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OPERATIONAL EVALUATION OF THE HIGH FLOW ALTERNATIVE FILTER TEST SYSTEM*

Ronald C. Scripsick, Roy L. Smitherman,[1] and Sam A. McNabb[1]

Los Alamos National Laboratory
Research and Development Section
Industrial Hygiene Group
Health, Safety, and Environment Division
Los Alamos, NM 87545
USA
[1]Oak Ridge Gaseous Diffusion Plant
Martin Marietta Energy Systems, Inc.
P. O. Box P
Oak Ridge, TN 37830
USA

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Abstract

An alternative to the current filter test system (Q107) used to test Size 4 (500 cubic feet per min rated flow) and larger nuclear grade high efficiency particulate air (HEPA) filters at DOE Filter Test Facilities (FTFs) has been developed. This new test system, called the High Flow Alternative Filter Test System (HFATS), has undergone a long-term operational evaluation at the Oak Ridge FTF (ORFTF) for: 1) comparison between HEPA filter penetration measurements made with the HFATS and with the Q107; 2) assessment of the HFATS' long-term routine operational performance in the FTF environment; and 3) determination of the potential operational impacts of the HFATS on the FTFs.

Data for the operational evaluation were collected by the Oak Ridge staff using both test systems. These data were analyzed and interpreted by Los Alamos staff. A total of 849 filters were tested in the evaluation. The data provided by the HFATS easily permits filter penetration to be reported in terms of: 1) penetration at the size of maximum penetration; 2) number, surface area, or mass penetration; or 3) penetration at 0.3 µm for reference to historical data. Results of the penetration measurement comparisons show that the HFATS measurements at approximately 0.3 µm aerosol diameter do not differ significantly from the Q107 measurements. Analysis of the HFATS penetration data indicates that for the 100% flow tests maximum penetration most frequently occurs at an aerosol diameter of approximately 0.15 µm as measured by a laser aerosol spectrometer (LAS). The 0.15 µm HFATS measurements at 100% test flow were markedly higher than the corresponding Q107 measurements. These measurements resulted in over 18% of the filters being rejected by the HFATS only, compared to no filters being rejected only by the Q107 and approximately 0.2% being rejected by both systems.

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Investigation of how the HFATS performed over the course of the study included monitoring of the HFATS diluter performance, the LAS size calibration, and the upstream count rate. The upstream count rate is a sensitive indicator of changes in the output of the blower and the HFATS aerosol generator as well as in the performance of the HFATS diluter and the LAS. Analysis of the monitoring results indicates that the HFATS performed at or above acceptable performance limits.

Review of information collected on the operational impact the HFATS had on the FTF indicates that: 1) there is no difference in the number of filters tested in a day by the two systems; 2) the HFATS presents certain operational safety advantages over the Q107; 3) the HFATS is easier to operate than the Q107; and 4) the HFATS may require less maintenance than the Q107.

The overall conclusion of the operational evaluation is that the HFATS is capable of performing well in the FTF environment and that the HFATS offers some important operational advantages relative to the Q107. Given the results of this study and a technical evaluation of the HFATS reported elsewhere the authors recommend that the DOE consider adoption of the HFATS as an approved filter test method.

I. INTRODUCTION

From FY 1981 and continuing through FY 1985, the Airborne Waste Management Program Office funded the "Filter Test Facility Support Laboratory," (FTFSL) project at Los Alamos to: 1) develop an aerosol test system suitable for use at the three Filter Test Facilities (FTFs) as a potential replacement for the current di(2-ethylhexyl) phthalate (DEHP, also known as DOP) test system (Q107) used to test size 4 and greater nuclear grade high efficiency particulate air (HEPA) filters and 2) provide technical assistance to the FTFs in solving technical problems and answering technical questions which arose. Completion of the FTFSL project provided recommendations for changes in the test systems used at the FTFs. One major recommendation of the FTFSL program was to perform a long-term operational evaluation of the high flow alternative filter test system (HFATS) which was developed in the program.

In late FY 1985 such a long-term study funded by DOE-Interim Waste Operations (IWO) was initiated at the Oak Ridge FTF (ORFTF) as a cooperative effort between the ORFTF and Los Alamos. The overall objective of the long-term study was to provide data necessary to qualify the HFATS as a DOE approved test method under the provisions of the Nuclear Standard NE-F-3-43, which require evidence that new test systems are capable of being "operated and maintained" by FTF operators.[1] In order to accomplish this overall objective certain subordinate objectives were identified. These subordinate objectives include:

1. Comparison of HEPA filter penetration measurements made with the HFATS and the Q107 including assessment of the potential impacts the HFATS measurements may have on the FTF filter rejection rates.

2. Assessment of the HFATS's long-term, routine performance in the FTF environment.

3. Determination of the potential impacts of the HFATS on the FTF's operation.

The data collection phase of the study began August 15, 1985, and was completed by the end of May 8, 1986. This report presents the results of the study.

Description of Alternative Test System

The HFATS, which is shown diagrammatically in Figure 1, uses a modified Laskin nozzle aerosol generator to provide the filter challenge.[2] This aerosol generation system is easier to operate than the Q107 thermal generator, operates well below the flash point of DEHP, and is expected to produce no decomposition materials. This unit is also less expensive to manufacture than the thermal generator.

A laser aerosol spectrometer (LAS, Model LAS-X-M, Particle Measuring Systems, Inc., Boulder, Colorado) interfaced with a microcomputer (Model HP-85B, Hewlett-Packard Co., Corvallis, Oregon) and a Los Alamos fabricated aerosol diluter are used to perform the required aerosol measurements in the HFATS. This monitoring system combines the function of the Owl and the scattered-light photometer

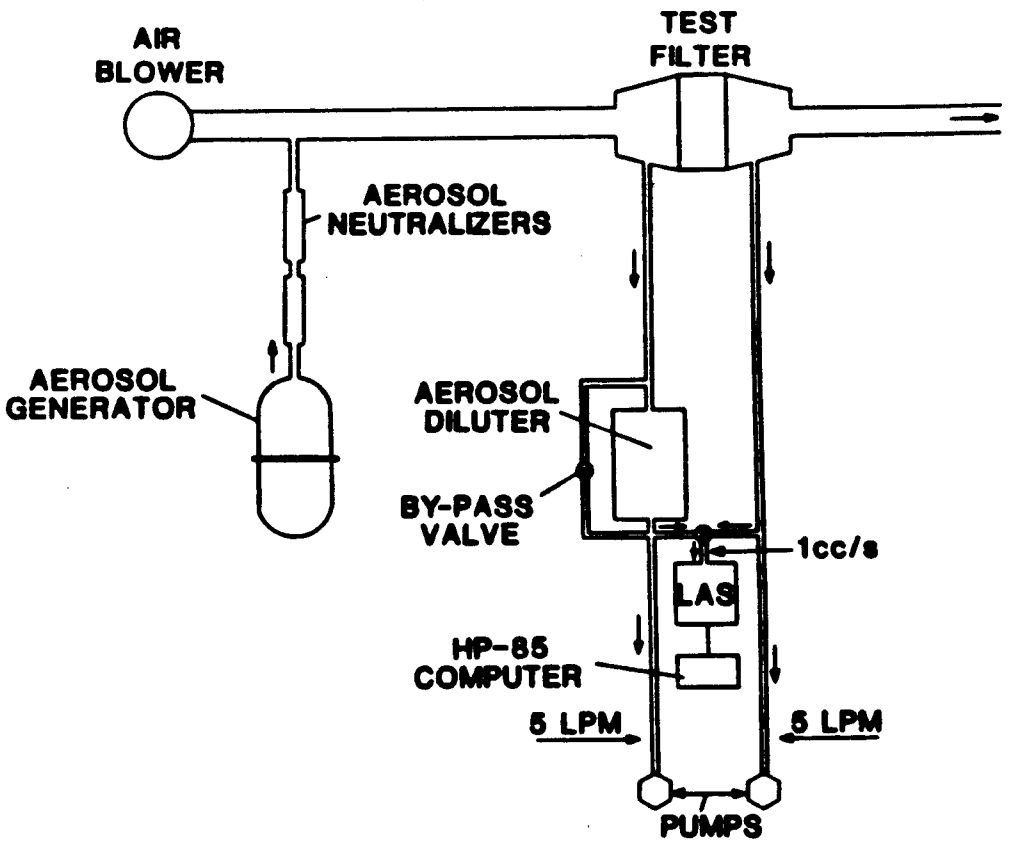

Figure 1. A diagram of the High Flow Alternative Filter Test System.

in the Q107 system. The monitoring system is capable of measuring penetration at a specific size or over a range of sizes in the aerosol diameter range from ∿0.1 µm to ∿0.4 µm.[2]

II. EQUIPMENT AND PROCEDURES

The operational evaluation was a long-term evaluation of the HFATS under routine operating conditions at a DOE FTF. The general study plan called for collection of penetration data at the ORFTF on a set of filters using both the HFATS and the Q107. Simultaneously, data detailing the performance and impacts of the HFATS were collected. The term of the data collection was approximately 9 months.

The HFATS was modified and installed at the ORFTF by Los Alamos staff prior to the start of the data collection. Modification of the HFATS was necessary to assure easy operation of the system when it was adapted to the ORFTF Q107. The major modification was to mount the HFATS aerosol sample transport valves, the HFATS diluter, the LAS and the HP-85 microcomputer so that they were within arm's reach of the Q107's work station. The HFATS aerosol generator system was installed between the Q107 blower and the Q107 thermal generator. Installation of the HFATS also involved performing a series of tests to insure proper operation. Installation and performance testing required approximately 4 working days.

The operational evaluation data collection entailed making filter penetration measurements using both the Q107 system and the HFATS, collection of data on HFATS performance, and collection of data on the impact of the HFATS on the FTF operation. The procedures for conducting the study at the FTF were modeled after those used in the One-Year LAS Comparison Study.[3,4] Los Alamos staff trained the FTF staff in the operation of the HFATS and the procedures to be used in collecting and recording data. The training required approximately 3 working days. All data collection and recording was performed by ORFTF staff.

The penetration data collected in the study provided information on penetration measurements made using the HFATS relative to those made using the Q107 under existing standard operating procedures. Penetration measurements on a group of filters were made first with the HFATS and then with the Q107 system. This measurement order insured final integrity of the FTF quality assurance (QA) measurements by precluding any out-of-the-ordinary handling of the filters subsequent to QA testing.

The HFATS penetration measurements were made in 15 size intervals (bins) over the aerosol diameter range from ∿0.1 µm to ∿0.4 µm with the LAS size measurement corrected for DEHP index of refraction.[5] These penetration values were automatically stored on cassette tape by the HP-85. The HFATS-measured penetration at the 0.31 um diameter LAS bin was printed separately by the HP-85 and recorded manually by the system operator because 0.3 µm diameter is the traditional reference size for Q107 measurements. The

penetration data stored on cassette tape permitted examination of penetration versus aerosol size.

A total of 849 filters were tested using both systems during the operational evaluation. A list of the sizes of filters tested is given in Table I. The "A" designation after a filter size indicates that filters in this category were tested at a flow above their rated-flow. Size "4A" filters were size "4" filters (500 cubic feet per min [CFM] rated-flow) that were tested at 600 CFM. Size "5A" filters were size "5" filters (1000 CFM rated-flow) that were tested at between 1170 CFM and 1400 CFM. Over 85% of the filters tested were size 5 filters.

In addition to penetration measurements, values of certain operational parameters for both test systems were recorded. The test system operator was required to manually record the filter serial number, the test airflow, and filter airflow resistance for the HFATS penetration measurements. The upstream particle count rate was automatically recorded by the HP-85 microcomputer for every filter test. This parameter is sensitive to changes in the output of the blower and the HFATS aerosol generator as well as to changes in the performance of the HFATS diluter and LAS. In addition, this parameter is printed by the HP-85 at the beginning of each filter test as an indication to the system operator as to how the HFATS is performing. At the beginning, of each filter test session the aerosol size calibration of the LAS was checked using monodisperse polystyrene microspheres. These data were automatically recorded by the HP-85 microcomputer. Information from the Q107 test system measurements that were required for the study was obtained from the FTF "Filter Inspection Reports."

The FTF staff kept track of the HFATS impacts/costs in terms of manpower, supplies, parts, operational difficulties, and maintenance/repair service. They noted any Q107 equipment or

TABLE I

FILTER SIZES TESTED

SIZE	NUMBER TESTED	RATED FLOW -CFM	100% TEST FLOW -CFM
4A*	21	500	600
5	737	1000	1000
5A*	39	1000	1170-1400
6	52	1250	1250

* The "A" indicates that filters were tested at flows greater than their rated-flows.

operating procedure changes or problems. The total time required to analyze a group of filters by each penetration measurement technique was recorded by the FTF staff.

Data recorded by the FTF staff were entered on a standard logsheet that was provided by Los Alamos. An example of this logsheet is shown in Figure 2. Data in the form of HP-85 data tapes and copies of logsheets were forwarded to Los Alamos on roughly a monthly basis. Los Alamos reviewed these data to insure that useful data were being collected.

LOG PAGE
COMPARISON STUDY OF THE ALTERNATIVE FILTER TEST SYSTEM
Conducted at OR FTF - FY1985/FY1986

DATE(S):_____ SYSTEM USED:_____

PURCHASE ORDER NO.:_____
NUMBER OF FILTERS TESTED:
Item No. _____ thru Item No. _____
Total number tested: _____
TIME - Number of man-hours for executing:
Normal routines and procedures -_____
Non-routine procedures -_____
COST - (Dollar value of requisitions signed on above date): _____

REMARKS : USE AS MUCH SPACE AS NECESSARY
(eg. equipment breakdown, problems with operation of the ATS or Q 107, or other occurrences that could affect the data being collected)

_____ Operator's Initials: _____

CONTACT: Ron Scripsick, Aerosol Science Section
Los Alamos National Laboratory
Los Alamos, NM 87544 (505) 667-7382
FTS 843-7382

Figure 2. Example of standard logsheet used in the operational evaluation.

