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IN-PLACE HEPA FILTER PENETRATION TEST*

by

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Abstract

We have demonstrated the feasibility of conducting penetration tests on high efficiency particulate air (HEPA) filters as installed in nuclear ventilation systems. The in-place penetration test, which is designed to yield equivalent penetration measurements as the standard DOP efficiency test, is based on measuring the aerosol penetration of the filter installation as a function of particle size using a portable laser particle counter.⁽¹⁾ This in-place penetration test is compared to the current in-place leak test using light scattering photometers for single HEPA filter installations and for HEPA filter plenums using the shroud method. Test results show the in-place penetration test is more sensitive than the in-place leak test, has a similar operating procedure, but takes longer to conduct. Additional tests are required to confirm that the in-place penetration test yields identical results as the standard dioctyl phthalate (DOP) penetration test for HEPA filters with controlled leaks in the filter and gasket and duct by-pass leaks. Further development of the procedure is also required to reduce the test time before the in-place penetration test is practical.

I. Introduction

Before a HEPA filtration system can be used in a DOE nuclear facility, the ventilation system and the HEPA filters must pass acceptance tests described in ASME N510 or AG1, and the HEPA filter must pass the MIL-STD-282 penetration test.⁽¹⁻³⁾ The acceptance tests consist of leak tests of ducts and housings, airflow capacity and distribution tests, and air-aerosol mixing uniformity tests. The airflow distribution test is designed to insure that HEPA filters see a uniform air flow, while the air-aerosol mixing test is performed to insure that the concentration of aerosols challenging the filter is uniform. This will insure that representative samples can be obtained before and after the filter for computing the filter penetration.

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The HEPA filter penetration test is given in MIL-STD-282.⁽¹⁾ This test requires HEPA filters to have less than 0.03% penetration for 0.3 μm DOP aerosols as measured by a light scattering photometer. The 0.3 μm aerosols were originally selected because they were believed to be the most penetrating aerosols and would yield the most conservative penetration values for the HEPA filters. These aerosols were generated in a very large machine by a controlled condensation of DOP vapor and were thought to be monodisperse.

After the HEPA filter is installed in a certified ductwork, and once a year thereafter, the filter installation must be tested for leaks.⁽²⁻⁴⁾ This in-place leak test is performed to insure that the HEPA filter is properly installed and has not been damaged, that there are no leaks in the mounting frame or between the mounting frame and the housing, and that the system contains no bypassing that would reduce the system penetration. The in-place leak test is not a filter penetration test and can not be used in determining the penetration of HEPA filters. The difference between the two tests is the particle size and the type of aerosol generator used to challenge the filter: the DOP penetration test uses near monodisperse 0.3 μm particles generated by a very large vapor condensation generator, while the in-place test uses heterodisperse 0.7 μm particles generated by small portable air or thermal generators.⁽²⁻⁴⁾ ERDA 76-21 recommends an acceptance criterion of 0.03% maximum penetration for the in-place DOP test.⁽⁴⁾

The HEPA filter leak test was implemented in 1960 in the U.S. to verify that the installed filtration systems did not have leaks.⁽⁵⁾ This test represented a second-best choice at that time since it was not possible to conduct in-place penetration tests using the available test equipment. The problem was that the particle measuring instruments at that time could not distinguish between particle sizes, and monodisperse 0.3 μm aerosol generators were not portable. The available light scattering photometers were portable but could not distinguish between different particle sizes. To measure HEPA filter penetration at 0.3 μm diameter, it was necessary to have a monodisperse 0.3 μm diameter generator, which were not portable. The only portable aerosol generators at that time produced heterodisperse aerosols.

Now, a variety of instruments and aerosol generators are commercially available that can be used for measuring in-place filter penetration. Portable particle spectrometers are available that can measure specific particle sizes in heterodisperse aerosols. Portable aerosol generators are also available that can generate monodisperse aerosols. Thus it is now possible to measure in-place HEPA filter penetration at 0.3 μm using portable equipment consisting of either a particle size spectrometer and a heterodisperse aerosol generator or an integrated particle analyzer (e.g. photometer, condensation nuclei counter) and a monodisperse aerosol generator. We will only address the in-place penetration method using laser spectrometers and heterodisperse aerosols in this paper.

II. Difference Between Penetration, In-Place Leak, and In-Place Penetration Tests

The difference between the results of the penetration and the in-place leak tests can be illustrated with a typical HEPA filter penetration curve shown as a function of particle size in Figure 1. The penetration is a maximum at $0.15\mu\text{m}$, decreases rapidly with increasing particle size and is negligible at $0.7\mu\text{m}$ for HEPA filters with no leaks. Although the penetration measurement at $0.3\mu\text{m}$ is significantly less than the maximum, it still provides a sensitive measurement of the filter penetration. In contrast to the in-tact HEPA filter installation in Figure 1, particle penetration through leaks is independent of particle size. Thus any penetration that is measured at $0.7\mu\text{m}$ diameter during the in-place leak test can be attributed to leaks.

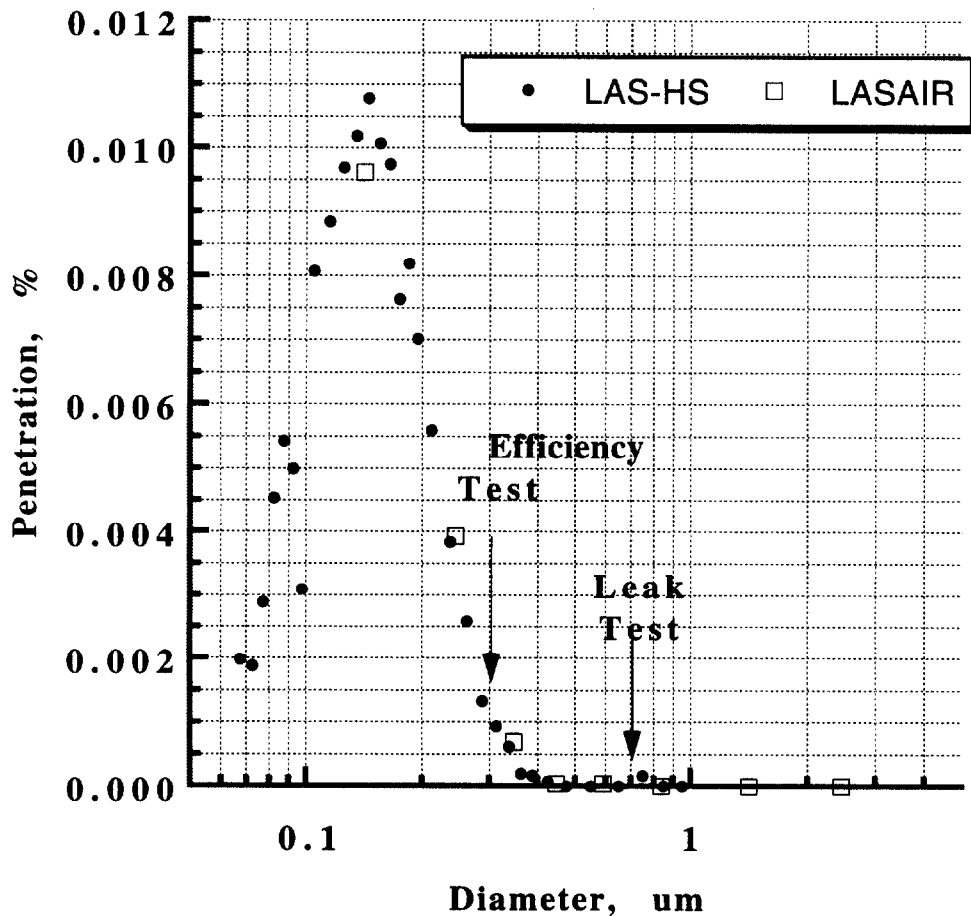


Figure 1. Plot of HEPA filter penetration measurements as a function of particle size for dioctyl sebacate (DOS) aerosols with two different laser spectrometers. Nuclear grade, 1,000 cfm HEPA filter.

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Two different laser particle counters (Particle Measurement Systems, Bolder, CO) were used to generate the curve in Figure 1: the LAS-HS laser counter, which measures particles from 0.067 to 0.95 μm diameter and the LASAIR laser counter, which measures particles from 0.14 to 2.4 μm diameter. The diameter measurements are based on the logarithm midpoint of each of the counter channels. A 100:1 diluter (TSI, Minneapolis, MN) was used to dilute the upstream measurements to avoid coincidence counting. The dioctyl sebacate aerosols were generated with a Laskin nozzle aerosol generator (Virtis, Gardiner, NY). Details of the test procedure are described in previous reports.^(6,7) The agreement between the two instruments is good.

