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TITLE: UNCERTAINTY IN IN-PLACE FILTER TEST RESULTS

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DISCLAIMER

UNCERTAINTY IN IN-PLACE FILTER TEST RESULTS*

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Abstract

Some benefits of accounting for uncertainty in in-place filter test results are explored. Information the test results provide relative to system performance acceptance limits is evaluated in terms of test result uncertainty. An expression for test result uncertainty is used to estimate uncertainty in in-place filter tests on an example air cleaning system. Modifications to the system test geometry are evaluated in terms of effects on test result uncertainty.

Introduction

In-place tests are performed on high efficiency particulate air (HEPA) filter systems to evaluate system performance. Test results are compared to system performance limits to judge acceptability of system performance relative to requirements of system design that assure health and environmental protection. In the absence of test result uncertainty, acceptance limits on test results coincide with limits on system performance (see Figure 1). Uncertainty in test results has the effect of offsetting test result acceptance limits from acceptable system performance limits. Test results below such a test result acceptance limit provide clear evidence that system performance acceptance limits are being met.

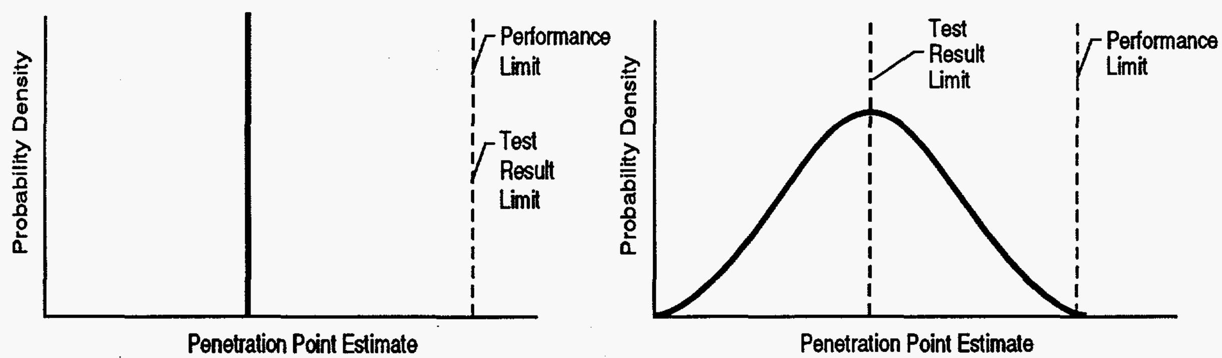

Figure 1 Two plots showing relation between system performance acceptance limit and test result acceptance limit for the case where test result uncertainty is zero and for the case where test result uncertainty is greater than zero.

Recently an expression for uncertainty in in-place filter test results for a single HEPA filter bank was developed using error propagation analysis.(1) The expression uses indices of spatial variation of test aerosol concentration, flow velocity, and penetration to estimate test result uncertainty. These indices are referred to as heterogeneities and are defined in terms of relative standard deviations. In this paper, the uncertainty expression is used to evaluate the benefit

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modifications to test geometry might have in reducing uncertainty of in-place filter tests on a HEPA filter system.

An illustration of the geometry of in-place filter tests is presented in Figure 2. Test aerosol is injected into the ventilation system upstream of the HEPA filter bank at the injection plane. Aerosol concentration is sampled upstream of the filter bank in the challenge plane and downstream of the filter bank in the downstream sample plane. Concentration heterogeneity of the challenge aerosol is reduced by an upstream mixing factor, h_U, between the injection and challenge planes. Heterogeneity of aerosol penetrating the filter banks is reduced by a downstream mixing factor, h_D, between the downstream plane and the downstream sample plane.