III. RESULTS AND DISCUSSION

COMPARISON OF PENETRATION MEASUREMENTS

HFATS Penetration Measurements

Typical HFATS penetration curves are illustrated in Figure 3. The 100% flow tests were characterized by a penetration maximum occurring at an aerosol diameter <0.2 µm which is in agreement with theoretical evaluations of modern nuclear grade HEPA filter media, experimental measurements made on flat sheets of nuclear grade HEPA filter media and experimental measurements made on constructed nuclear grade HEPA filters operated at 100% of rated flow.[6,7,8] The 20% flow tests did not display a maximum penetration within the aerosol size range studied (see Figure 3) which is contrary to theoretical predictions and measurements on flat sheet media.[6,7] Review of the literature revealed no independent penetration measurements of constructed nuclear grade HEPA filters operated at 20% of rated flow. Evaluation of the performance of the HFATS components gave no evidence that this characteristic might be an artifact of HFATS measurements. One possible explanation for this phenomenon is the presence of pinholes in the constructed filters.[2] Further investigation is necessary to explain this penetration behavior of HEPA filters operated at 20% flow.

Penetration Comparison with the 0.31 µm HFATS Data

Recent theoretical investigations that account for the Q107 challenge being polydisperse with a count geometric mean diameter between 0.14 µm to 0.18 µm suggest because of the photometer response bias towards larger particles that the Q107 penetration measurements

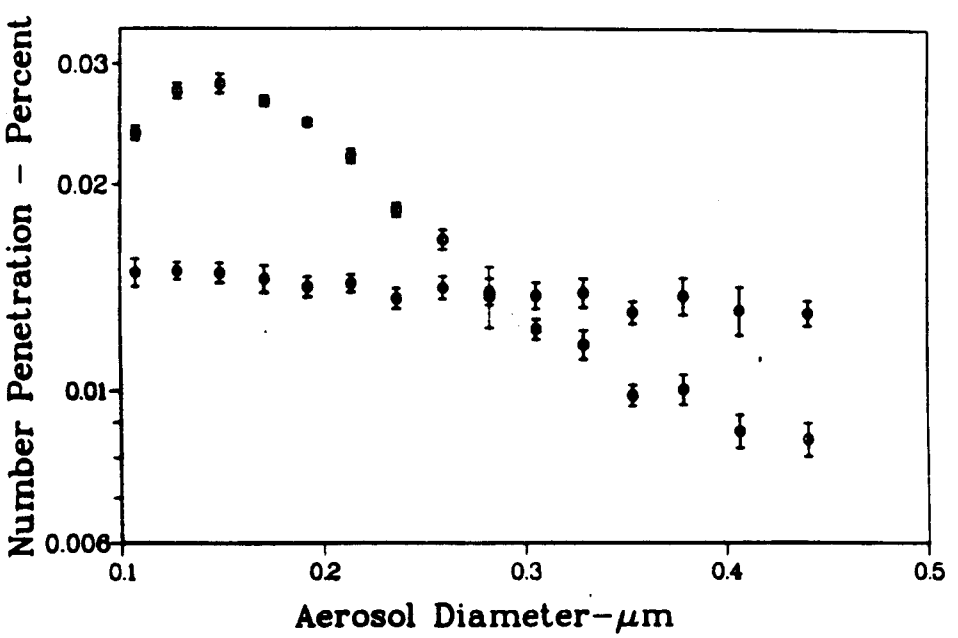

Figure 3. An example of the typical HFATS penetration curves obtained in the study. The 100% flow test data are indicated by the open circle data points and the 20% flow test data are represented by the closed circle data points.

are approximately equal to the penetration at 0.3 µm.[3,4 & 8] Because of this finding and the fact that the Q107 measurements have traditionally been referenced to 0.3 µm, the HFATS penetration measurements at the 0.31 µm bin diameter were compared with the Q107 measurements. This LAS bin was found to be approximately equal to 0.3 µm diameter as measured by the electrostatic classifier (Model 3071, TSI Incorporated, St. Paul, Minnesota).[2]

The results of the 0.31 um comparison for the 100% flow tests are shown in Figure 4 and for the 20% tests are shown in Figure 5. The results are similar for both flow tests. Also, no obvious difference was observed for the different sizes of filters. Average differences in penetration are listed in Table II. For both test flows the magnitude of the differences is ≤0.002%.

The number of filter tests where penetration measurements were above the penetration rejection limit of 0.03% (which to two significant digits is 0.035%) are listed in Table III. A total of seven filter tests resulted in both systems measuring penetrations above the rejection limit. The HFATS measured penetrations above the rejection limit in three situations where the Q107 measured penetrations were below the limit. In only one situation did the Q107 measure a penetration above the rejection limit where the HFATS measured penetration was below the limit.

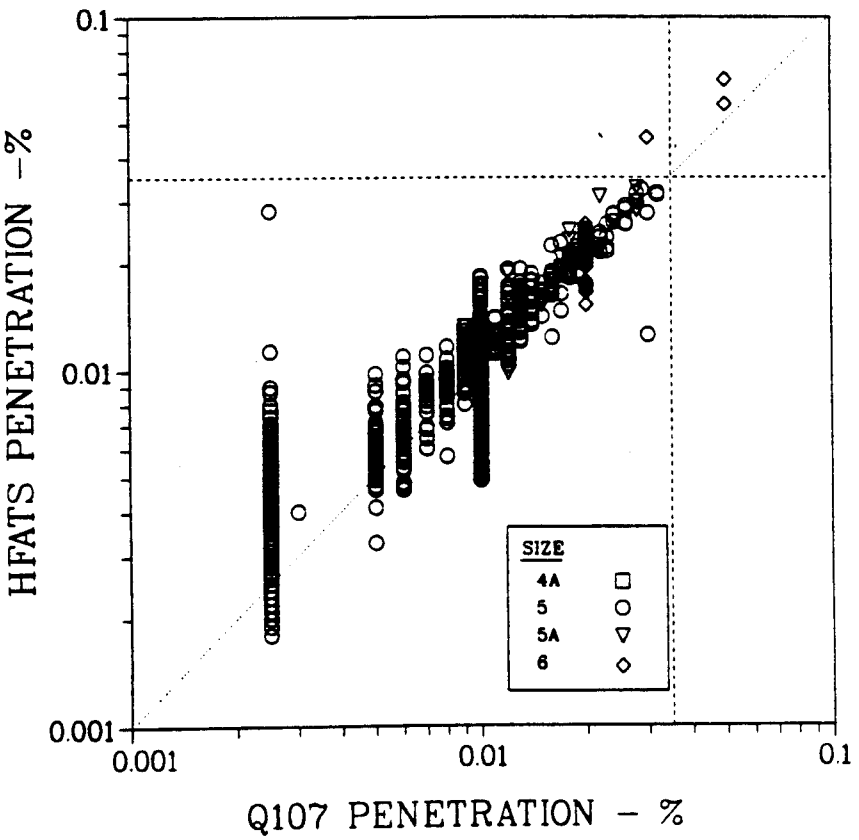

Figure 4. Comparison of the 100% flow test penetration measurements using the 0.31 µm HFATS data.

KEYWORDS: filter efficiency, filter tests, penetration measurement system, filter efficiency standards, HEPA filters

INTRODUCTION

The United States Department of Energy (USDOE) uses nuclear grade high efficiency particulate air (HEPA) filters in critical air handling systems for protection of public and worker health and the environment. The filters are used to decontaminate ventilation airstreams of hazardous particulate radionuclides and other hazardous particulate materials. The performance of these filters is directly related to the quality of the air that is introduced in the workplace or released to the environment. The lowest allowable airborne concentrations (AACs) of these hazardous materials can be on the order of 10^{-13} g/m^3 for workplace releases and on the order of 10^{-14} g/m^3 for environmental releases [1,2]. The highest filter challenge concentrations of these materials can be in the range from 100 mg/m^3 to 10 g/m^3 during severe upset conditions [1,3]. Consequently, the air cleaning systems must have a design capacity capable of decontaminating airstreams by as much as a factor of 10^{12} to 10^{15}. To achieve these capacities system designers often use HEPA filter banks in tandem. For example, to obtain a decontamination factor on the order of 10^{14} requires four tandem banks of HEPA filters with each bank having a collection efficiency $\geq$99.97 per cent.

To assure that filters placed in air cleaning systems meet design specifications, every nuclear grade HEPA filter purchased for use in USDOE facilities must pass a quality assurance (QA) test at a USDOE Filter Test Facility (FTF) before it is forwarded to the purchaser. This QA testing includes filter efficiency measurements made at rated flow and also at 20 per cent of rated flow for filters with rated flow of 125 cubic feet per min (CFM, ~3.5 m^3/min) and higher. The current test specifications call for measurement of filter efficiency at 0.3 µm using a thermally generated di-(2-ethylhexyl) phthalate (DEHP) or di-(2-ethylhexyl) sebacate (DEHS) aerosol, an Owl polarized light aerosol size analyzer and a scattered-light photometer (SLP). New standards for USDOE filter testing are in the final stages of being adopted [4-7]. Specifications of the filter efficiency test proposed for these standards are discussed in this report. In addition a new filter efficiency test system is described that was developed for the USDOE by Los Alamos National Laboratory.

PROPOSED FILTER EFFICIENCY TEST SPECIFICATIONS

Aerosol Size

The major change proposed in the new filter efficiency test specifications is to require penetration measurements to be made at a

particle size in the diameter range from 0.1 μm to 0.2 μm rather than at a particle diameter of 0.3 μm which is currently required [5]. Examination of the predicted rated flow performance of HEPA filters available when the currently designated test systems were developed indicates that the size of maximum penetration was near 0.3 μm, which corresponds to the particle size at which the current systems were designed to operate [8]. This result suggests that the designers of the current systems intended to measure penetration near the aerosol size of maximum penetration. The merit of such a test of filter performance is that the measurement result is a conservative or worst case estimate of filter performance in terms of challenge aerosol size. For a given air flow, no challenge aerosol consisting of particles similar in shape to and of the same or greater density (ρ, specific gravity) as the test aerosol particles should have a greater penetration than the test penetration. This conclusion follows directly from theoretical and experimental evidence that shows HEPA filter penetration as a unimodal function with respect to aerosol size [8-13].

Theoretical evaluation of the performance of the current generation of nuclear grade HEPA filters operating at flows between rated flow and 20 per cent rated flow predicts the maximum penetration aerosol diameter to be in the range from ~0.1 μm to ~0.2 μm [8]. This predicted shift from a maximum penetration diameter of ~0.3 μm is predominately a result of the median fiber diameter used in the media being reduced from 1 - 2 μm to median diameters in the range from 0.3 μm to 0.5 μm [8]. Experimental measurements of the maximum penetration diameter at rated flow for the media used in modern HEPA filters and the HEPA filters themselves show the diameter to be in the range from ~0.13 μm to ~0.17 μm [11,13, and 14]. Variations in the size of maximum penetration arising from differences in the fiber composition and fiber volume fraction of HEPA filter media, as well as other factors, make specification of a precise size of maximum penetration impossible. In terms of the USDOE test, the predicted maximum penetration aerosol diameter at rated flow is different than the diameter at 20 per cent rated flow. Therefore, a maximum penetration test should specify measurement of penetration at a particle size within a range of particle sizes. The theoretical and experimental evidence cited above indicates that this diameter range should be 0.1 μm to 0.2 μm for the current generation of nuclear grade HEPA filters.

Penetration Rejection Criterion

The penetration rejection criterion of the proposed new filter efficiency test specifications is 0.03 per cent penetration at a particle size in the diameter range from 0.1 μm to 0.2 μm. This criterion is in general more stringent for intact filters than the currently designated penetration rejection criteria because measurements made with the current system are approximately equivalent to the penetration near 0.3 μm which is distinctly below the penetration at the size of maximum penetration. However, penetration measurements on filters with pinholes or other defects can be

independent of aerosol size (see the "Damaged Filter Tests" section) with penetration at a diameter of 0.3 μm being approximately equal to the penetration at a particle size in the diameter range from 0.1 μm to 0.2 μm. In this case the current and proposed criterion are equally stringent. Therefore, the 0.03 per cent penetration limit is necessary to guarantee that in all cases the proposed criterion is at least as stringent as the current criterion.

Examination of the penetration of over 800 nuclear grade HEPA filters at specific aerosol diameters over the range from ~0.1 μm to ~0.4 μm shows that all but a small fraction of the filters could meet the above criterion [14]. However, the examination also showed that the fraction of filters failing to meet the proposed criterion was larger than the fraction of filters failing to meet the current penetration rejection criterion [14].

Test Material Density

The new filter test specifies that penetration measurements are to be made with an aerosol material with a density near $\rho = 1\ g/cm^3$. A theoretical study by Tillery shows the magnitude of maximum HEPA penetration decreasing as the ρ of the challenge aerosol material increases [9]. Experimental support for this finding was observed by Tillery in a study where the maximum HEPA filter penetration of plutonium dioxide aerosol particles ($\rho = \sim 10\ g/cm^3$) was observed to be significantly lower than the penetration measured using the current approved DEHP/DEHS ($\rho = 0.983/0.915\ g/cm^3$) test method [15,16]. These findings indicate that, for a given aerosol size, test measurements made with a material of low ρ relative to the ρ of materials encountered in the field provide a worst case estimate of filter penetration. For the USDOE, much of the particulate airborne contaminants of concern are composed of actinide compounds which rarely, if ever, have densities less than $1\ g/cm^3$. The actinide compounds also include materials with AACs that are among the lowest of all AACs, so that conservative filter efficiency estimates may be necessary to insure that exhaust air is sufficiently decontaminated [1,2]. Certain particulate materials found in USDOE facilities, like lithium compounds, may have densities less than $1\ g/cm^3$. In general, these materials have higher AACs than the actinides so that conservative estimates of filter efficiency may not be as critical as they are for filters used in actinide air cleaning systems [1,2].

NEW FILTER EFFICIENCY TEST SYSTEM

The method for QA penetration testing of size 5 HEPA filters (rated flow of 1000 CFM [~28 m^3/min]) at USDOE FTFs comes largely from military standard MIL-STD-282 [17]. Since the adoption of MIL-STD-282, there have been many advances in aerosol technology which have potential for beneficial application to QA penetration testing in the areas of reproducibility, accuracy, ease of operation,

and development of more detailed and meaningful filter performance data.