It is possible to conduct filter penetration tests as described in ASME N-510 and ASME AG-1 using a laser particle counter during in-place filter tests.^(2,3) If the laser counter is used for measuring the total number of particles without regard to particle size, then the filter test becomes another leak test. However, if the laser counter is used to discriminate between different particle sizes, such as 0.3 μm , then the laser test becomes an in-place penetration test. Using the laser particle counter also allows the maximum filter penetration, as shown in Figure 1, to be determined with the in-place penetration test. A description of the filter efficiency test using the laser particle counter is given by Bergman and Biermann and by Scripsick et al.⁽⁶⁻⁸⁾

The in-place penetration test using the laser particle counter is a measurement of the penetration of the total filtration system. This test incorporates the aerosol penetration from both the HEPA filter and leaks in the filter housing or gaskets. In separate filter penetration and leak tests, the total penetration of the filtration system is determined from the sum of the filter penetration and the leak penetration. In separate penetration and leak tests, once the filter is installed, it is only possible to determine system leaks with the light scattering photometer and assume the filter penetration remains the same. The in-place leak test using the light scattering photometer can only detect a major deterioration in filter penetration.

The increased sensitivity of the laser particle counter allows filter penetration measurements of two stages of HEPA filters for both the leak test and the penetration test. This capability, which is not possible for the standard photometer based leak test, is advantageous because of the reduced testing time and the difficulty in measuring the penetration of individual stages in systems having minimal space between stages. Schuster and Osetck were the first to use a laser particle counter to measure the filter penetration of one-stage and two-stage, size 1 HEPA filters.⁽⁹⁾ They found typical DOP penetrations of 0.003% for single stage and 0.000005% for two stage HEPA filters. However measurements of penetration versus particle size were only reported for the single stage HEPA filters.⁽⁹⁾

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Ortiz determined the filter leaks in a number of 20,000 cfm two-stage HEPA filter systems.⁽¹⁰⁾ He did not discriminate between particle size, but rather used the total particle count before and after the filters to determine the system leaks. The test was therefore a leak test and not a penetration test. The leak measurements for ten systems varied from 0.0067% to 0.00000009%. The maximum allowable leakage for two stage HEPA filters is 0.000009%. This study was significant not only because the test system was demonstrated under field conditions, but also because it showed the laser particle counter detected filter system failures that were not seen with the standard single stage method described in ASME N510.⁽²⁾

Ortiz et al also conducted a round robin test of two-stage HEPA filtration system in which they measured filter penetration as a function of particle size using a laser spectrometer.⁽¹¹⁾ In this configuration, the filter test was an in-place penetration test. To avoid coincidence counting, the upstream concentration was diluted. The test apparatus and procedure were incorporated into an ASTM test method for evaluating HEPA filters.⁽¹²⁾

The Los Alamos National Laboratory (LANL) uses a laser spectrometer and heterodisperse aerosols as developed by Ortiz and incorporated in the ASTM standard for conducting in-place HEPA filter leak tests in all of their facilities.⁽¹⁰⁻¹³⁾ Since the particle measurements are made by adding all of the sizes into a single count, the LANL in-place filter measurements can not be used for determining filter penetration, but rather for leaks. Adding together the particle counts in the different particle size bins destroys the ability to measure filter penetration with heterodisperse aerosols. However, by keeping the particle counts in the different size bins separate, the LANL test procedure for leaks can be converted to a test of filter penetration test.

III. Correlation of In-Place Penetration Test With Standard Penetration Test

In order to claim that an in-place filter penetration test is equivalent to the standard HEPA filter penetration test at 0.3 μm , it is necessary to establish a correlation between the in-place penetration test with the standard penetration test specified in MIL-STD-282.⁽¹⁾ Such a correlation would include penetration measurements on HEPA filters with varying defects in the filter and the gasket as well as by-pass leaks in the ventilation ducting. These correlation tests have not yet been completed. However Scripsick et al conducted tests on 849 new HEPA filters using laser measurements at 0.31 μm and the standard Q-107 measurements at 0.3 μm .⁽⁸⁾ The correlation between the laser measurements at 0.31 μm and the Q-107 measurements at 0.3 μm is good, as shown in Figure 2.⁽⁸⁾ Note that the correlation becomes worse at smaller penetration values. This is not surprising considering the photometer in the Q-107 measurements is increasingly noisy below 0.01% penetration. We plan to conduct similar correlations using filters with controlled leaks in the media and gaskets and using controlled by-pass leaks in the ducting.

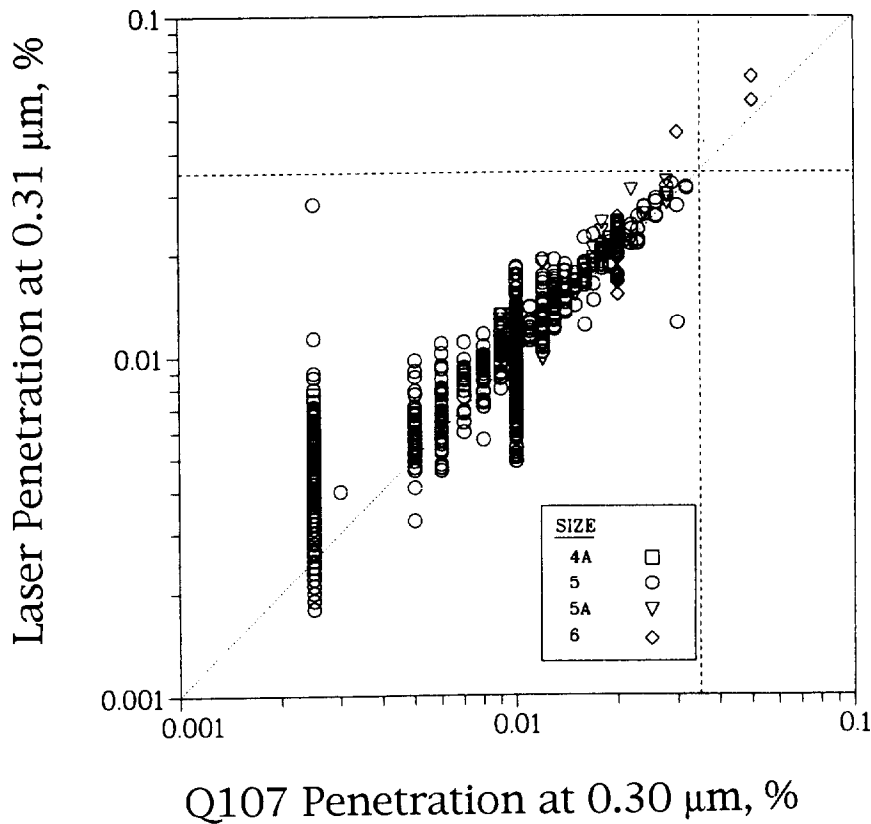


Figure 2. Correlation of HEPA filter penetration between laser spectrometer and Q107 photometer.⁽⁸⁾

For measurements of the maximum filter penetration, it is not necessary to conduct correlation tests with the Q107 tester because it only measures the penetration at 0.3 μm . The Q107 can not be used to determine the maximum filter penetration at 0.15 μm , as seen in Figure 1. In fact, there are no standard reference tests for the maximum filter penetration. The laser spectrometer can be used in a primary test standard for the maximum filter penetration if the particle size range is sufficient to clearly show a maximum as seen in Figure 1.

IV. Correlation of In-Place Penetration Test With Standard Leak Test

We have conducted a series of filter penetration tests on a HEPA filter with an increasing number of pin holes to establish a correlation between the in-place penetration test and the standard leak test. A nuclear grade, 1,000 cfm HEPA filter was used in these correlation tests. Two different laser spectrometers were used to

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determine the in-place filter penetration as a function of size: the LAS-HS laser counter, which measures particles from 0.067 to 0.95 μm diameter and the LASAIR laser counter, which measures particles from 0.14 to 2.4 μm diameter. A 100:1 diluter (TSI, Minneapolis, MN) was used to dilute the upstream measurements to avoid coincidence counting. The dioctyl sebacate aerosols used in the in-place penetration tests were generated with a Laskin nozzle aerosol generator (Virtis, Gardiner, NY). Filter penetration was determined from the ratio of the downstream concentration divided by the upstream concentration after correcting for the upstream dilution and subtracting background aerosols. Figure 1 shows the penetration of the new HEPA filter as a function of particle size.