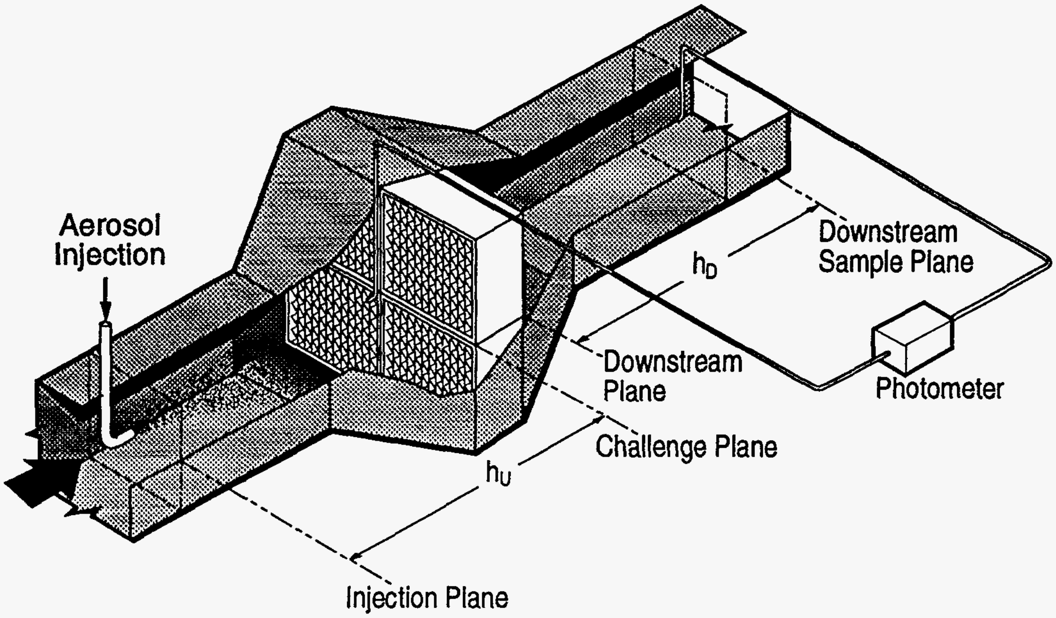

Figure 2 Generalized HEPA filter system showing in-place filter test geometry and mixing factors.

An estimate of aerosol penetration through the bank is given by:

$$\hat{P} = \frac{X_{DS}}{X_{US}} \qquad (1),$$

where,

$\hat{P}$ = penetration point estimate,

X_{DS} = the downstream sample concentration, and

X_{US} = the upstream sample concentration.

Error propagation analysis(1) yielded an approximate expression for the uncertainty in $\hat{P}$:

$$H_{\hat{P}} = \left[\frac{\left(\frac{1}{X_U} - 1\right)}{h_U^2} \left(\frac{1}{h_D^2} + 1\right) + \frac{\left(\frac{1}{\hat{P}} - 1\right)}{h_D^2} + \frac{H_Q^2}{h_D^2} \right]^{1/2} \qquad (2),$$

where,

H_P= heterogeneity of the penetration point estimate or estimate of test result uncertainty,

X_U = dimensionless test aerosol challenge concentration, $= \frac{Q_{inj}}{Q}$,

Q_{inj} = volume flow rate of injected test aerosol,

Q = total HEPA filter system volume flow rate, and

H_Q = heterogeneity of the challenge flow velocity.

Analysis and Results

The expression for test result uncertainty (Equation 2) was used to estimate uncertainty in in-place filter tests on an example HEPA filter system. Example system design is based on an existing system at the Mound Facility in Miamisburg, Ohio.[2] A diagram of the example system is shown in Figure 3. The system has two air flow entries immediately upstream of the HEPA filter bank. Test aerosol is injected in the primary entry. There is no aerosol injection in the secondary entry.