An investigation of alternative filter penetration test methods was undertaken at Los Alamos National Laboratory starting in 1982 with funding from the USDOE Airborne Waste Management Project Office. Commercially available aerosol instrumentation and technology was reviewed with regard to needs identified in the current high flow (500 CFM [~14 m^3/min] and greater rated flow) test system (Q107 test system). Consideration was given to developing a test system that would meet the current test specification and at the same time be capable of measuring penetration at the size of maximum penetration which is required in the proposed new test specifications. Once the most promising alternative test system components were selected, a laboratory evaluation of the components was carried out to determine the best match to meeting the identified needs of the Q107. From this evaluation, a set of components comprising the High Flow Alternative Filter Test System (HFATS) were selected. Laboratory-scale and full-scale systems were evaluated and refined at Los Alamos. In late 1984 and early 1985, full-scale proof-testing and a public demonstration of the prototype system were conducted at the Oak Ridge Filter Test Facility (ORFTF), Oak Ridge Gaseous Diffusion Plant at Oak Ridge, Tennessee. A summary report on the development of the HFATS was published in 1985 [18]. A final report is in preparation [19]. An operational evaluation of the HFATS was initiated in late 1985 at the ORFTF. Data collection for this evaluation was completed in early 1986. A report on the results of the operational evaluation is to be published in the proceedings of the 19th DOE/NRC Nuclear Air Cleaning Conference to be held August 17-21, 1986, in Seattle, Washington [14].

HFATS Description

The HFATS takes advantage of commercially available aerosol technology. The system, which is shown diagrammatically in Fig. 1, uses a modified Laskin nozzle aerosol generator/aerosol neutralizer system to provide the filter challenge [19,20]. The neutralizer is used to standardize electrical charge on the aerosol challenge. The challenge has a measured geometric mean diameter of ~0.2 μm and a geometric standard deviation of ~1.6 [19]. The aerosol concentration produced by the system in an ~28 m^3/min flow test stream has been measured to be ~5 mg/m^3 which is approximately one-tenth the concentration produced by the currently used thermal generation system [19]. Operation of the generation system over a period of months under actual test conditions indicates that the lower challenge concentration may significantly reduce potential operator exposure to test aerosol materials [14]. In addition, the new generation system is easier to operate than the current thermal generator, operates well below the flash point of DEHP, and is expected to produce no decomposition materials.

A laser aerosol spectrometer (LAS, Model LAS-X, Particle Measuring Systems, Inc., Boulder, Colorado) interfaced with a microcomputer (Model HP-85B, Hewlett-Packard Co., Corvallis, Oregon) and an aerosol diluter has shown the greatest potential for fulfilling the aerosol

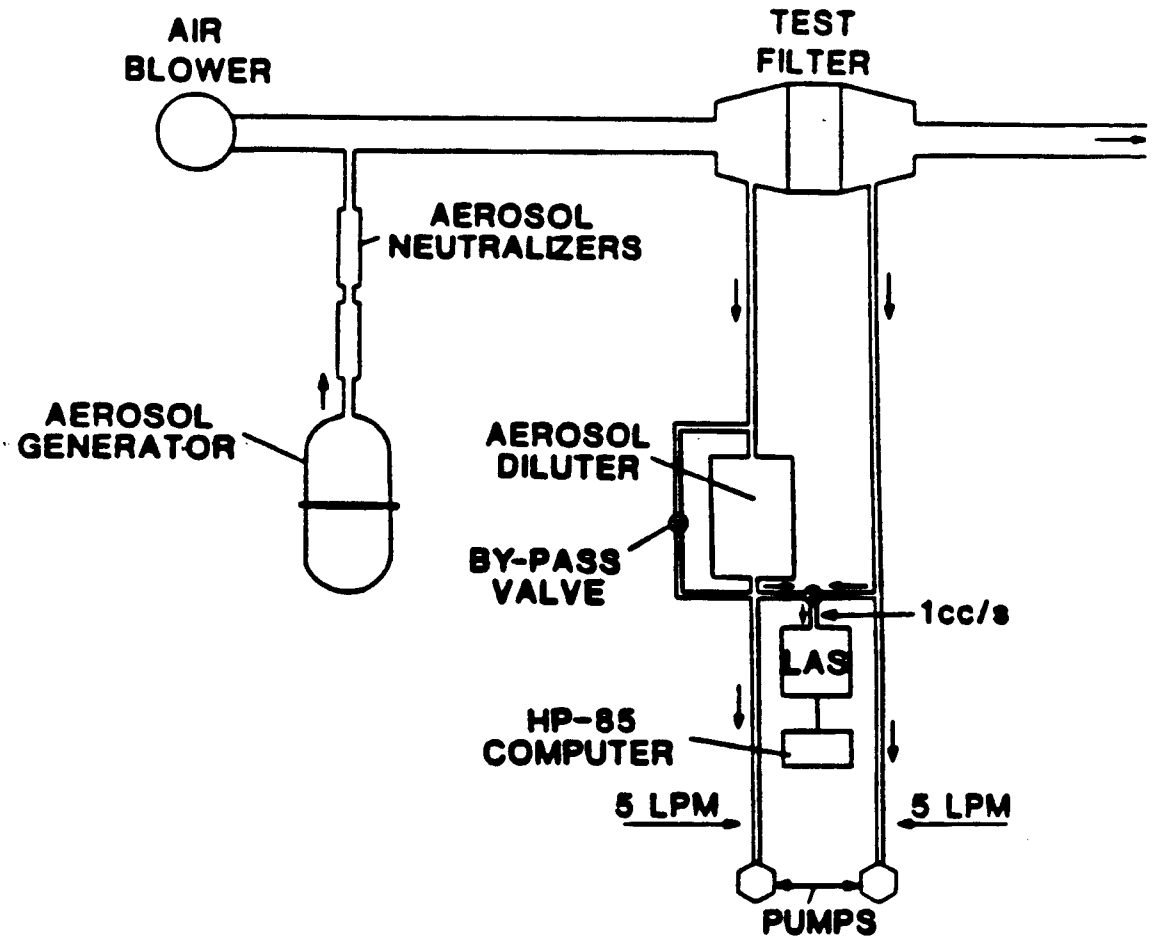

Figure 1. A schematic diagram of the HFATS showing the major components of the system which includes the aerosol generator, the aerosol neutralizers, the HFATS aerosol diluter, the laser aerosol spectrometer, and the HP-85 computer.

monitoring needs of the HFATS [18,19]. Laboratory evaluation indicated that the LAS can accurately measure aerosol diameter size from ~0.12 μm diameter to over 0.4 μm and can accurately measure aerosol size distributions with concentrations up to ~3 x 10^3 particles/cm^3. Because filter challenge concentrations over 10^5 particles/cm^3 are required for filter testing it was necessary to use a diluter in conjunction with the LAS. The LAS/microcomputer/diluter aerosol monitoring system combines the function of the Owl and SLP. It is capable of measuring penetration at a specific aerosol size or over a range of sizes.

All evaluations of the alternative test system conducted thus far have been performed using DEHP. The system was designed so that operation with a variety of test materials is possible. During the course of the investigation, alternatives to DEHP have been identified in terms of certain toxicological and physical criteria [18,19]. Enough information has been obtained so that alternatives to DEHP could be put into use at the FTFs with limited testing should USDOE decide to eliminate the use of DEHP.

HFATS Performance

Damaged Filter Tests: A series of damaged filter tests were performed to evaluate the response and sensitivity of the HFATS to filters with 2 mm holes. After one hole was placed at the edge of the filter, penetration measurements were made in four different positions on the test chuck, each time rotating the filter in the plane of the chuck by 90°. At airflow rates of ~28 m^3/min and 200 CFM (~5.7 m^3/min) a significant difference in the measured penetration was observed relative to the intact filter but no significant difference was observed in the penetration measurements made in the four positions. These results indicate that the penetration measurements using the alternative test system were not sensitive to the position of leaks.

A series of penetration measurements were also made at both airflow rates on the filter with 0, 1, 3, 5, and 9 2-mm holes. The penetration values were calculated by dividing the aerosol concentration at a specific size measured downstream of the filter by the upsteam concentration measured at the same aerosol size. Figure 2 shows, as expected, that for both filter flow rates, penetration increased with increased damage to the filters. For every level of damage, penetration measurements were greater for the lower airflow rate than for the high airflow rate. This finding agrees with filter "pinhole leak" theory which states that the fraction of flow passing though holes in a filter increases as total flow through the filter decreases over the regime where flow through the holes remains turbulent [21]. For the tests on the intact filter, this trend was reversed with the 5.7 m^3/min test showing a lower penetration relative to the ~28 m^3/min test.

Penetration dependence on aerosol size is evident for the intact filter operating at ~28 m^3/min (Figure 2) with maximum penetration at an aerosol diameter of ~0.15 μm, and penetration

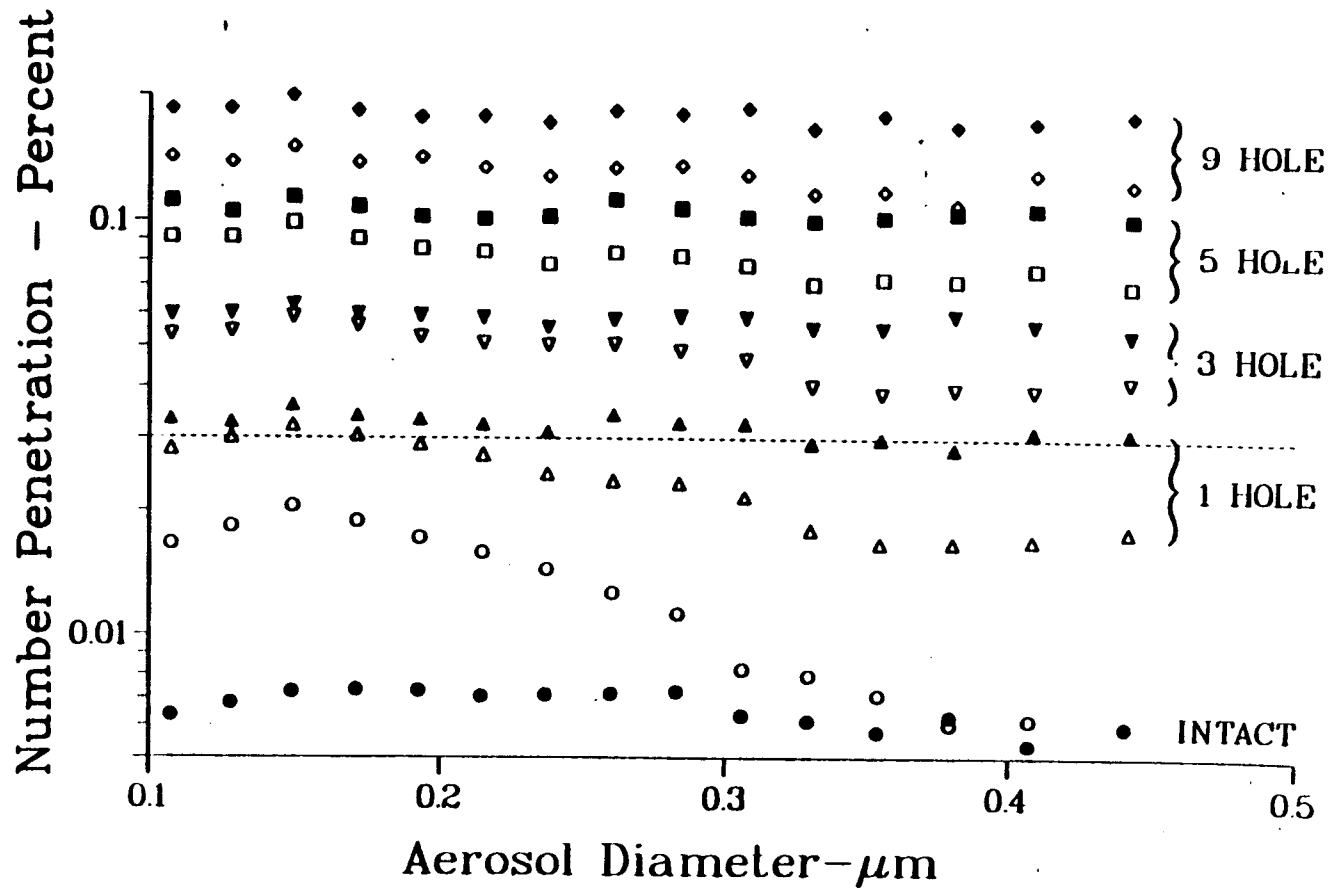

Figure 2. Result of damage filter tests. Solid symbols indicate tests conducted at 5.7 m^3/min. Open symbols indicate tests conducted at 28 m^3/min.

for 0.3 μm diameter particles approximately half the maximum. For damaged filters operated at ~28 m^3/min, the "shape" of the penetration curve flattens as damage to the filter progresses, with penetration virtually independent of aerosol size for the measurements of the filter with five and nine holes. Independence of penetration as a function of aerosol size is a result of the increased fraction of the downstream aerosol that is associated with leaks. In contrast, intact filter penetration, as shown in Figure 2, is a function of aerosol size, which is a result of different upstream and downstream aerosol size distributions. As the aerosol penetrating through the holes dominates the aerosol penetrating the filter, any dependency of penetration on size is eliminated.

Results of this series of studies on damaged filters demonstrates that the HFATS can be used to measure penetration of size 5 filters operated at airflows of ~28 m^3/min and ~5.7 m^3/min and is sensitive to leaks in these filters.

Intact Filter Tests: Because the HFATS is capable of measuring penetration as a function of size in the aerosol diameter range of ~0.1 μm to ~0.4 μm, the measurements made with the HFATS provide information on the performance of the HEPA filters purchased by DOE and DOE contractors that the Q107 system is not capable of providing. Some typical penetration measurement results on individual filters are shown in Figures 3, 4, and 5. The measurements were made on size 5 filters operating at ~28 m^3/min and ~5.7 m^3/min.

The data presented in Figures 3, 4, and 5 are typical of the penetration measurement results routinely observed for the filters tested in HFATS operational evaluation where over 800 nuclear grade HEPA filters were tested [14]. For the full rated flow, maximum penetration is normally observed in the vicinity of 0.15 μm diameter which agrees with theoretical and experimental evaluations of nuclear grade HEPA filter media and constructed filters [8,11, and 13]. For 20 per cent of rated flow, penetration is observed to be largely independent of aerosol size.