The standard leak test was conducted using a TDA-2GN light scattering photometer (ATI, Owings Mills, MD) to obtain aerosol measurements before and after the HEPA filter. A TDA-5B aerosol generator (ATI, Owings Mills, MD) was used to generate the alpha-olefin (Emery 3004) aerosols for the in-place leak tests. Filter leak measurements were made by electronically setting the photometer upstream concentration to 100% and reading the downstream concentration directly. The in-place leak test yielded a leak of 0.01% for the test shown in Figure 1.

Following the initial test on the new HEPA filter, we made a single pinhole in the filter medium using a 0.025 inch diameter needle and repeated the in-place penetration and in-place leak tests. Additional pin holes were then made in the filter, and the filter was retested each time for penetration and leakage. The test results for the in-place penetration measurements are shown in Figure 3 for the filter having 0, 1, 2, and 6 pin holes and in Figure 4 for the filter having 9, 13, 19, 27, and 40 pin holes. The photometer measurements for each of the filter tests are shown in Table 1 along with the designated number of pinholes. Table 1 also shows the filter pressure drop and the penetration measured at 0.15, 0.3, and 0.7 μm diameter. Note that the pressure drop is not affected by the pin holes, whereas the laser penetration and photometer leaks show large increases with increasing number of pin holes.

The agreement between the HS-LAS and the LASAIR laser counters is very good over the overlapping size range as seen in Figures 3 and 4. The HS-LAS and LASAIR data are indicated by the open and closed data points, respectively. Both laser counters also yield the same value at the maximum filter penetration. However, the maximum penetration for the LASAIR occurs in the first size channel (0.1-0.2 μm), which will not allow verification of maximum penetration when the LASAIR instrument is used alone. This is not a serious problem since the maximum penetration occurs at 0.15 μm diameter for filters with and without pin holes. The preferred laser counter should have several measurements between 0.1 and 0.2 μm to verify that the maximum filter penetration is bracketed.

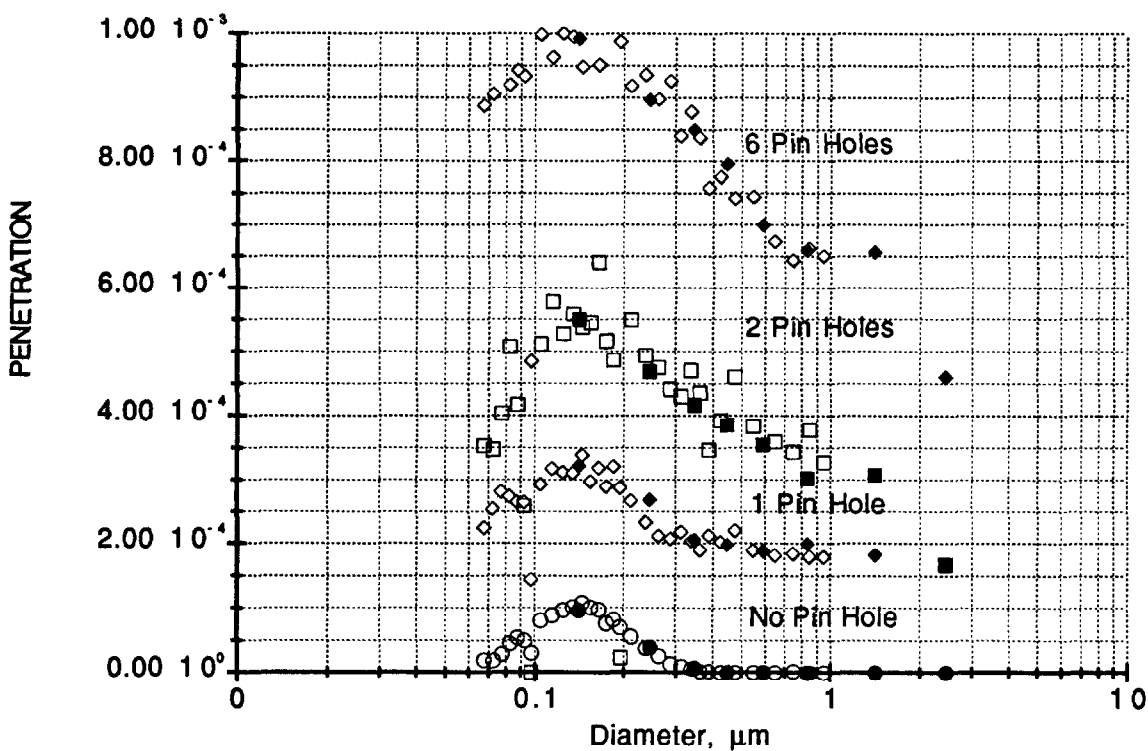


Figure 3. Penetration of DOS aerosols as a function of aerosol diameter for the same HEPA filter having 0, 1, 2, and 6 pin holes produced with a 0.025 inch needle. HS-LAS, open points, LASAIR, closed points.

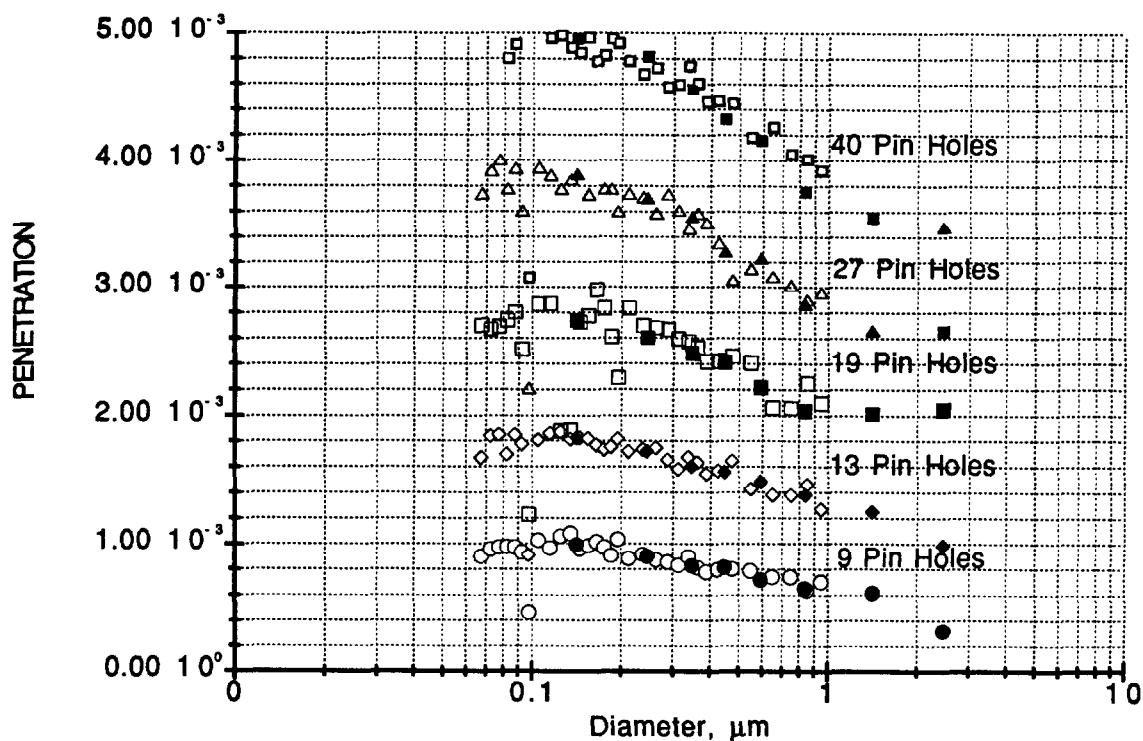


Figure 4. Penetration of DOS aerosols as a function of aerosol diameter for the same HEPA filter having 9, 13, 19, 27, and 40 pin holes produced with a 0.025 inch needle. HS-LAS, open points, LASAIR, closed points.

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Table 1. Penetration and leak measurements on a HEPA filter with varying pin holes .