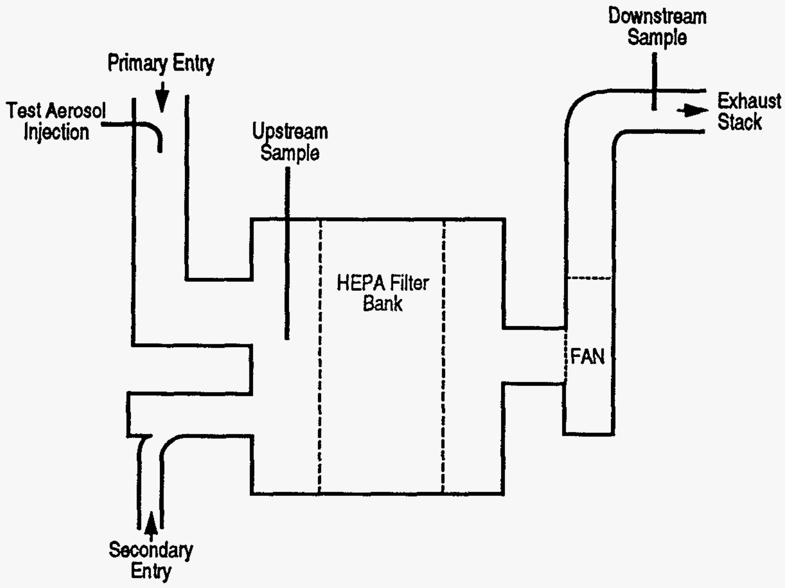

Figure 3 Example exhaust filtration system with two entries. In-place filter testing injection and sampling locations are shown.

For this analysis, Q_{inj} will be 2 cfm and Q will be 30,000 cfm, both values are within the range of values observed for nuclear facility HEPA filter systems.[2] Test aerosol is assumed to be well mixed in the primary entry to the filter plenum. However, because no aerosol is injected in the secondary entry, the challenge concentration is almost certainly not uniform over the challenge plane. Consequently, h_U for this analysis was estimated to be 150, which is a tenth of the value needed for this system to meet the ASME N510 'air-aerosol mixing uniformity' requirements.[3] Because flow downstream of the filter bank passes through a fan prior to being sampled, h_D is likely to be much greater than h_U. For this analysis h_D was estimated to be 1500. The division of the air flow between the two entries is assumed to be balanced such that the system meets ASME N510 'airflow distribution' requirements.[3]

Values of test result uncertainty predicted from Equation 2 are shown in Figure 4 for test aerosol injected in the primary entry. At a typical system performance acceptance limit of 0.05% penetration, the predicted uncertainty was 0.82.

One potential approach to reduce uncertainty in test results here is to inject aerosol into both entries. If aerosol injection rates are adjusted so that the average concentration is the same in both entries, the value of h_U is likely to increase, thus decreasing the uncertainty estimate. To illustrate this point, the analysis was repeated with test aerosol injection in both entries. This modification was assumed to increase h_U by a factor of five to 750. Uncertainty estimate predictions for this test aerosol injection configuration are shown in Figure 4. At the penetration point estimate of 0.05%, the uncertainty prediction is reduced to <0.17, approximately one-fifth that for injection in the primary entry only.

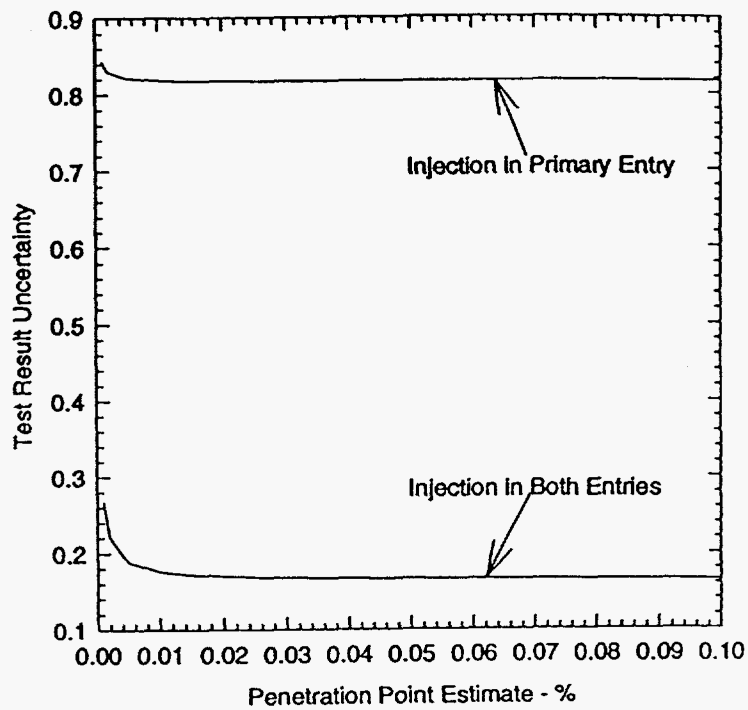

Figure 4 Values of relative test result uncertainty plotted against penetration point estimate.