This latter observation does not agree with the theoretical and experimental findings for nuclear grade HEPA filter media [10,12]. The fact that the penetration is independent of aerosol size for constructed filters at 20 per cent of rated flow suggests the possibility that penetration through filter defects created during construction is dominating the overall filter penetration. From pinhole leak theory, if indeed the defect penetration is dominating overall penetration, this dominance would become more pronounced as flow is decreased [21]. Some limited testing of size 5 filters at 80 CFM (~2.25 m^3/min) was performed by the OR FTF staff to evaluate this hypothesis. These data showed a marginally higher penetration at the lower flow relative to the penetration at ~5.7 m^3/min which supports the defect penetration hypothesis. Additional low flow studies conducted by Los Alamos staff in early February 1986 indicate that the higher penetration measurements associated with the ~2.25 m^3/min flows may be the result of background aerosols and not filter penetration. Additional studies will be required to make definitive conclusions.

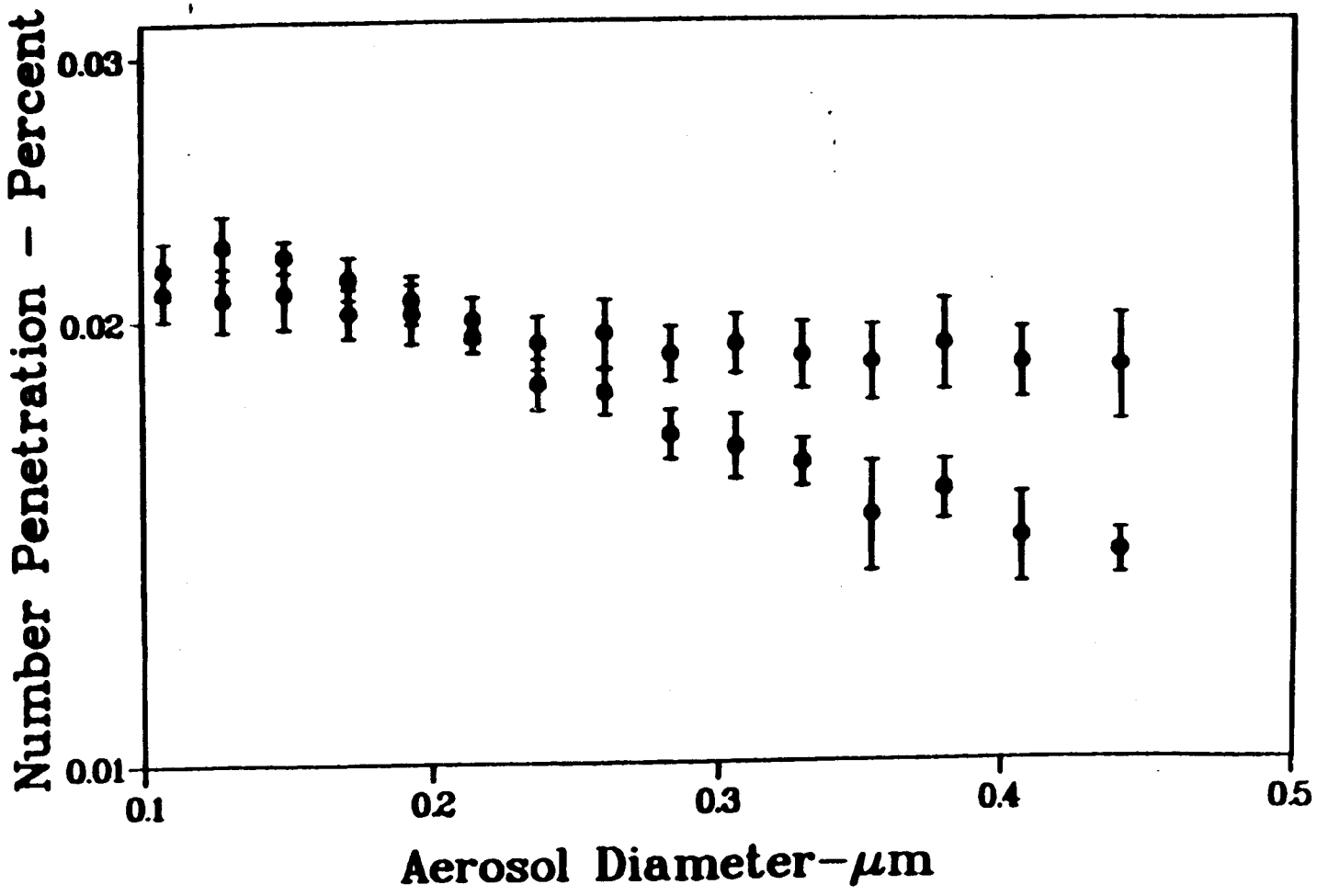

Figure 3. Typical HFATS penetration measurement results on size 5 filters operating at 28 m^3/min (open circles) and 5.7 m^3/min (solid circles).

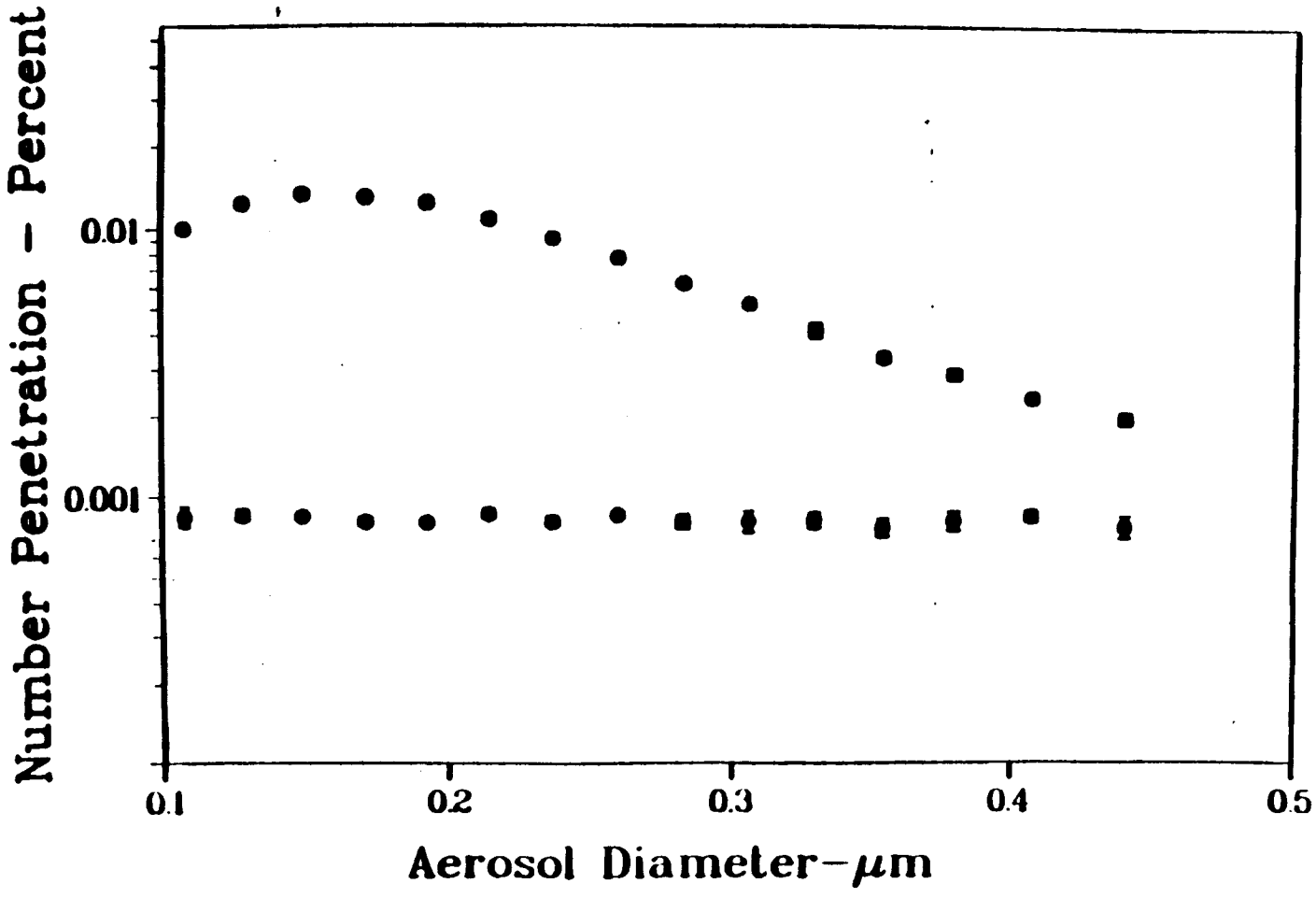

Figure 4. Typical HFAIS penetration measurement results on size 5 filters operating at 28 m^3/min (open circles) and 5.7 m^3/min (solid circles).

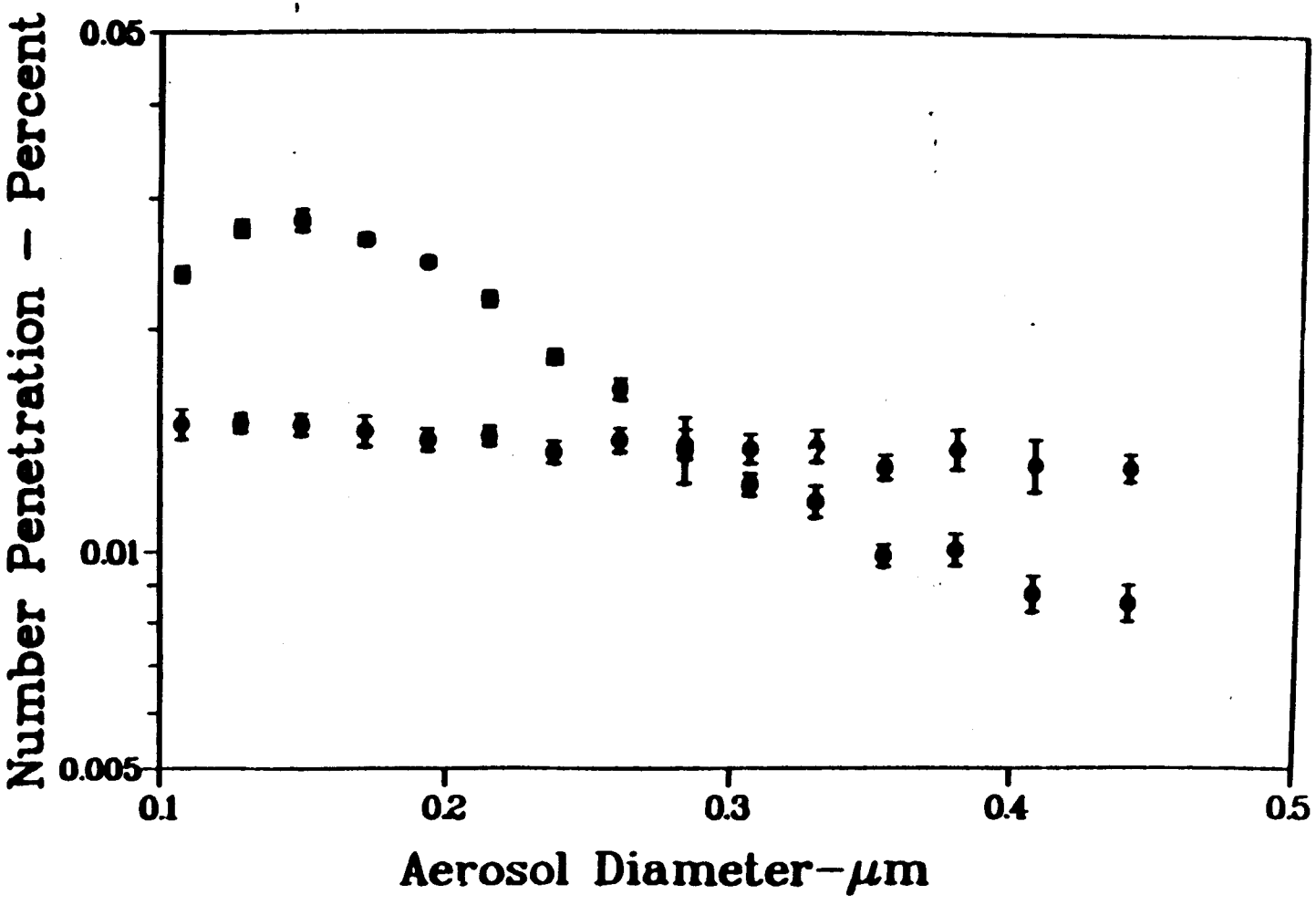

Figure 5. Typical HFAIS penetration measurement results on size 5 filters operating at 28 m^3/min (open circles) and 5.7 m^3/min (solid circles).

The three filter penetration curves shown in Figures 3, 4, and 5 demonstrate typical measurements on size 5 HEPA filters in the HFATS operational evaluation. These curves also represent three classes of HEPA filter performance that have been observed in the operational evaluation which are: (1) 20 per cent flow penetration equal to or greater than the rated flow penetration over the HFATS size range (see Figure 3), (2) 20 per cent flow penetration below the rated flow penetration over the HFATS size range (see Figure 4), and (3) 20 per cent flow penetration curve intersecting the rated flow penetration curve in the HFATS size range. These curves demonstrate that, depending on the filter and the aerosol size, the penetration at rated flow may be greater than, equal to, or less than the penetration at 20 per cent rated flow.

HFATS Measurement Uncertainty: Two key design criteria for the HFATS were (1) the system was capable of making filter penetration measurements within the individual filter test time requirements of the USDOE FTFs and (2) the precision of the system measurements were within acceptable limits. The allowable time for HFATS measurements was based on the existing time required for testing of filters on the Q107. This time was estimated to be in the range of 3 to 5 min for tests at 100 per cent flow and 20 per cent flow.

No guidance was found to independently suggest acceptable limits for the precision of test system measurements. A precision of ~10 per cent coefficient of variation was adopted for penetration values of 0.03 per cent or larger.

A theoretical model was developed to estimate the uncertainty of alternative test system penetration measurements. The model is based on standard propagation of error techniques neglecting covariance terms and uses Poisson statistics to estimate uncertainties in the upstream and downstream LAS concentration measurements. The model equation is as follows:

$$CV_p = [(P\ N\ T_d)^{-1} + (D/(N\ T_u)) + CV_D^2]^{1/2} \quad , \qquad (1)$$

where

CV_p = coefficient of variation for penetration,
P = aerosol number penetration,
N = undiluted upstream count rate, counts/s,
T_d = downstream counting time in seconds,
D = dilution ratio,
T_u = upstream counting time in seconds, and
CV_D = coefficient of variation for dilution ratio.