Pin Holes	ΔP , inches	Laser Penetration at Diameter			Photometer Leak
		0.15 μm	0.3 μm	0.7 μm	
0	1.06	1.5×10^{-4}	1.0×10^{-5}	1.0×10^{-6}	1×10^{-4}
1	1.06	3.2×10^{-4}	2.2×10^{-4}	1.8×10^{-4}	2×10^{-4}
2	1.06	5.8×10^{-4}	4.5×10^{-4}	3.5×10^{-4}	2×10^{-4}
6	1.06	1.00×10^{-3}	8.8×10^{-4}	6.5×10^{-4}	8×10^{-4}
9	1.07	1.03×10^{-3}	8.8×10^{-4}	7.5×10^{-4}	9×10^{-4}
13	1.07	1.85×10^{-3}	1.65×10^{-3}	1.40×10^{-3}	1.1×10^{-3}
19	1.06	2.9×10^{-3}	2.6×10^{-3}	2.3×10^{-3}	1.2×10^{-3}
27	1.06	3.8×10^{-3}	3.6×10^{-3}	3.0×10^{-3}	1.3×10^{-3}
40	1.06	4.9×10^{-3}	4.6×10^{-3}	4.1×10^{-3}	1.7×10^{-3}

We have plotted the three different penetration measurements versus the photometer measurements from Table 1 in Figure 5 to examine the correlation between the various measurements.

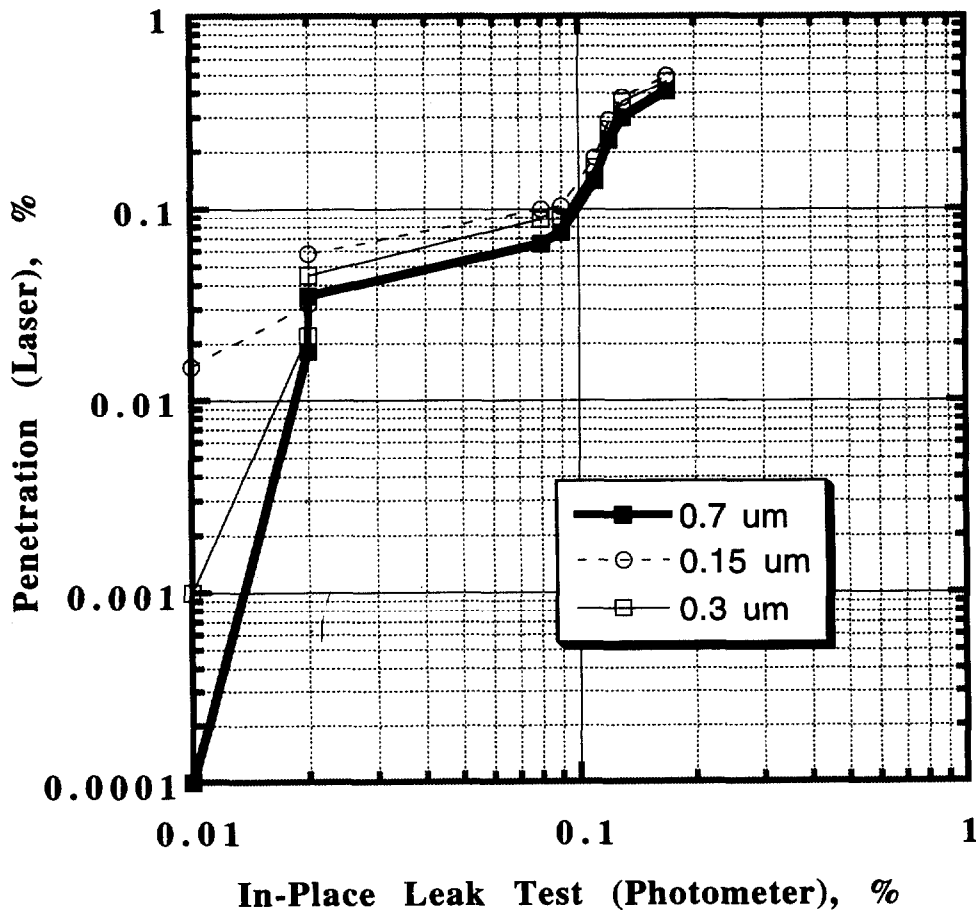


Figure 5. Correlation of laser penetration test with in-place leak test.

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In general, there is poor correlation between the photometer leak and the laser penetration measurements, even for the $0.7\mu\text{m}$ data, which is supposed to represent the average size of the test aerosol in the photometer test. One of the reasons for the poor correlation is the lack of sensitivity of the photometer for penetration measurements less than 0.01%. However, the major reason for the poor correlation between the photometer leak and the laser penetration measurements is due to the fundamental difference between differential and integrated size measurements with heterodisperse aerosols. Bergman and Biermann have shown that large variations in the photometer measurements are possible compared to laser or condensation nuclei counters depending on the degree of aerosol heterodispersion and the extent of filter leaks.^(7,14) Figure 5 also shows that the photometer measurements, although still not satisfactory, correlate better with the maximum penetration measurements at $0.15\mu\text{m}$ than with the measurements at 0.3 or $0.7\mu\text{m}$. The lack of correlation between the in-place penetration test and the in-place leak test illustrates that the present leak test provides only an approximate measure of the system penetration.

V. Field Evaluation of In-Place Penetration and In-Place Leak Tests

We have conducted in-place penetration and leak tests on two typical HEPA filter installations at LLNL, a single HEPA filter system and a two-stage HEPA filter plenum, to evaluate the practicality of the in-place penetration test. The single HEPA filter system located on the roof of a LLNL building is shown in Figure 6 with the HS-LAS laser counter on the HEPA filter, the LASAIR laser counter on the blower, and the TSI aerosol diluter on the floor. The Laskin nozzle aerosol generator, not shown, was placed inside a ventilation hood in one of the building laboratories. After several in-place penetration tests were completed, the standard in-place leak test was performed using a TDA-2GN aerosol photometer (ATI, Owens Mills, MD) and a TDA-4A aerosol generator (ATI, Owens Mills, MD) with Emery 3004. The in-place leak test indicated the HEPA filter system had 0.006% leakage.

Several in-place penetration tests were conducted on the single HEPA filter system to determine the effect of challenge concentration and the repeatability of the test results. The challenge concentration is an important factor in the in-place penetration test because it affects the accuracy of the data and the duration of the test. Higher aerosol concentrations result in shorter and more precise tests but also result in instrument error due to coincidence counting. Counting errors due to coincidence occur at higher concentrations when two or more particles are counted as a single particle. Since filter penetration measurements involve two measurements at significantly different concentrations, one upstream and one downstream of the filter, separate optimizations are required for each measurement. In theory, the challenge concentration is adjusted so the downstream concentration after the filter is just below coincidence counting. The upstream concentration then has to be diluted to avoid coincidence counting. However, since the commercially available diluters have a fixed dilution ratio; e.g. 100:1 for one stage dilution, 10,000:1 for two stages of dilution; the challenge

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concentration must be adjusted to avoid coincidence in both the upstream (challenge) and downstream measurements.