The uncertainty estimates were used to predict test result acceptance limits. The test result limits were determined using an offset below the system performance acceptance limit equal to three times the uncertainty estimate. Results of this analysis for both test aerosol injection configurations are shown in Figure 5. For injection in the primary entry, the test result acceptance limit was approximately 0.014% penetration at the system performance acceptance limit of 0.05% penetration. The analysis indicates that test results below 0.014% penetration provide clear evidence that system penetration is no greater than 0.05%. For test aerosol injection in both entries, this performance limit is assured by test results of 0.033% penetration or less.

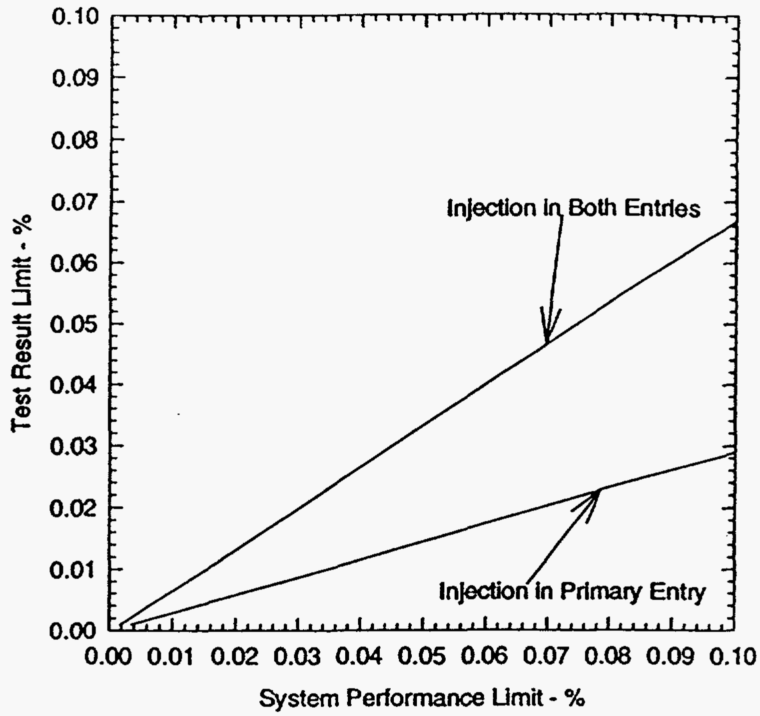

Figure 5 Test result acceptance limit plotted against system performance acceptance limit.

Discussion and Conclusions

The method presented here to account for uncertainty in in-place filter tests provides an objective rationale to judge whether tests results support the conclusion that system performance meets acceptance limits. Test result acceptance limits coincide with system performance acceptance limits only when there is no uncertainty in test results. Uncertainty in test results can be accounted for by offsetting test result acceptance limits below system performance acceptance limits by an increment related to the uncertainty. Here this increment was set equal to three times the test result uncertainty estimate. By this rationale, penetration point estimates below the test result acceptance limit are judged to provide clear evidence that limits on system performance are being met.

In addition to providing a rationale to judge HEPA filter system performance, test result uncertainty estimates can provide a metric to assess potential benefits of test geometry modifications. In the example described here, the test result acceptance limit could be increased by more than a factor of two through a modification in the test procedure. This metric provides facility managers a means to evaluate whether benefits from such modifications are cost effective. In this example, the facility manager could assess whether the extra cost of injecting test aerosol in both entries is offset by reducing the number of times system performance is rejected. If no test results have been reported in the 0.014% to 0.033% penetration range, then the analysis indicates the test procedure modification would not be cost effective. However, if even a few test results are expected in this range, then the procedure modification may be cost effective in delaying such costly system maintenance actions as filter replacement.

The utility of the uncertainty estimates may increase when ventilation system modifications are considered to reduce test result uncertainty. Such system modifications can be costly, especially for systems contaminated with hazardous materials. Ventilation system modifications are an option for establishing compliance of existing systems to standards that post-date system design and construction. A number of DOE nuclear air cleaning systems are in this category. The uncertainty estimates can help identify what system modifications might be needed to provide performance assurance equivalent to that provided by tests on fully compliant systems. The estimates can also help identify costly modifications that contribute little to establishing this equivalency. Systems that pass these equivalent tests can be reasonably expected to provide levels of health and environmental protection equivalent to that provided by the fully compliant systems.

References

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