A plot of Eq. 1 over the penetration range specified by NE-F-3-43 is shown in Figure 6 for $N = 1.4 \times 10^4$ counts/s (undiluted count rate at 0.3 μm)), $T_d = 60$ s, $D = 220$, $T_u = 10$ s, and $CV_D = 0.05$, which are the selected operating conditions for the alternative test system [5]. The value for N made at ~0.3 μm

aerosol diameter on the HFATS challenge aerosol. The value of CV_p was measured in a HFATS diluter evaluation reported elsewhere [18,19]. Under these operating conditions, the total time required to measure the penetration of a filter at two airflow rates would be less than 5 min, which meets the first design criterion. The plot in Figure 6 shows that for penetration measurements greater than 0.02 per cent, the CV_p is less than 0.1, which satisfies the second design criterion. The higher CV_p values for penetrations below 0.02 per cent are acceptable because the precision of penetration measurements in this range is not as critical as the precision of the measurements above 0.02 per cent.

In order to examine the accuracy of the model, the predictions of the model were compared to estimates of uncertainty made from testing of five size 5 filters at rated flow. Six penetration measurements were made on each filter using the alternative test system operating with a 10 s upstream count and a 60 s downstream count. The average penetration and the coefficient of variation associated with each filter were calculated and the results plotted in Figure 6. This comparison is limited in that only five filters were studied. However, it is encouraging to note that four of the five measured data points were at or below the predicted coefficient of variation. The single CV_p measurement in excess of this prediction is for a measured penetration of <0.005 per cent, so that the relatively high CV_p (~20 per cent) still represents a relatively small variation in penetration ($<\pm$ 0.001 per cent).

DISCUSSION AND CONCLUSION

Conservative Quality of Test Efficiency Measurements

From the discussion above it is apparent that the current and proposed filter tests were designed to provide conservative estimates of filter efficiency. Estimates of filter penetration from experimental studies of flat sheet HEPA filter media indicate that penetration at a particle size of ~0.5 μm can be an order of magnitude lower than the penetration at the size of maximum penetration [11]. This finding indicates that penetration measurements at the size of maximum penetration are a very conservative estimate of filter penetration and that depending on the challenge aerosol size can over-estimate field penetration by an order of magnitude or more. This conclusion coupled with the conservative penetration estimate related to the relatively low density of the DEHP/DEHS test aerosol serve to give the USDOE filter test the appearance of being ultra-conservative.

Certain factors serve to mitigate this conservative quality of the test. HFATS penetration measurements on HEPA filters at 20 per cent rated flow show an independence to aerosol size so that the penetration measured at 0.17 μm may be the same penetration that would be measured at larger sizes. This finding suggests that the

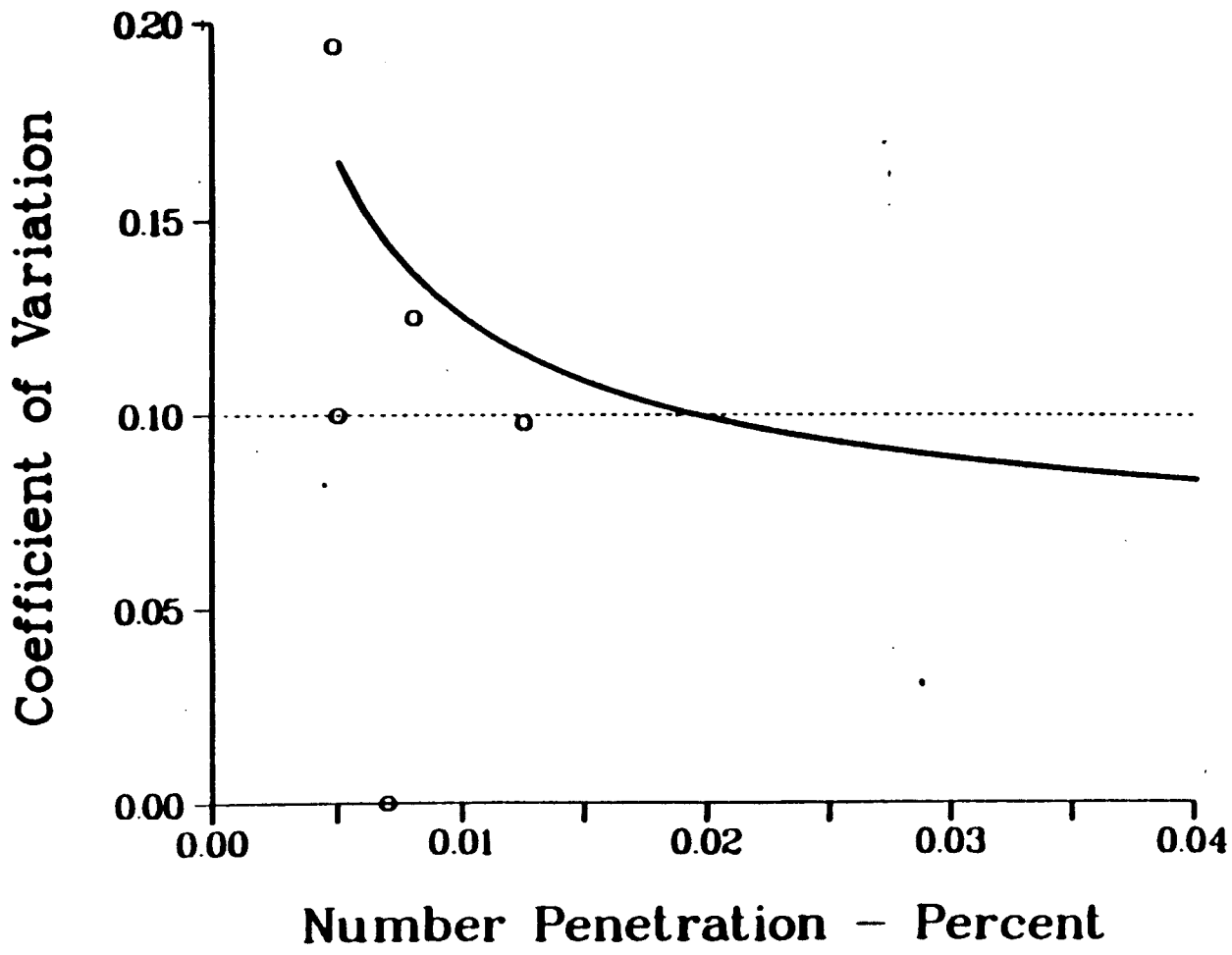

Figure 6. Uncertainty in penetration measurements. The solid curve is the theoretical prediction of uncertainty. The data points (O) are uncertainty estimates based on actual penetration measurements.

20 per cent rated flow measurements may not be as conservative an estimate of field penetration as the rated flow penetration measurements appear to be. The extent of the aerosol size independence of penetration should be investigated.

As is pointed out in the text, not all materials encountered by USDOE filters have a density greater than or equal to the density of DEHP/DEHS. For the materials which have a density less than the density of DEHP/DEHS the rated flow maximum penetration may be greater than the DEHP/DEHS measured maximum penetration [9]. This observation indicates that for materials of relatively low density, the DEHP/DEHS measured maximum penetration at rated flow may not be a conservative estimate of the maximum field penetration at rated flow. The penetration behavior of these lighter materials at 20 per cent rated flow is not known.

Studies of the performance of tandem HEPA filters indicates that the penetration through successive banks of filters increases because the aerosol penetrating each successive bank is enriched in particles of the size of maximum penetration [9,22]. The penetration of the successive banks of filters approaches but does not exceed the penetration at the size of maximum penetration [9]. These findings indicate that penetration at the size of maximum penetration may be a conservative estimate of field performance of the filters in the first bank of a tandem HEPA filter system but this estimate of performance becomes less conservative for filters in successive banks.

Because the USDOE uses these filters to protect public and worker health and the environment, some degree of conservative estimation of field filter performance is necessary. Overall, the indications are that the proposed USDOE test will provide a conservative estimate of HEPA filter performance. For single bank systems or the first bank of tandem systems, operating at rated flow and being challenged with material of high density relative to the test aerosol density, the test is probably a very conservative estimator of field filter performance. The test is probably a less conservative estimator for filters in the backup banks of tandem systems, operating at flows other than rated flow, and being challenged by materials of low density relative to the test aerosol density.

Plans for Adoption of Proposed Tests Specifications and the HFATS

The proposed test specifications are to be reviewed by a USDOE-selected technical review group along with other standards that are in the final stages of being adopted [4-7]. This review is to be completed by Fall 1986. The standards will be revised as necessary to accommodate the comments of the technical review group. These standards will be identified as mandatory standards in USDOE order 6430 [23].

The USDOE is to be petitioned to consider adoption of the HFATS in mid-1986 according to procedures specified in NE-F-3-43 [5]. Upon acceptance of the petition, Los Alamos is to submit evidence supporting adoption of the HFATS to USDOE. The USDOE with input from

the technical review group will decide whether to adopt the HFATS as an improved test method. This decision could be made by the end of 1986. If adopted, the HFATS would be ready for placement in the FTFs by the end of 1987.

In 1987, the US Army Product Assurance Directorate (PAD) plans to initiate evaluation of the HFATS for use in the PAD QA HEPA filter testing program. Implementation of the HFATS at PAD is scheduled to be completed by the end of 1987.

Also in 1987, the USDOE and PAD plan a cooperative effort to adapt the HFATS technology to a Low Flow Alternative Filter Test System (LFATS) for testing size 3 and smaller HEPA filters (rated flows of 125 CFM [~3.5 m^3/min] and lower). The adaptation is scheduled to be completed by the end of 1987. The USDOE plans to perform an operational evaluation on the LFATS in 1988.

ACKNOWLEDGMENTS

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REFERENCES

[1] Hinds, W. C., Aerosol Technology, John Wiley and Sons, New York, 1982, pg. 10.

[2] Sowby, F. D., "Limits for Intakes of Radionuclides by Workers: A Report of Committee 2 of the International Commission on Radiological Protection," Annals of the ICRP, Vol. 3, No. 1-4, 1979.

[3] Selby, J. M., Watson, E. C., Corley, J. P., et al., "Considerations of Effluents from Mixed Oxide Fuel Fabrication Plants," Pacific Northwest Laboratories Report BNWL-1697, June 1975.

[4] Filter Test Facility Standards Writing Group, "Operating Policy of DOE Filter Test Program," U.S. Department of Energy, DOE Nuclear Standards number NE-F-3-42, February 1986.

[5] Filter Test Facility Standards Writing Group, "Quality Assurance Testing of HEPA Filters and Respirator Canisters," U.S. Department of Energy, DOE Nuclear Standards number NE-F-3-43, February 1986.

[6] Filter Test Facility Standards Writing Group, "DOE Filter Test Facilities Quality Program Plan," U.S. Department of Energy, DOE Nuclear Standards number NE-F-3-44, February 1986.

[7] Filter Test Facility Standards Writing Group, "Specifications for HEPA Filters Used by DOE Contractors," U.S. Department of Energy, DOE Nuclear Standards number NE-F-3-45T, February 1986.

[8] Lee, K. W. and Liu, B. Y. H., "On the Minimum Efficiency and the Most Penetrating Particle Size for Fibrous Filters," J. Air Pollution Control Association, Vol. 30, 1980, pp. 377-381.

[9] Tillery, M. I., "Determination of Protection Factors for Tandem HEPA Filters" in the Proceedings of the 27th Annual Technical Meeting of the Institute of Environmental Sciences, 1981 , pp. 47 - 51.

[10] Lee, K. W. and Liu, B. Y. H., "Theoretical Study of Aerosol Filtration by Fibrous Filter," Aerosol Science Technology, Vol. 1, 1982, pp. 147 - 162.

[11] Liu, B. Y. H.; Rubow, K. L.; and Pui, D. Y. H., "Performance of HEPA and ULPA Filters," in the Proceedings of the 31st Annual Technical Meeting of the Institute of Environmental Sciences, 1985, pp. 25 - 28.

[12] Lee, K. W. and Liu, B. Y. H., "Experimental Study of Aerosol Filtration by Fibrous Filter," Aerosol Science Technology, Vol. 1, 1982, pp. 35 - 46.

[13] Bergman, W.; Bierman, A.; Kuhl, W.; Lum, B.; Bogandoff, A.; Hebard, H.; Hall, M.; Banks, D.; Muzumder, M.; and Johnson, J., "Electric Air Filtration Theory, Laboratory Studies, Hardware Developments and Field Evaluations," Report UCID-10052 DE84 004668, Larwence Livermore National Laboratory, Livermore, California, 1984.

[14] Scripsick, R. C.; Smitherman, R. L.; and McNabb, S. A., "Operational Evaluation of the High Flow Alternative Filter Test System," in preparation to be published in the Proceedings of the 19th DOE/NRC Nuclear Air Cleaning Conference, 1986 (to be published).

[15] Tillery, M. I.; Gonzales, M.; Elder, J.; Royer, G.; and Ettinger, H. J., "Measurements of the Penetration of High Efficiency Air Filters Using Plutonium Oxide Aerosols," in AEROSOLS: Science, Technology and Industrial Applications of Airborne Particles, Liu, B. Y. H.; Lui, D. Y. H.; and Fissan, H. J., Eds., Elsevier, New York, 1984, pp. 625 - 627.

[16] Hinds, W., Macher, J. and First M. W., "Size Distributions of Aerosols Produced From Substitute Materials by the Laskin Cold DOP Aerosol Generator," in the proceedings 16th DOE Nuclear Air Cleaning Conference, Report CONF-801038, U.S. Department of Energy, Vol. 1, 1981, pp. 125-138.

[17] "Filter Units, Protective Clothing, Gas Mask Components and Related Products, Performance Test Methods," Military Standard MIL-STD-282, May 28, 1956.

[18] Scripsick, R. C. and Soderholm, S. C., "Summary Report: Evaluation of Methods, Instrumentation and Materials Pertinent to Quality Assurance Filter Penetration Testing," Los Alamos report LA-UR-85-2104, June 1985.