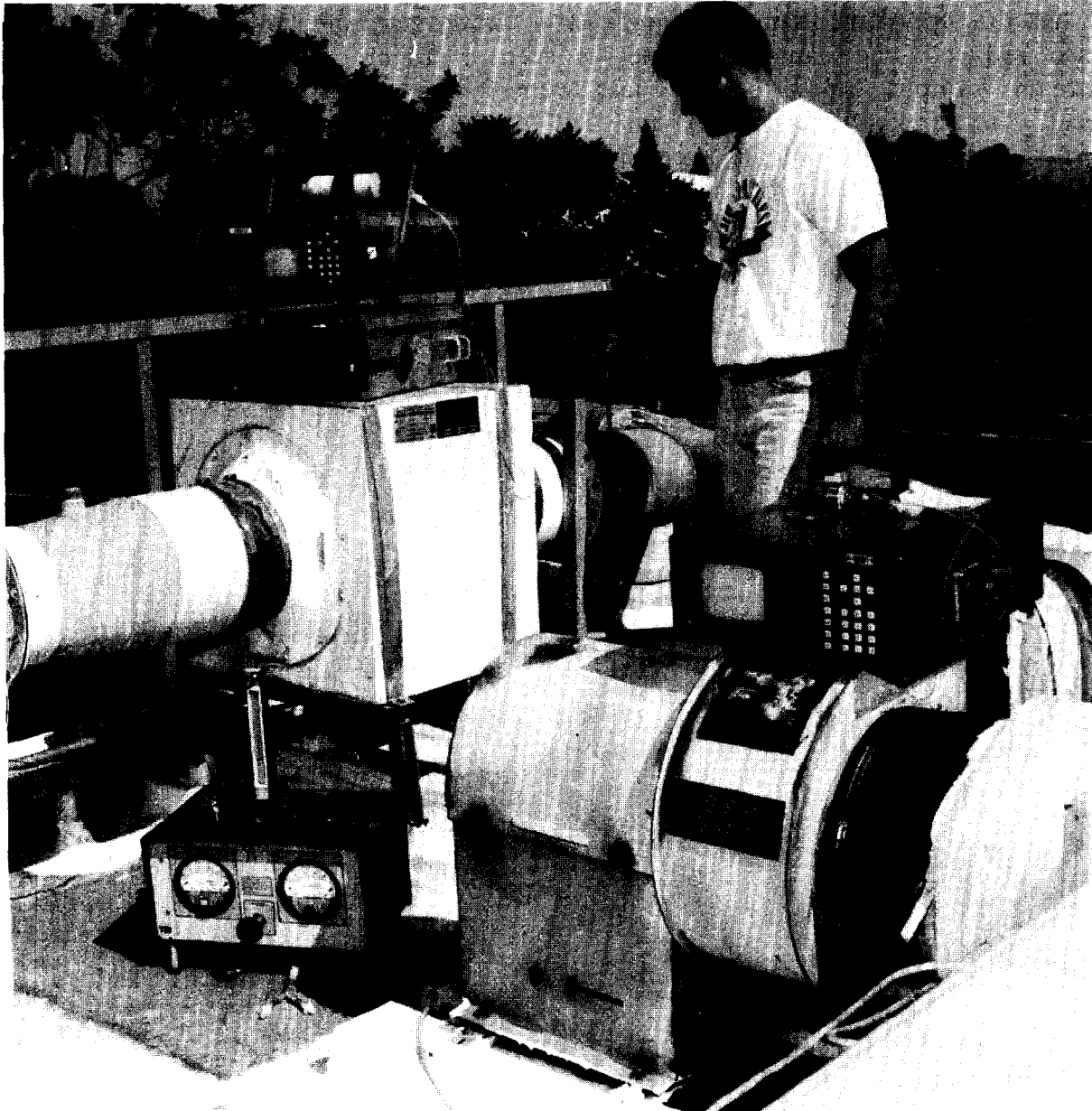


Figure 6. Photograph of the in-place penetration test apparatus on a single HEPA filter system using laser counters. The HS-LAS laser counter is on the HEPA filter, the LASAIR laser counter on the blower, and the TSI aerosol diluter on the floor.

The available dilution ratios did not allow for optimization of the concentration measurements as shown with the following illustration. Figure 7 shows the filter penetration curve derived from measurements using a 100:1 dilution of the upstream (challenge) aerosols for a single HEPA filter system which is similar to the system shown in Figure 6. The filter penetration curve is

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extremely noisy, even with a 1 minute upstream and a 15 minute downstream sample, because the low downstream aerosol concentration is at the background level. This resulted from reducing the challenge concentration to avoid coincidence counting. Increasing the sampling time did not help in this case because the measurement of background aerosols also increased. Using a 10,000:1 diluter on the upstream sample significantly improved the precision of the data and also reduced the sampling time as seen in Figure 8. The upstream and downstream sample times for that test were 2 and 6 minutes, respectively. An optimized diluter between 1,000:1 and 2,000:1 would reduce the sample time to about 1 minute for each measurement. The optimized diluter and associated calibration procedure must be developed before the in-place penetration method is adopted for routine measurements.

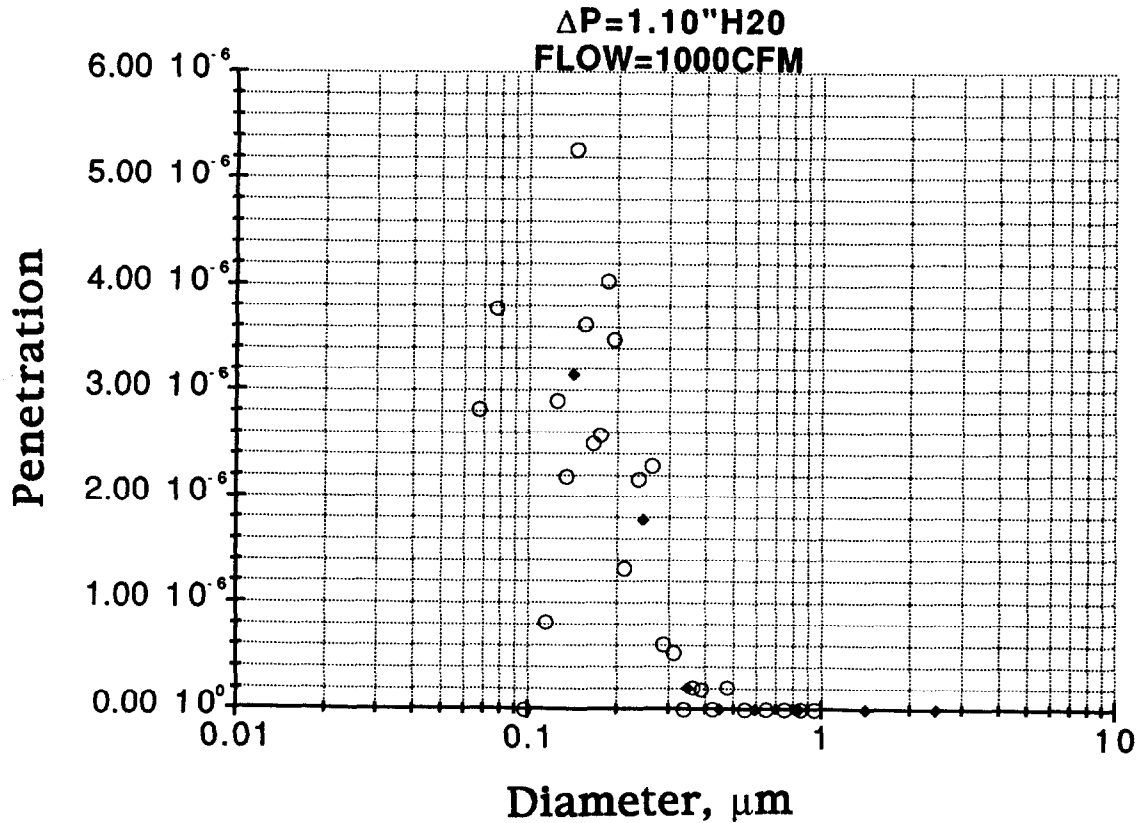


Figure 7. Filter penetration as a function of aerosol diameter for a single HEPA filter system using the in-place penetration measurement with a 100:1 diluter. Open data was generated with HS-LAS, closed data with LASAIR. In-place leak test with a photometer was 6×10^{-5} .

