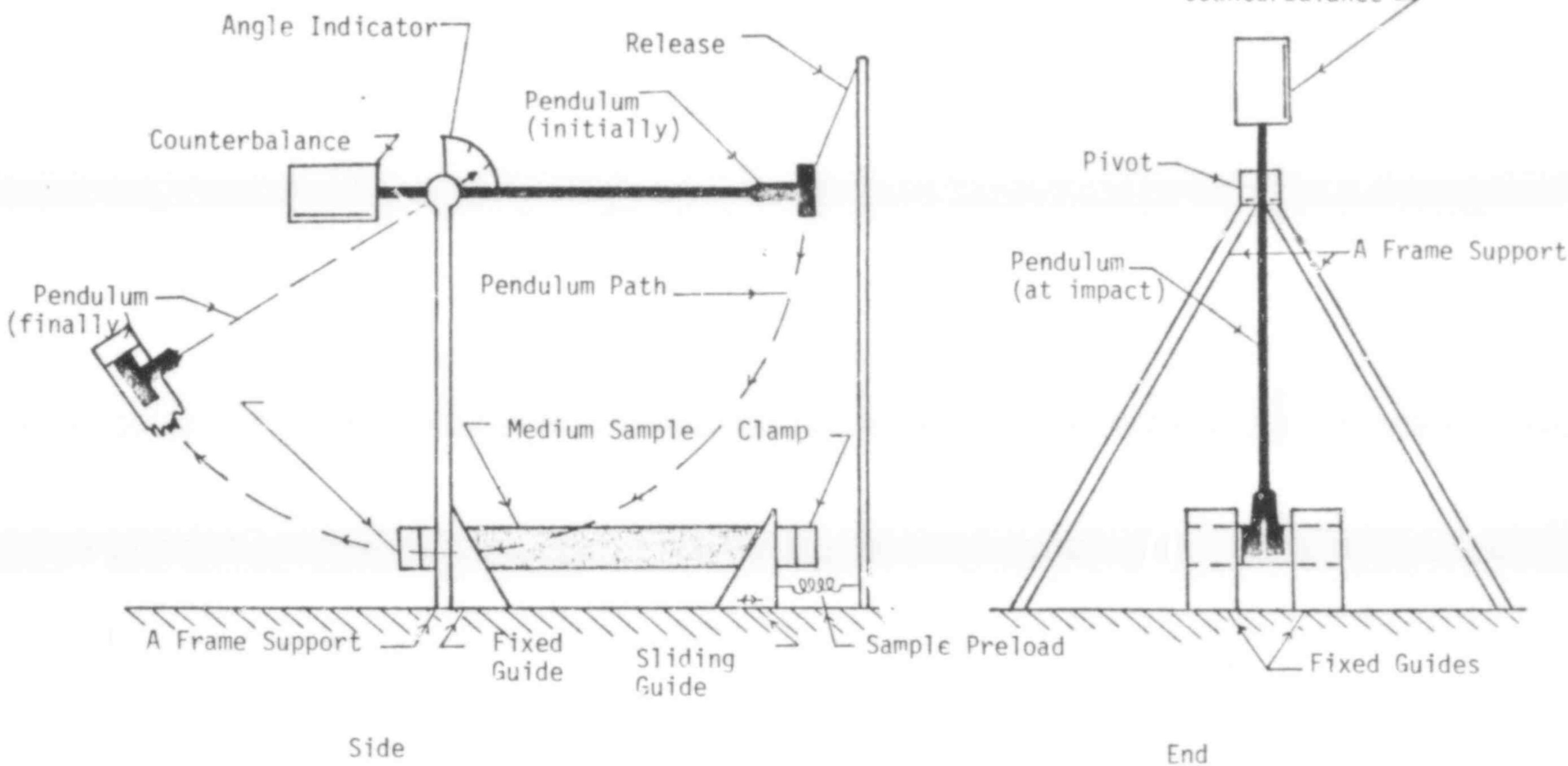

Fig. D-1.
Impact test apparatus for HEPA filter media.