[19] Scripsick, R. C. and Soderholm, S. C., "Final Report: Evaluation of Methods, Instrumentation and Materials Pertinent to Quality Assurance Filter Penetration Testing," being prepared as a Los Alamos report.

[20] Echols, W. and Young, J., "Studies of Portable Air-Operated Aerosol Generators," NRL report No. 5929, Naval Research Laboratory, 1963.

[21] Thomas, J. W. and Crane, J. D., "Aerosol Penetration Through 9 mil HV-70 Filter Paper With and Without Pinholes," in the Proceedings of the 8th AEC Air Cleaning Conference held at Oak Ridge National Laboratory, TID-7677, October 22-25, 1963.

[22] Schuster, B. G. and Osetek, D. J., "A New Method for In-Place Testing of Tandem HEPA Filter Installations," American Industrial Hygiene Association Journal, Vol. 40, 1979, pp. 979 - 985.

[23] USDOE, "General Design Criteria Manual," USDOE Order 6430, Issued June 10, 1981 (in revision).

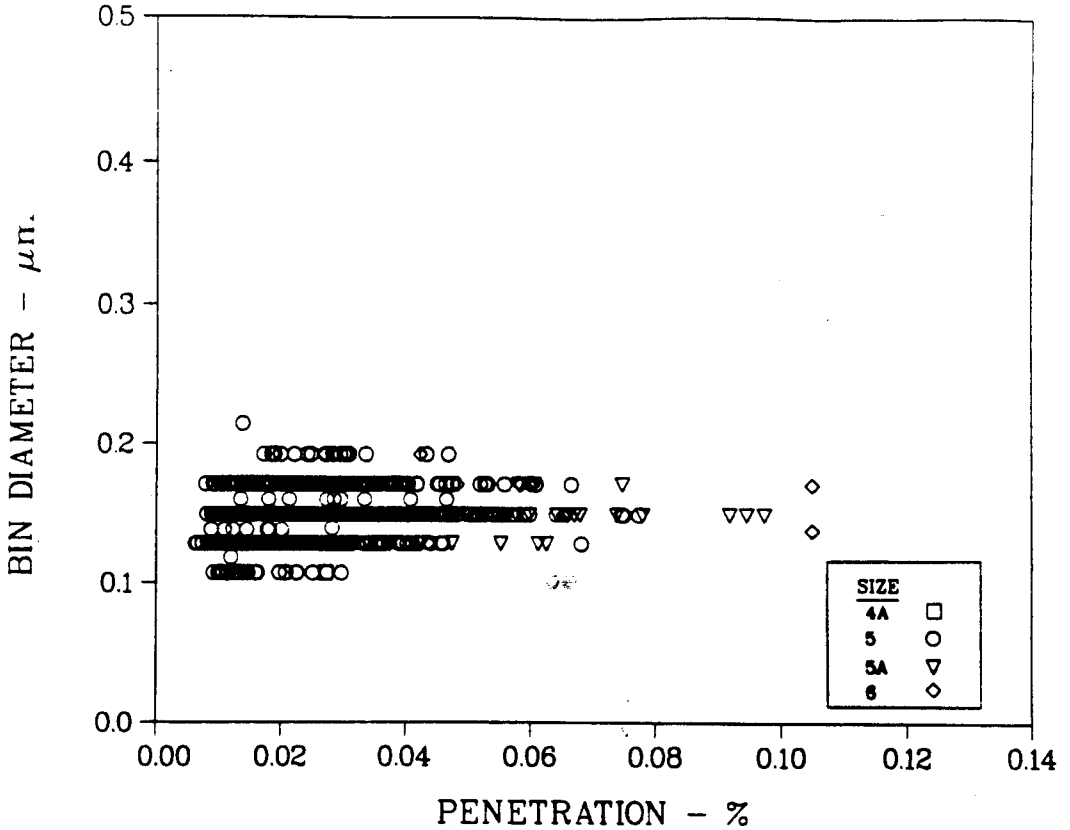

Figure 6. Plot of the maximum penetration bin diameter versus the maximum penetration for the 100% flow test data showing the grouping of the data in the bin diameter range from 0.1 µm to 0.2 µm.

sizes studied and for the total filter population, the maximum penetration was most frequently found in the 0.15 µm diameter bin. This corresponds to an electrostatic classifier measured diameter of approximately 0.17 µm. Table IV lists the number and percentage of filter tests that occurred in the various bins. For each of the filter sizes and for the total filter population, over 90% of the maximum penetration measurements occurred in the 0.13 µm to 0.17 µm bin diameter range. This range corresponds to an electrostatic classifier diameter range from approximately 0.14 µm to approximately 0.18 µm. No maximum penetration analysis of the 20% flow data was performed because those penetration data were found to be largely independent of aerosol size.

Results of the comparisons of the 0.15 µm HFATS data with the Q107 penetration data are shown in Figures 9 and 10. For the 100% flow data (see Figure 9), in almost every case the HFATS measurements are greater than the Q107 measurements. The results of the 20% flow comparison shown in Figure 10 are similar to the results of the 0.31 µm-HFATS comparison (see Figure 5) in which little difference was

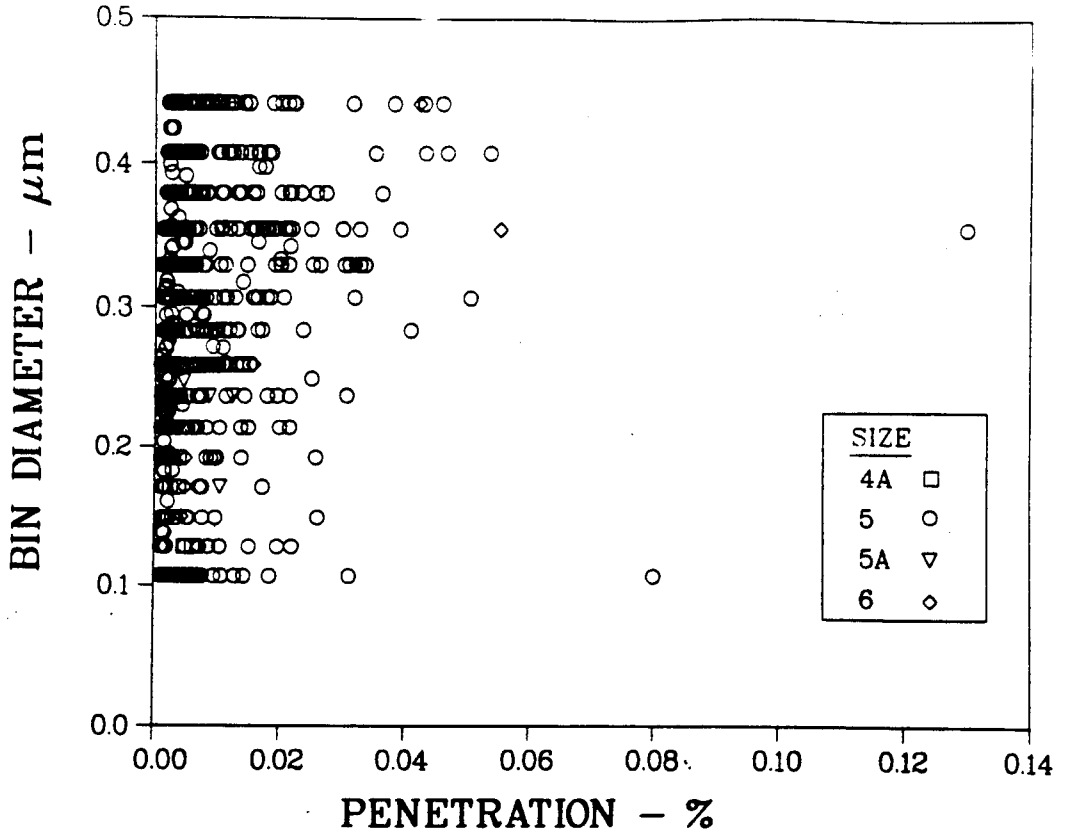

Figure 7. Plot of the maximum penetration bin diameter versus the maximum penetration for the 20% flow test data. No grouping of the data in a narrow bin diameter range was observed.

observed between the HFATS measurements and the Q107 measurements. Average differences in penetration are listed in Table V. The average differences for the 100% flow tests ranged from 0.012% to 0.025% which are much greater than the corresponding differences observed in the 0.31 μm comparison. For the 20% flow tests the average differences were <0.002% which is similar to the differences observed in the corresponding tests in the 0.31 μm comparison.

The number of filter tests where penetration measurements were above the penetration rejection limit are listed in Table VI. A total of five filter tests resulted in both systems measuring penetrations above the rejection limit. For the 100% flow tests, the HFATS measured penetrations above the rejection limit in 156 situations where the Q107 measured penetrations were below the limit. For this same set of tests, the Q107 rejected no filters that were accepted by the HFATS. The number of filters that were rejected by the two systems in the 20% tests was similar to the number of filters rejected in the corresponding tests of the 0.31 μm comparison (see Table III).

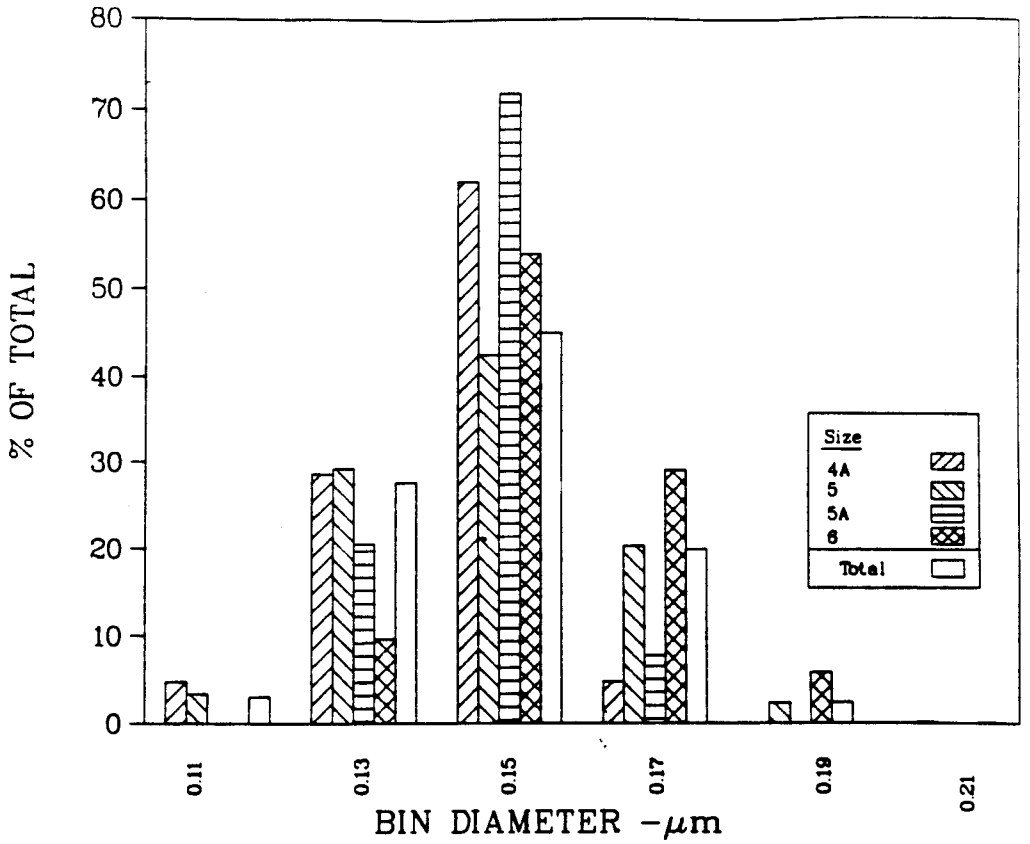

Figure 8. **A discrete frequency plot of the bin diameters that contain the maximum penetration for all the filter sizes tested.**

TABLE IV

AEROSOL SIZE OF MAXIMUM PENETRATION

	FILTER SIZE									
	4A		5		5A		6		TOTAL*	
BIN-um	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%
0.11	1	4.8	25	3.4	0	0	0	0	26	3.1
0.13	6	29	21.5	29	8	21	5	10	234	28
0.15	13	62	312	42	28	72	28	54	318	45
0.17	1	4.8	149	20	3	7.7	15	29	168	20
0.19	0	0	17	2.3	0	0	3	5.8	20	2.4
0.21	0	0	1	0.1	0	0	0	0	1	0.1

* Filters with maximum in two or more bins were not included; therefore, this column adds to 830 rather than 849.

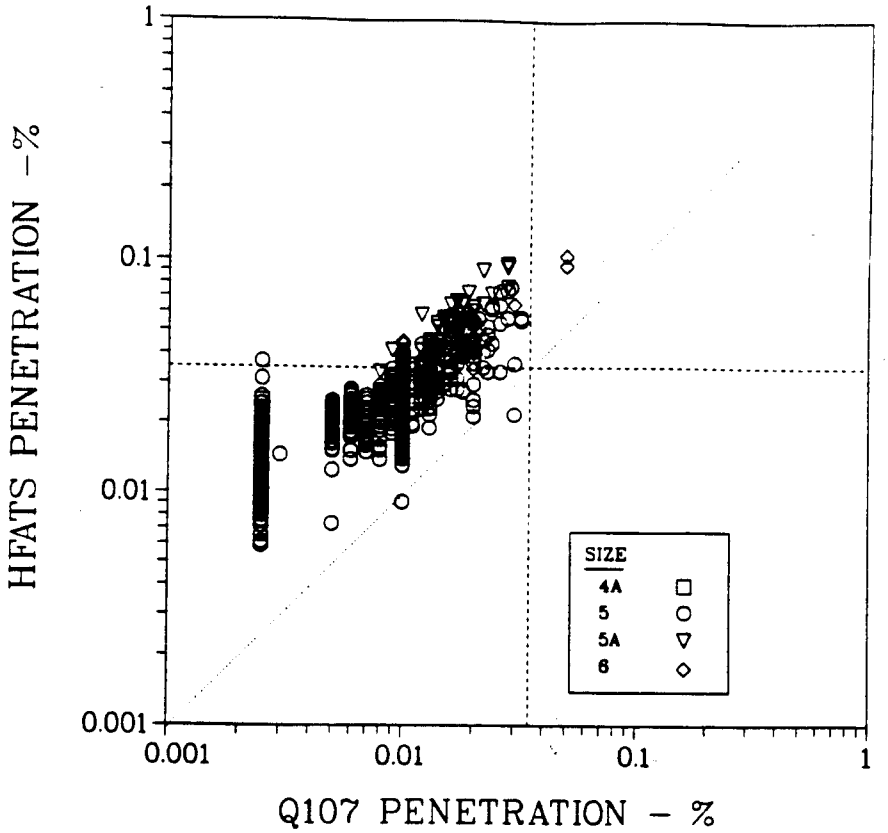

Figure 9. Comparison of the 100% flow test penetration measurements using the 0.15 µm HFATS data.