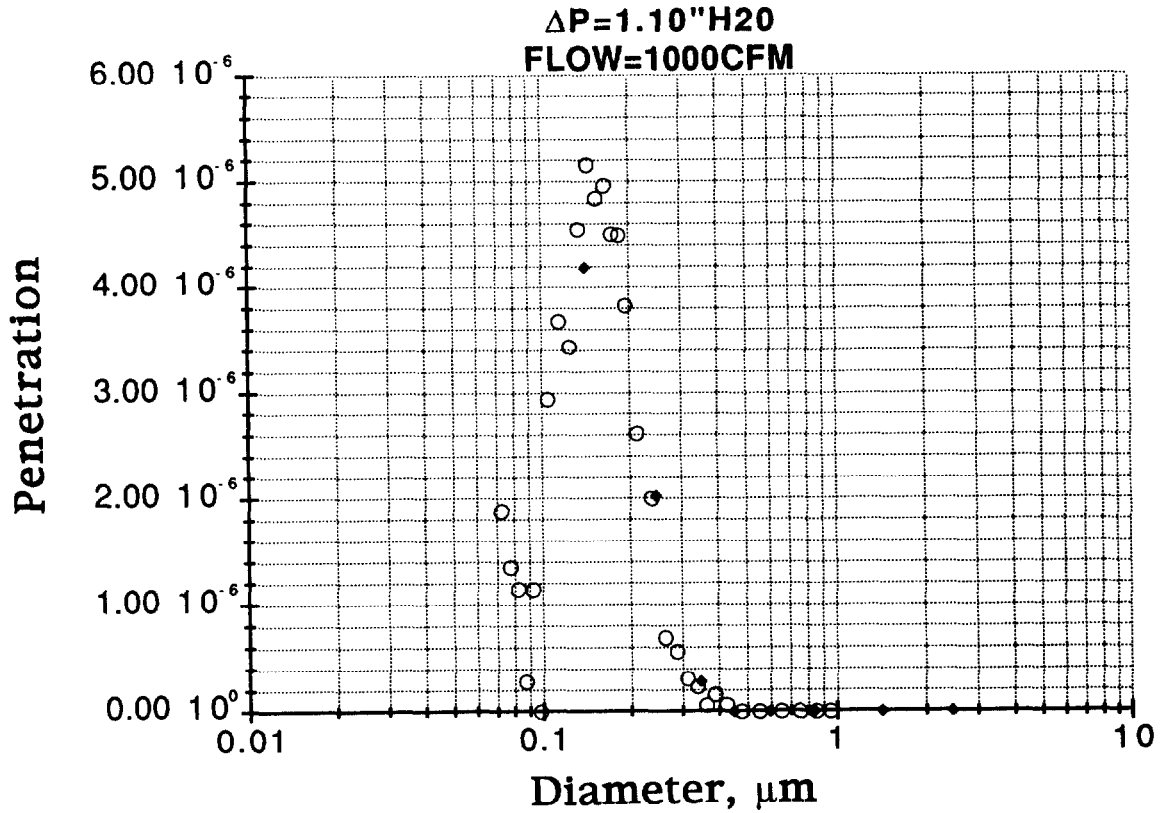


Figure 8. Filter penetration as a function of aerosol diameter for a single HEPA filter system using the in-place penetration measurement with a 1,000:1 diluter. Open data was generated with HS-LAS, closed data with LASAIR. In-place leak test with a photometer was 6×10^{-5} .

A detailed comparison of the time requirements for the in-place leak and the in-place penetration test is given in Table 2. The increased time to carry the penetration equipment was due to the additional laser counter, the diluter and pumps and miscellaneous items. After the in-place penetration equipment and procedure is finalized, the time for carrying the equipment will be the same for both in-place tests. The much longer test time for the penetration test can be reduced to be comparable to the leak test once the optimum diluter is developed.

Table 2. Comparison of time requirements for in-place leak and in-place penetration measurements on a single HEPA filter installation.

Task	Leak Test	Penetration Test
Carry equipment to roof	2 min.	10 min.
Set up equipment	2 min.	3 min.
Set up generator	8 min.	8 min.
Test filter	2 min.	12 min.
Total	14 min.	33 min.

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We repeated the in-place penetration test two additional times to assess the repeatability of the test. Figure 9 shows the three in-place penetration tests on the single HEPA filter installation are very repeatable.

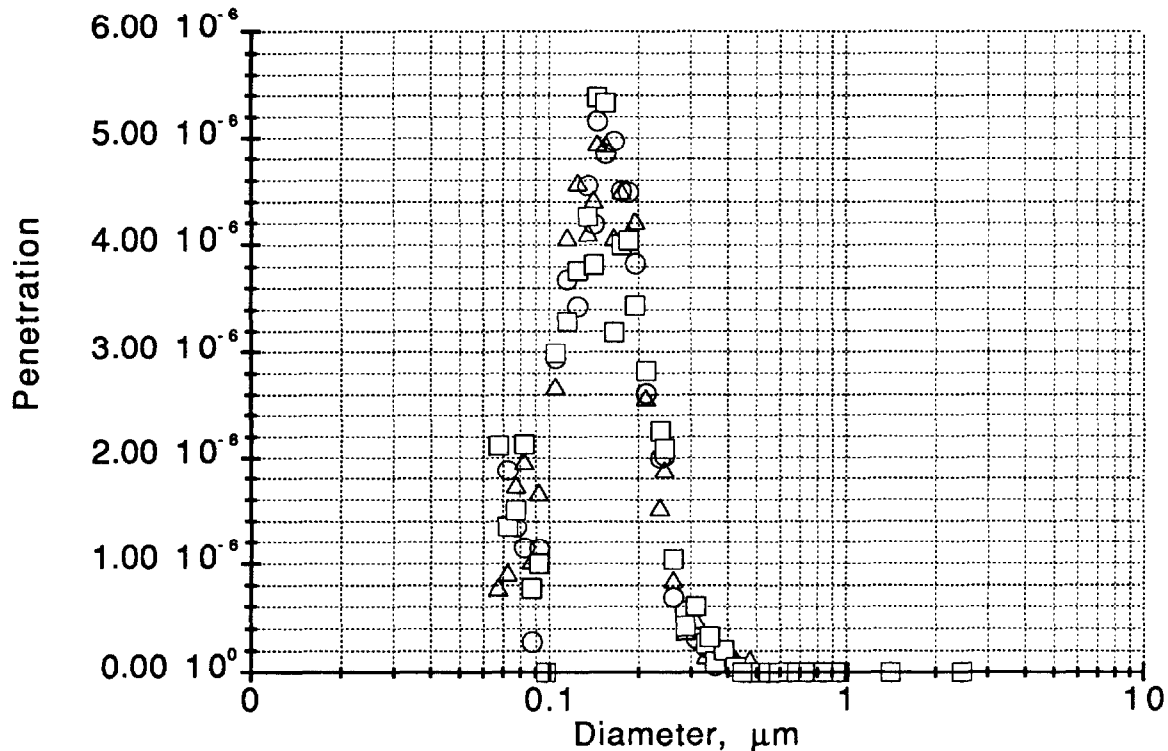
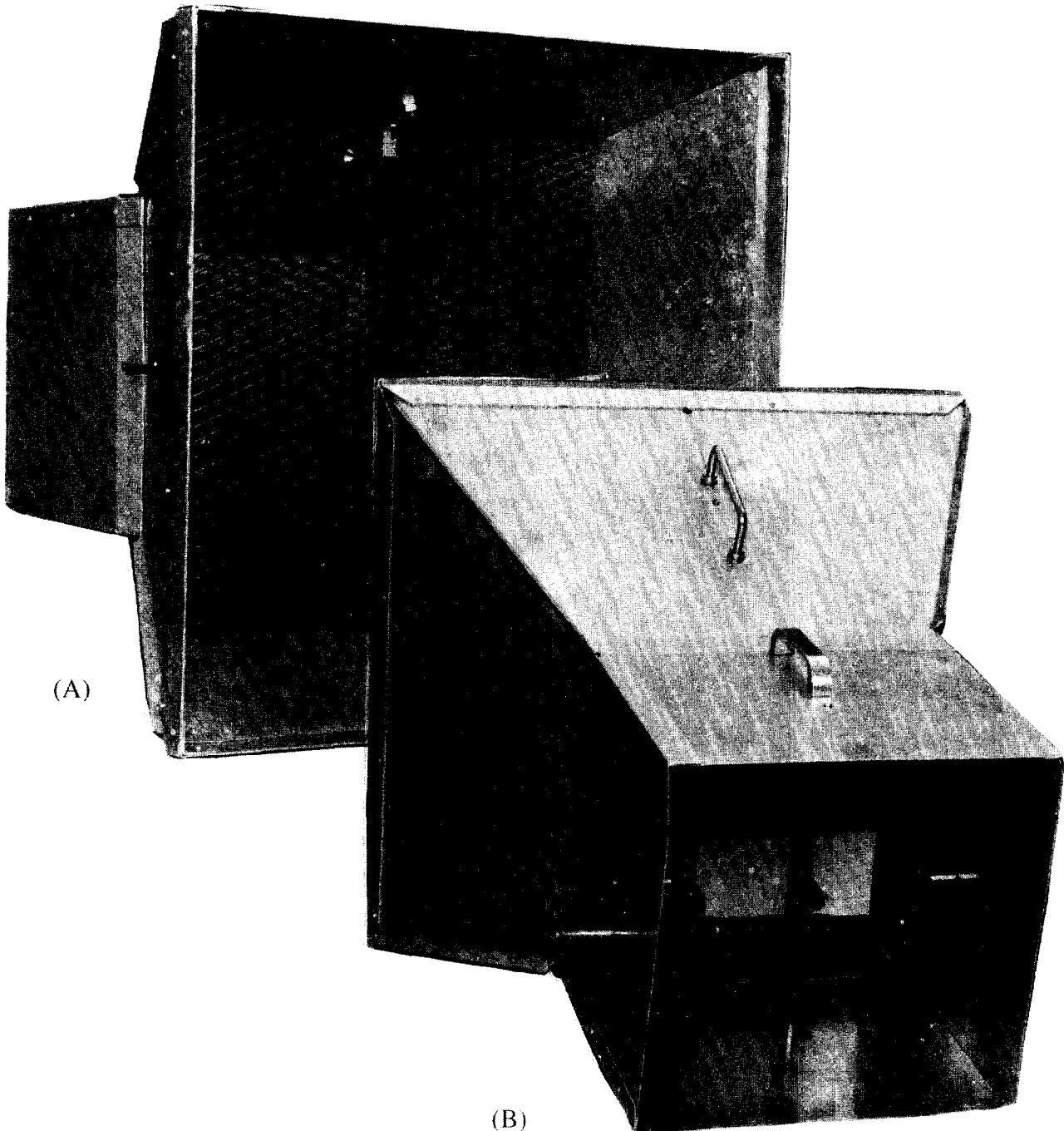


Figure 9. Measurements of the filter penetration obtained with the in-place penetration test apparatus shown in Figure 6 repeated three times.

The second field evaluation of the in-place penetration measurement was in a two-stage HEPA filter plenum using the shroud sampling method. The shroud sampling method allows individual HEPA filters to be leak tested independent of the other HEPA filters in a filter bank. This is done by placing shrouds on the upstream and the downstream side of individual HEPA filters to effectively isolate the HEPA filter from all others in the filter bank. Each shroud is a sheet metal duct that is held against the HEPA filter or frame on one end and has a reduced 1' x 1' section on the other end. The upstream shroud is used for injecting aerosols, and the downstream shroud is used for sampling the downstream aerosols. Figure 10 shows the front (A) and rear (B) sides of the upstream shroud, that is used to expose a HEPA filter to a uniform aerosol concentration. Figure 10 B shows the rear side of the upstream shroud with the 9 point aerosol injection manifold. The aerosols are then mixed by a baffle plate seen in Figure 10 A and B and further dispersed by a screen seen in Figure 10 B. The upstream shroud also has a sample

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port for sampling the challenge concentration. The downstream shroud, shown in Figure 11, has a 9 point sampling manifold and no internal mixing devices. The filter leak or penetration is obtained by simultaneously placing the upstream and downstream shrouds against the HEPA filter or frame as shown in Figures 12 and 13 respectively.



10. Upstream shroud for exposing individual HEPA filters in a filter plenum to challenge aerosols. (A) shows the front side, (B) shows the rear side.

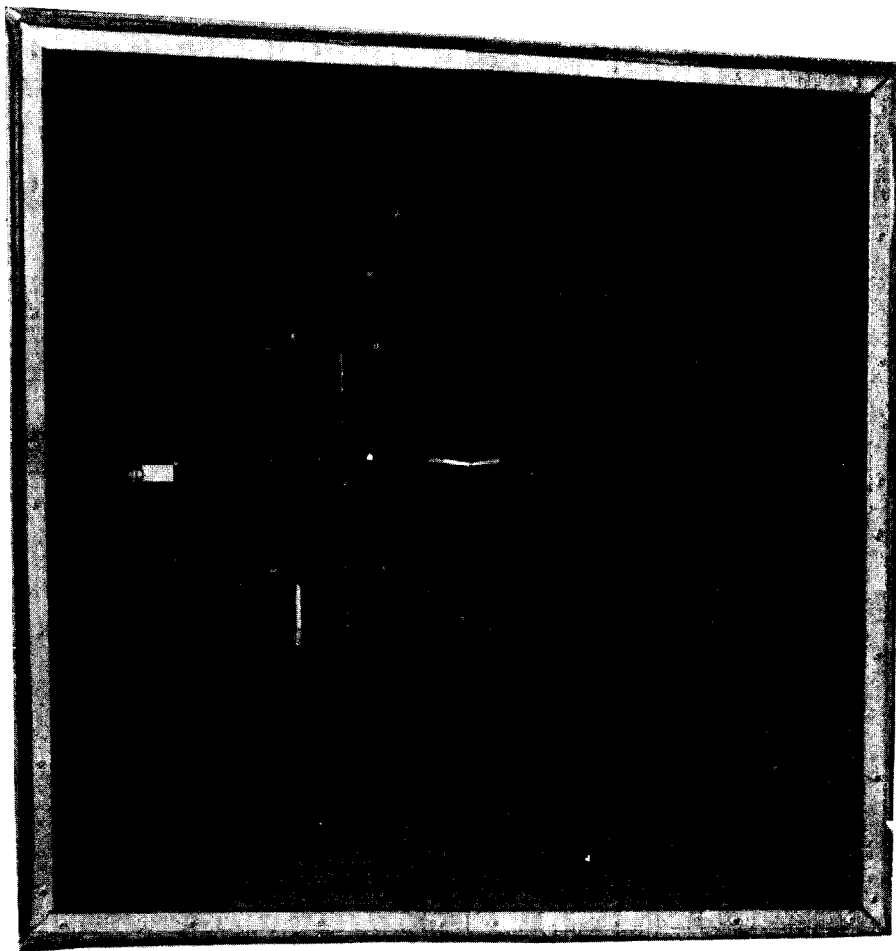


Figure 11. Downstream shroud for sampling filter penetration or leak. Nine point sampling manifold is seen from the inlet side facing the HEPA filter.

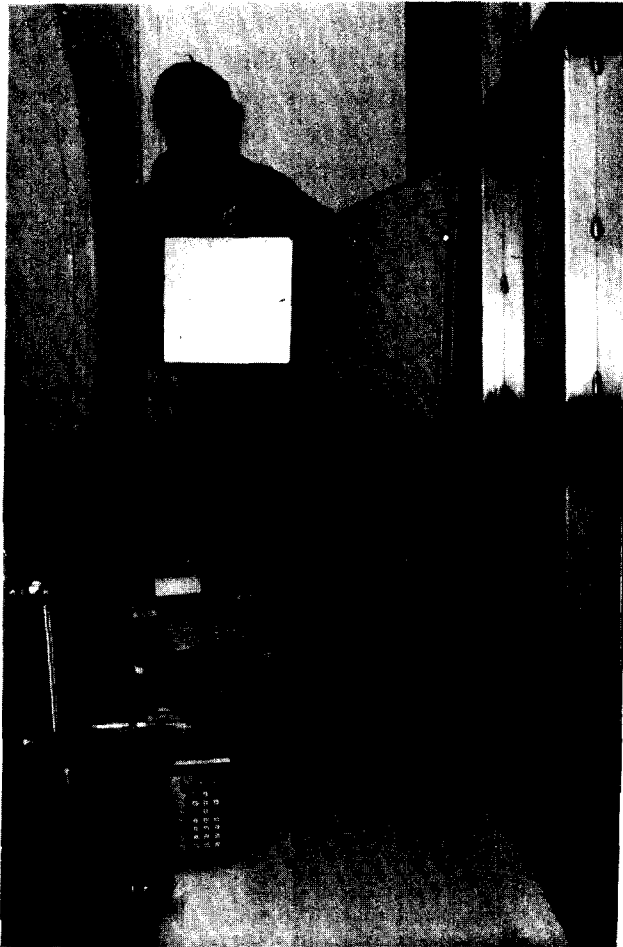


Figure 12. Downstream shroud for sampling aerosol penetration from individual filter. In-place penetration equipment used in this test.

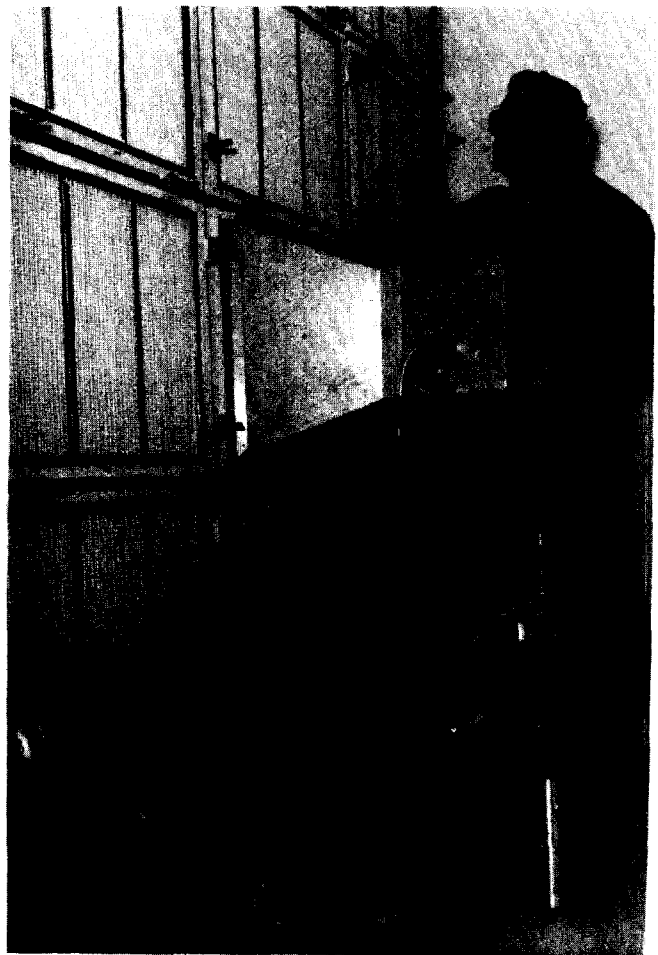


Figure 13. Upstream shroud for generating challenge aerosols. Laskin nozzle aerosol generator used in this test.