Rejection rates for the 0.15 µm-HFATS comparison are also listed in Table VI. The 100% flow "HFATS only" rejection rate for all filters tested was 18% which is much greater than the rejection rates observed under routine conditions at the FTFs. Over 50% of the size 5A and the size 6 filters were rejected by the HFATS in the 100% flow test. Thirteen per cent of the size 5 filters were rejected by the HFATS in this test. The remainder of the rejection rates listed in Table VI are at the lower end of the range of rejection rates observed at the FTF under routine conditions.

HFATS PERFORMANCE EVALUATION

Diluter Evaluation

A detailed calibration check of the HFATS diluter was performed at the beginning of the study (August 1985), once in the middle of the study (February 1986) and at the end of the study (May 1986). A plot of the dilution ratios measured during these three calibration sessions is shown in Figure 11. The dilution ratios at a given aerosol size were within 10% of one another. This indicates that the diluter calibration was stable during the 9-month study period.

LAS Size Calibration Evaluation

Prior to each HFATS test session the size calibration of the LAS was checked using a 0.22 µm manufacturer's diameter polystyrene

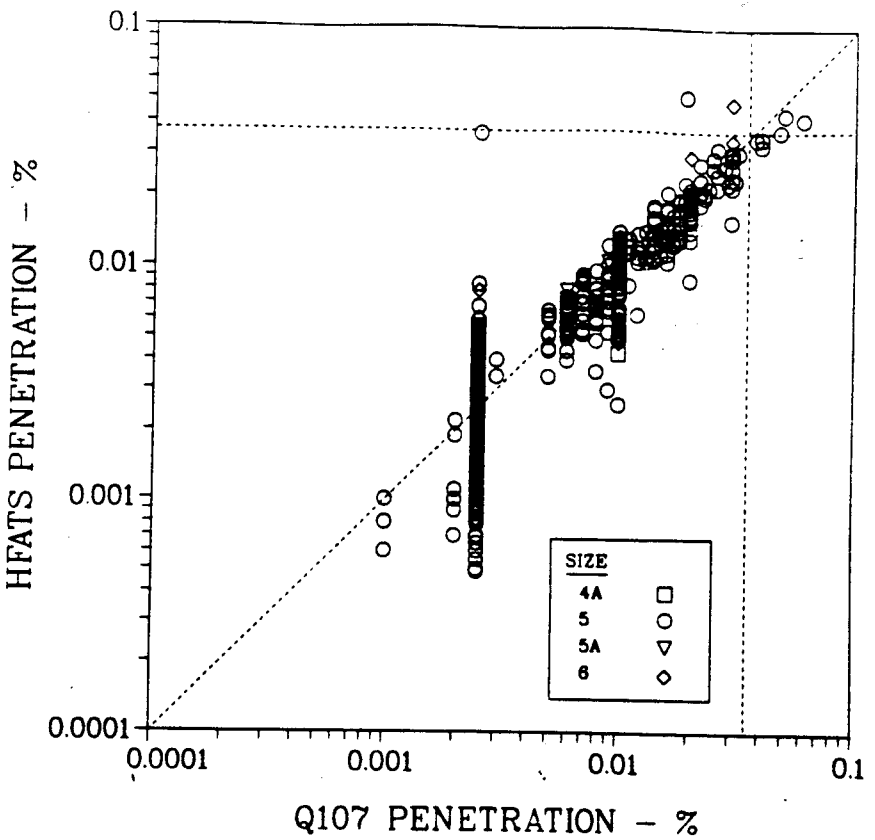

Figure 10. Comparison of the 20% flow test penetration measurements using the 0.15 µm HFATS data.

TABLE V

PENETRATION DIFFERENCES - 0.15 µm
(HFATS - Q107)

FILTER SIZE	AVERAGE DIFFERENCE 100% FLOW	AVERAGE DIFFERENCE 20% FLOW
4A	0.017*	-0.0002
5	0.015	-0.0009
5A	0.012	-0.0002
6	0.025	0.0005

* Underline indicated significant differences (P <0.05).

microsphere suspension (PMS). The results of these calibration checks throughout the study are presented in Figure 12. Because the LAS is calibrated by the manufacturer with polystyrene microspheres no index of refraction correction was required for the calibration checks. The calibration of the LAS was within one bin of the manufacturer's diameter in all but one calibration check. A cleaning of the critical LAS optics in February 1986 shifted the LAS calibration from a diameter of 0.2 µm back to the PMS manufacturer's diameter. The 0.18 µm diameter calibration check in early May 1986, is suspected to be the result a steam excursion during a repair of the Q107 that dirtied the LAS optics. In this situation, the LAS reference voltage was below the manufacturer's recommended limit for operation. Again, cleaning of the critical optics by FTF personnel restored the calibration.

Upstream Count Rate Evaluation

After the upstream count of every filter test the upstream count rate measured by the LAS was automatically recorded and printed by the HP-85 microcomputer. As described earlier, this provides the operator with a continuing frequent indication on how well the HFATS is performing. Changes in the output of the blower or the HFATS generator or changes in the performance of the HFATS diluter or the LAS would affect this count rate. A plot of the measured count rates over the term of the study is shown in Figure 13. The plot shows no trend upwards or downwards over the term of the study. In general, the occasional single measurement changes in count rate were found to be associated with blower adjustments to accommodate the operation of the Q107. The count rate returned to its normal magnitude (between approximately 1400 and 1600 counts/sec) when the blower output was adjusted back to its standard level. The one sustained drop in count rate that occurred in early January 1986 was the result of the operator leaving the blower in the high output position after a Q107 test series. These data indicate that the performance of the HFATS equipment was stable during the 9-month study. Examination of the data during individual test sessions shows no distinct general increase or decrease in the upstream count rate.

TABLE VI

PENETRATION REJECTIONS FOR THE 0.15 µm-HFATS COMPARISON

		FAILING 100% TESTS						FAILING 20% TESTS					
		HFATS ONLY		Q107 ONLY		BOTH		HFATS ONLY		Q107 ONLY		BOTH	
FILTER SIZE	NUMBER TESTED	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%
4A	21	0	0	0	0	0	0	0	0	0	0	0	0
5	737	95	13	0	0	0	0	2	0.3	3	0.4	3	0.4
5A	39	34	87	0	0	0	0	0	0	0	0	0	0
6	52	27	52	0	0	2	3.9	1	1.9	0	0	0	0
TOTAL	849	156	18	0	0	2	0.2	3	0.4	3	0.4	3	0.4

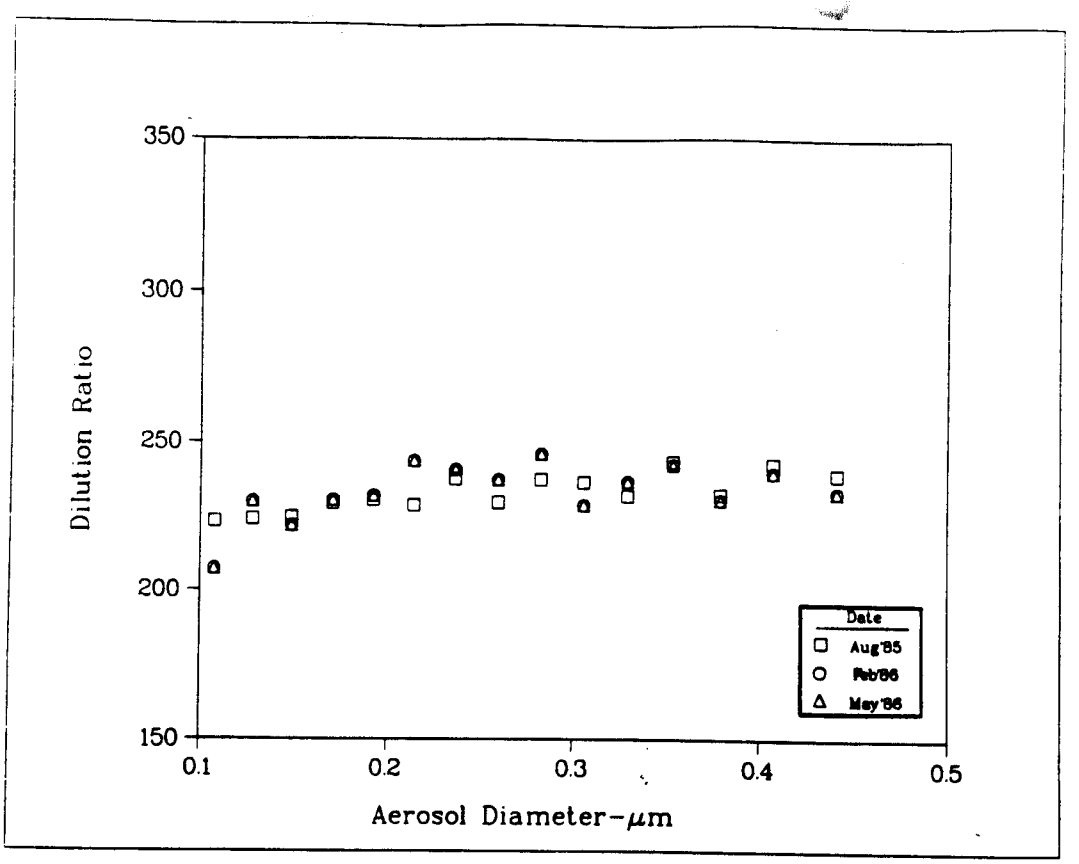

Figure 11. Comparison of three diluter calibration evaluations performed over the course of the study.

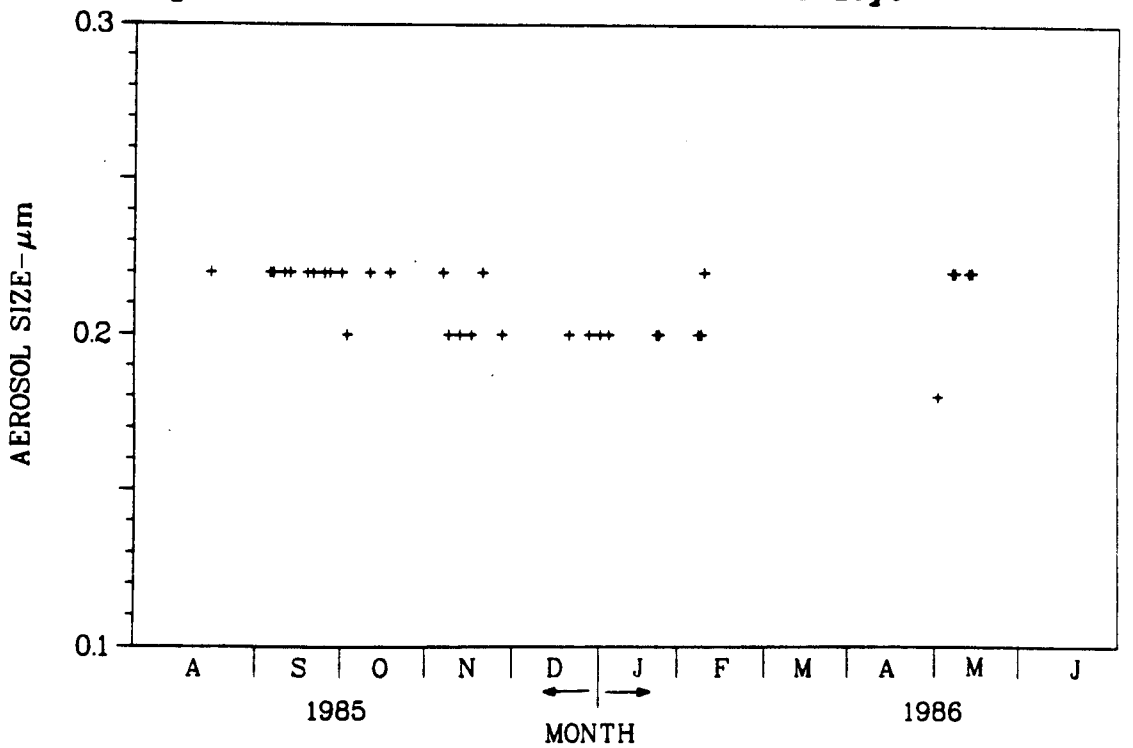

Figure 12. Results of the LAS calibration checks performed throughout the study.

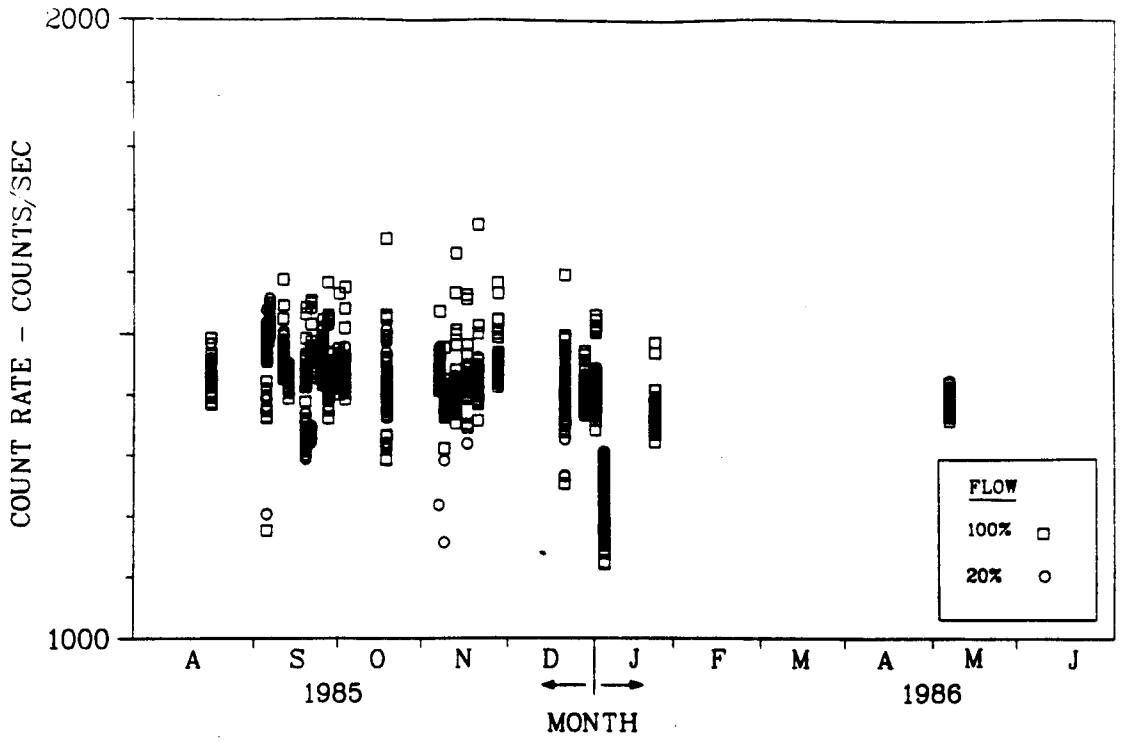

Figure 13. Results of the upstream count rate evaluation performed throughout the study.