The result of the in-place penetration measurement on one filter in the plenum is shown in Figure 14. We were unable to generate the required high concentration of challenge aerosols to use the 10,000:1 diluter because the compressor shown in Figure 13 could not supply sufficient pressure to the Laskin nozzle aerosol generator. As a result, we used the 100:1 diluter with a lower aerosol concentration. This resulted in lower precision and a longer sampling time than would be required with a higher aerosol concentration and a 10,000:1 diluter. The upstream and downstream sample times were 2 and 8 minutes, respectively. The equipment used for the in-place penetration measurement using the shroud method was the same as previously described for the single filter test.

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Since the shroud method only measures the penetration or leaks through the filter, and not around gasket leaks, a separate leak test is performed on each filter. This is done by directing a concentrated aerosol challenge around the perimeter of the upstream side of the filter using a long tube. Another person samples the perimeter of the downstream side of the filter using a long probe that is moved in synchronization with the upstream challenge tube. If the downstream leak is greater than 0.03% of the upstream concentration, then the filter is replaced. This traverse leak test is far more conservative than the leak or penetration measurement through the filter because no significant air volume passes through the leak compared to that flowing through the filter. Since the air flow through a gasket leak path is not known, the traverse leak test is not quantitative, but rather a qualitative test. When using the laser counter in this leak test, the counter output is set to the concentration mode and not the count mode.

The conventional in-place leak test indicated the filter in Figure 14 had a leak of 2×10^{-4} . We used a TDA-2EN photometer and a TDA-5B aerosol generator, both from ATI, for the in-place leak test. The test aerosol for the in-place leak test was Emery 3004.

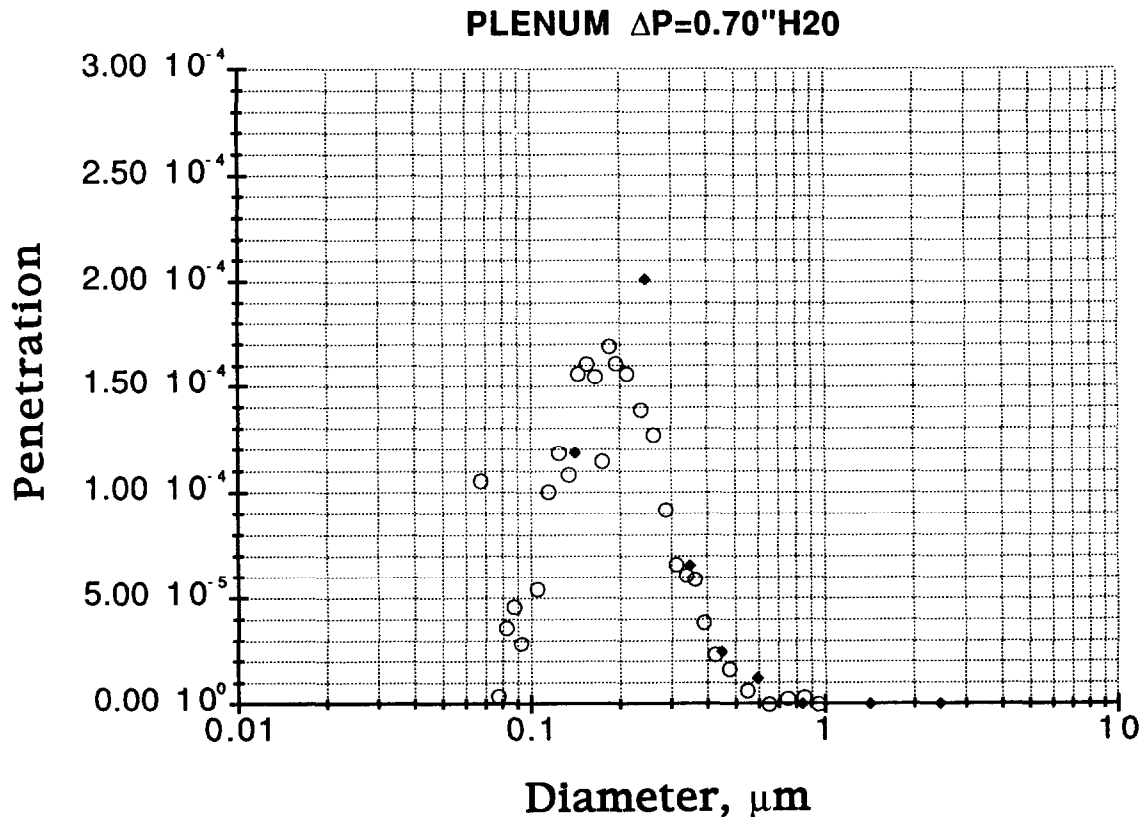


Figure 14. In-place penetration measurement of a HEPA filter in a plenum using the shroud sampling method. Open data obtained with HS-LAS, closed data with LASAIR.

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We performed a detailed analysis of the time requirement for the in-place leak and the penetration test using the shroud method and tabulated the results in Table 3. The time requirements for all of the tasks except for the downstream measurements are comparable for the two in-place tests. As noted before, the long downstream sampling times was primarily due to the inability to generate a sufficient concentration. We anticipate that the in-place penetration measurement would not require much more time than the in-place leak test once the experimental test system is optimized.

Table 3. Comparison of time requirements for in-place leak and in-place penetration measurements on a HEPA filter bank using the shroud method.

Task	Leak Test	Penetration Test
Equipment set up	10 min.	15 min.
Equipment warm up	10 min.	10 min.
Upstream meas./filter	(5 min.)	(4 min.)
Upstream bank (16 filters)	80 min.	64 min.
Downstream meas./filter	(0.3 min.)	(10 min.)
Downstream bank(16 filters)	5 min.	160 min.
Tear down	30 min.	30 min.
Total	135 min.	279 min.

VI. Conclusions

We have demonstrated the feasibility of conducting in-place penetration tests on high efficiency particulate air (HEPA) filters as installed in nuclear ventilation systems. The in-place penetration test, which is designed to yield equivalent penetration measurements as the standard DOP penetration test, is based on measuring the aerosol penetration of the filter installation as a function of particle size using a portable laser particle counter.⁽¹⁾ Additional tests are required to confirm that the in-place penetration test yields identical results as the standard DOP penetration test for HEPA filters with controlled leaks in the filter and gasket and duct by-pass leaks. Further development of the procedure is also required to reduce the test time before the in-place penetration test is practical.

VII. Acknowledgments

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DISCUSSION

FRANKLIN: On the DOP feed of the sampler, was that downstream of the grid? I could not tell where you were sampling the concentration of the DOP feed.

BERGMAN: The upstream sample was measured through a single probe that was inserted through a porthole in the shroud just before the HEPA filter. A single probe is sufficient at this point because the Emory 3009 aerosols were well mixed. The aerosols are injected through a nine-port manifold within a one foot by one foot area. The aerosols then hit a baffle that covers about 70% of the open area and is further mixed by a grid. The sample is then taken after the grid.

KOVACH, B: I have one question . When you tested with the shroud method I understand how you calculated the average leak with the shroud, but how did you add the gasket leakage to the efficiency?

BERGMAN: The shroud method only allows you to measure the average leak if the HEPA filter is mounted on the upstream, dirty side of the frame. In this case, the shroud is placed against the frame on the downstream side. Penetrations through gasket leaks and the filter are measured together as a single measurement. If the HEPA filter is mounted correctly on the downstream, clean side of the frame, it is not possible to quantify the leak through the gasket. The shroud is placed over the HEPA filter and only measures the leak through the filter. Leaks through the gasket are determined in a separate test in which a probe is traversed around the perimeter of the gasket. If the aerosol penetration at any point exceeded 0.03% the filter was removed.