HFATS IMPACTS ON FTF OPERATION

Comparison of Filter Test Rates

Records of the time required to test a filter set were kept by the Oak Ridge test system operator. The time recorded by the operator included the test system start-up time as well as the time required to test the set of filters. The time required to shutdown the test systems was not included in the recorded time because the time of day that testing had to cease was largely determined by the amount of time at the end of the work day that had to be allocated to storing the tested filters and recording filter test results.

The rate at which filters were tested was calculated by dividing the recorded time into the number of filters tested. A plot of these rates over the term of the study is shown in Figure 14. The HFATS test rates in the initial weeks of the study increased from a low of approximately 5 filters/hr to a rate of almost 6.5 filters/hr. This increase is probably related to the operator becoming familiar with the study and HFATS operating procedures. The HFATS rates measured from the beginning of October 1985 through the end of the study were constant, save one case, at a rate just below 6.5 filters/hr. The Q107 rates showed some fluctuation early in the study, but again by about the beginning of October 1985 the rates became constant, save two cases, at a rate of just below 7.5 filters/hr. The high rates (>7.5 filters/hr) observed in January 1986 were found to be associated with filter test sessions that were conducted after a

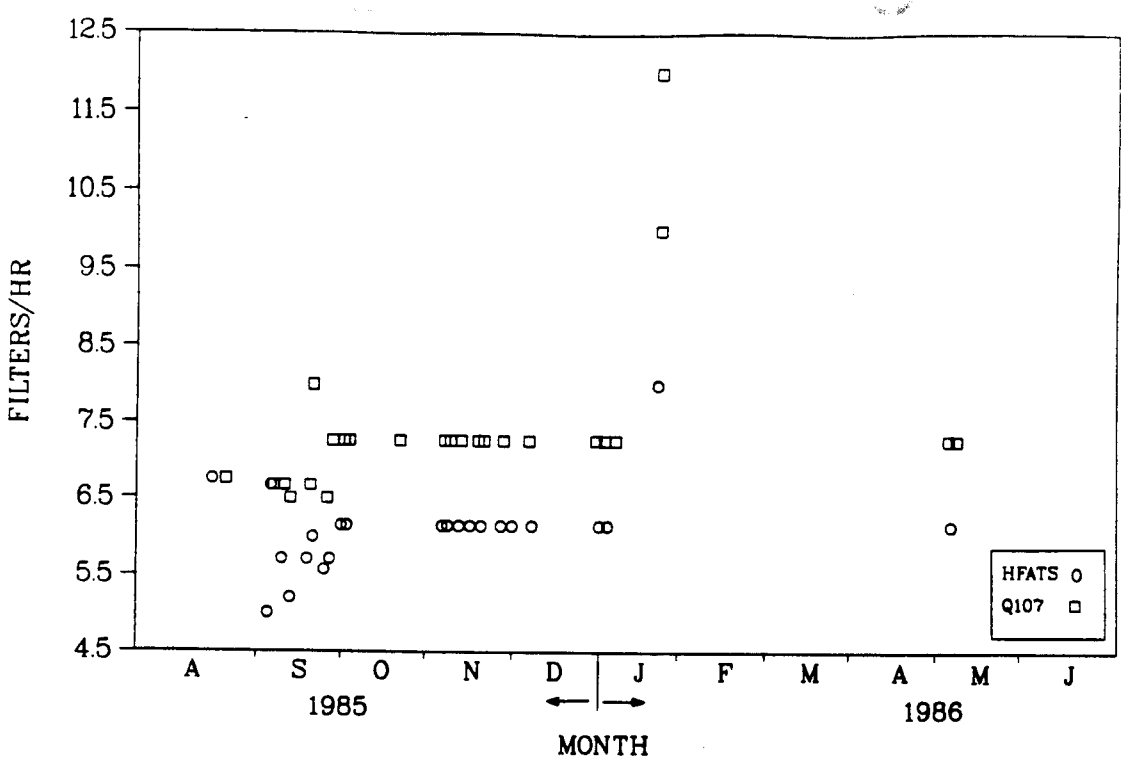

Figure 14. A plot of the filter test rates for the HFATS and the Q107 over the term of the study.

previous test session for which the test systems had been started. Consequently, no start-up time was included in the high rate session's recorded time.

Even though the rate at which the Q107 test filters is distinctly greater than the HFATS test rate, there was no difference in the number of filters that could be tested by either system in a work day. This conclusion comes from the fact that the number of filters that can be tested in a day at the ORFTF is largely dependent on the logistics of conveying filters to and from the location where they are tested and the Q107 cool down time. Filters are conveyed to and from the test location by a batch process in which a set of filters is unpacked, placed on a conveyor, and moved to the test location. After testing, they must be conveyed back to the store room and stored prior to loading the next set of filters for testing. Testing of two batches of up to 24 filters with the Q107 required enough of the work day that with the time required prior to the end of the work day for attending the Q107 during its cool down (approximately a half hour) there was no more time to load and begin testing another set of filters. The same two batches of filters can be tested by the HFATS in a day because the shorter time required to shutdown the HFATS (<5 min) allowed enough extra testing time to make up for the slower rate at which the HFATS tested filters. Operationally, the main difference in a day of testing with the two systems is that the operator spends more time testing filters with the HFATS and is not available to carry out other duties that the

individual might be able to do while attending to the Q107 during its cool down phase.

Certain possibilities exist for increasing the HFATS filter test rate. First, the series of calibration checks and the extensive data collection that were conducted in the operational evaluation may not be necessary for routine FTF operation of the HFATS. The high degree of stability displayed by the HFATS supports extending the time between calibration checks. A significant amount of time was required to automatically store the large amount of data retained for each filter test. This time could be significantly reduced by using a faster data storage system and by limiting the amount of data stored. Another way of reducing the time required to test filters would be to reduce the clearing time between the upstream and downstream counts and between the 100% flow test and the 20% test. A valve design that would permit reduction of the required clearance time is being investigated.

These recommendations have the potential of increasing the HFATS test rate to approximately that of the Q107. However, it is unlikely that the HFATS test rate could be increased to a rate much higher than the Q107 rate because of the 4 to 5 minutes required by the HFATS to make the necessary count measurements for a filter test.

HFATS Operational Safety

A major advantage that was attributed by the Oak Ridge staff to the HFATS was that the DEHP odor present when operating the Q107 was not present during the operation of the HFATS. In addition, a former Oak Ridge test system operator who had stopped testing filters because of sensitivity to DEHP odors, was able to test filters with the HFATS. The Department of Energy has adopted the policy of limiting workplace exposures to filter test material through the use of engineering controls.[1] The challenge aerosol concentration used in the HFATS is at least an order of magnitude lower than the Q107 challenge concentration, which means the source term for emissions to the workplace is greatly reduced for the HFATS relative to the Q107. The reduced source term is probably at least partially responsible for the absence of odor associated with the HFATS operation. Reduction of the source term represents an appropriate engineering control for limiting workplace exposures.

Another major operational safety issue is the potential fire hazard the Q107 thermal generator presents. Because of the possibility of fire, Q107 systems are fitted with costly fire suppression equipment. None of the HFATS components present a safety problem of this magnitude. The HFATS generator uses air-operated jets to produce the challenge aerosol. This method of aerosol production greatly reduces the risk of fire.

Operation of the HFATS

The Oak Ridge staff gained several insights into the operation of the HFATS in the FTF environment relative to the operation of the Q107. A major difference in the systems was the relative amounts of operator attention that they required. Because the Q107 uses a thermal generator that heats the test aerosol material to near its

flash, once the system is started, it must be attended to until approximately a half hour after the cool down phase is initiated in order to assure that temperature excursions are thwarted.

During actual operation of the test systems the HFATS required much less attention and adjustments than did the Q107. Most of the attention and adjustments required by the Q107 was associated with maintaining the challenge aerosol particle size and concentration. The challenge aerosol particle size requirements for the HFATS are less stringent than those for the Q107 because the HFATS particle size discrimination is performed by the LAS. The output of the HFATS generator and the performance of the HFATS diluter and the LAS as indicated by the performance indicators was so stable that close monitoring by the operator was not needed. The HFATS required almost no adjustment during the study.

Maintenance of the HFATS

Direct comparison of the maintenance time required by the test systems is not completely appropriate because of the differing ages of the system's components. The HFATS system components, however, were not all new. For example, the LAS used in the study was over 7 years old and used a laser tube that at the beginning of the study was more than 1 year old. The HFATS required less than 2 hours maintenance during the 9-month operational evaluation, which was associated with cleaning the critical optics of the LAS. The Q107 aerosol generation system required more than 2 days maintenance. Maintenance of the large capacity equipment used to condition high flow air streams of the Q107 generating system to within very close tolerances has been a recurring problem at Oak Ridge. Repair of these conditioning systems has required significant periods of down time and has been costly.

A concern with the HFATS is the availability of repairs and replacement parts for the LAS. A possible remedy to this potential problem is to contract with the LAS manufacturer to maintain a LAS that would be ready to be shipped to a FTF in the event a replacement was needed. The time between maintenance periods for the LAS should be increased according to the LAS manufacturer because the useful life of the laser tubes has been extended from 1 year to 5 years by the use of a new glass to metal sealing process. The tube in the LAS used in the study has lasted over 2 years to-date.

IV. Summary

The comparison of 0.31 μm HFATS penetration measurements and rejection rates to those of the Q107 indicated that there was not much difference in the magnitude of the measurements. This indicated that operation of the HFATS in this mode would not greatly affect the measurements reported by the FTFs. On the other hand the 0.15 μm HFATS measurements made at the 100% test flow were distinctly greater than the corresponding Q107 measurements. The HFATS provides the capability of measuring worst case filter penetration and readily determining penetration in terms of physical factors of concern (i.e. mass, radioactivity, etc.).

The HFATS demonstrated excellent stability as indicated by the diluter evaluation results, the LAS size calibration results and the upstream count rate results. These data suggest that an extended calibration check schedule would be appropriate for the HFATS.

The major negative impact that the HFATS appears to have on the FTF operation is the lower rate at which filters are tested. However, there was no difference in the number of filters that could be tested by either system in a day. The HFATS exhibited certain positive effects on the FTF operation. These included potential reduction in the workplace airborne levels of the test aerosol material, limiting the fire hazard associated with testing filters, easier operation and potentially less costly and less frequent maintenance.

V. Conclusion

The results of this study demonstrate the operability and maintainability of the HFATS in the FTF environment. The operational advantages cited above and the technical advantages cited elsewhere demonstrate that the use of the HFATS at the FTFs would improve the FTF operation and improve the technical defensibility of the FTF penetration measurements.[2] Because of this conclusion, the authors recommend that the Department of Energy consider adoption of the HFATS as an approved filter test system under the provisions of the NE-F-3-43.[1]

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References

1. US DOE Nuclear Standard NE-F-3-43 (Draft), Filter Test Facility Standards Writing Group, "Quality Assurance Testing of HEPA Filters and Respirator Canisters," US Department of Energy (as revised February 1986).

2. R. C. Scripsick and S. C. Soderholm, "Final Report: Evaluation of Methods, Instrumentation and Materials Pertinent to Quality Assurance Filter Penetration Testing," Los Alamos Report, LA-10748 (June 1986).

3. S. C. Soderholm and M. I. Tillery, "Intermediate Results of a One-year Study of a Laser Spectrometer in the DOE Filter Test Facilities," in the Proceedings of the 18th DOE Nuclear Airborne Waste Management and Air Cleaning Conference, Baltimore, Maryland, M. W. First, Ed., March 1985, pp. 1149 - 1167 (August 12-16, 1984).

4. S. C. Soderholm and M. I. Tillery, "Final Results of a One-year Study of the Operation of a Laser Spectrometer in the DOE Filter Test Facilities," Los Alamos report LA-UR-85-179 (revised July 1985).

5. G. Salzman, H. Ettinger, M. Tillery, L. Wheat, and W. Grace, "Potential Application of a Single Particle Aerosol Spectrometer for Monitoring Aerosol Size at the DOE Filter Test Facilities," in the Proceedings of the 17th DOE Nuclear Air Cleaning Conference, Denver, Colorado, M. W. First, Ed., February 1983, pp. 801 - 820 (August 1 - 6, 1982).

6. K. W. Lee and B. Y. H. Liu, "On the Minimum Efficiency and the Most Penetrating Penetrating Particle Size for Fibrous Filters," J. Air Pollution Control Association, Vol. 30, pp. 377 - 381 (1980).

7. K. W. Lee and B. Y. H. Liu, "Theoretical Study of Aerosol Filtration by Fibrous Filters," Aerosol Science Technology, Vol. 1, pp. 147 - 162 (1982).

8. W. Bergman, A. Beirmann, W. Kuhl, B. Lum, A. Bogandoff, H. Hebard, M. Hall, D. Banks, M. Muzumder, and J. Johnson, "Electric Air Filtration Theory, Laboratory Studies, Hardware Developments and Field Evaluations," Report UCID-10052 DE84 004668, Lawrence Livermore National Laboratory, Livermore, California (1984).