SESSION 3

FILTER TESTING

Monday: August 24, 1992
Co-Chairmen: H. Gilbert
R. Dorman

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OPENING COMMENTS OF SESSION CO-CHAIRMAN DORMAN

The title somewhat belies the range of topics that we have today. We have everything from a DOP substitute to a new in-place filter testing method. We have test results of the DOE filter test stations. We have an inhalation study on glass fibers which is a repetitive-type topic that comes up all the time, and the uniformity of air in ducts.

AN UPDATE: DOP REPLACEMENT IN TESTING MACHINES FOR FILTERS AND RESPIRATORS

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Abstract

The U.S. Army's Office of the Surgeon General (OTSG) approved, in January 1992, a poly-alpha olefin (PAO) trade-named "Emery 3004" as a safe, non-mutagenic replacement for dioctyl phthalate (DOP) in "hot-smoke" and "cold-smoke" testing Army-wide. This material was selected from among other promising candidate materials based upon properties including its toxicology and thermal stability, ability to perform at least as well as DOP, low cost, and ability to replace DOP directly in existing penetrometers without modification, simply by adjusting existing machine controls.

I. Introduction

Di (2-ethylhexyl) phthalate, also called dioctyl phthalate, di-sec octyl phthalate, DOP, or DEHP, is a widely used industrial material. Over ninety percent of the material produced is used as a plasticizer, primarily for PVC plastics. The properties of DOP that make it useful as a plasticizer, including low vapor pressure, chemical stability, and insolubility in water, also make it useful as a test aerosol. DOP aerosols are used in respirator fit testing, HEPA filter testing, aerosol research, aerosol instrument calibration, and other applications. These uses involve human occupational exposure to submicrometer-sized DOP aerosols, often briefly but in moderately high concentrations.[1]

Concern about the potential health effects to people working with DOP test aerosols has led to a search for substitute materials. This search has taken a number of different directions, depending in part upon the specific test applications for which a DOP replacement has been sought. The U.S. Army routinely performs 100% quality control testing of filter canisters manufactured for use with field-issue gas masks, and periodic sampling and testing of canisters stored in its supply depots. In April, 1986, the U.S. Army's Office of the Surgeon General (OTSG) placed severe restrictions upon testing with DOP; agencies were also informed that dioctyl sebacate (DOS) would no longer be acceptable as a DOP replacement material, and that similar restrictions would apply for both. These restrictions included occupational exposure monitoring of workers exposed to DOP aerosols and liquid, medical surveillance, issue of personal protective equipment, formal notification to workers of associated risks, and labeling of work areas as "cancer suspect agent areas."

Clearly, the above actions placed severe restrictions upon routine, 100% quality assurance testing of filters and other equipment. For this reason, in 1988 the U.S. Army initiated a detailed study of the problem of finding an acceptable substitute material for DOP that could meet all standard military test specifications while itself being a non-carcinogen and, ideally, having other attributes including acceptable acute inhalation toxicity, low cost, ready availability, and the ability to replace DOP directly in machines at test installations without retrofit or other modification of these machines.

In an earlier report[2] we described experimental procedures and results of our study which are applicable to both "cold pot" and "hot smoke" aerosol penetrometer machines including the Army-standard "Q-127" machine that is currently produced as the Model TDA-100 by Air Techniques, Inc.[3] (ATI, Figure 1.) Our cold pot machine was the Los Alamos Monodispersed Aerosol Prototype Penetrometer (LAMAPP, Figure 2.) That report identified the materials that are the best candidates to replace DOP in many kinds of penetrometer machines. Thus our recent effort was directed toward implementation of DOP replacement in many applications with one of our best materials, a poly-alpha olefin (PAO), "Emery 3004."

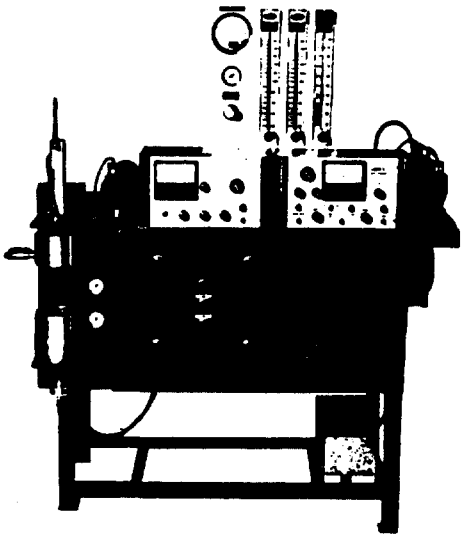

Figure 1. Q-127 (TDA-100) "Hot Smoke" Penetrometer Machine.

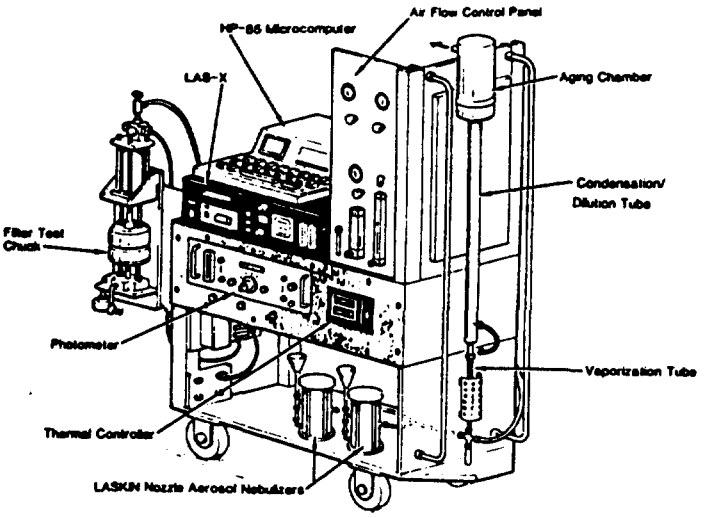

Figure 2. "LAMAPP" Cold Pot Penetrometer Machine.

The present paper discusses this implementation, including the mutagenicity testing carried out, and results. These results were considered by the U.S. Army's Office of the Surgeon General (OTSG), prior to recent approval by that office for the use of Emery 3004 to replace DOP (dioctyl phthalate) Army-wide. Since the Army's restrictions on the use of DOP are stricter than those of other military and civilian organizations, Army approval could eventually lead to acceptance of its new material as a universal DOP replacement.

We also report recent data on the performance of our best materials in penetrometer machines, and new information of general interest regarding the problem of DOP replacement. Several viable DOP replacement materials found in our research study are ranked here, for each machine, in order of probable success. Some of these materials outperform DOP in meeting U.S. Army test smoke specifications. All are inexpensive and readily available.

II. Experimental Approach

Present U.S. Army test specifications for acceptable "hot smokes" prescribe a geometric mean diameter (GMD) of between 0.18 um and 0.33 um, with a geometric standard deviation (GSD) equal to or less than 1.30, and a mass concentration at the test chuck, where filters are held for penetration measurements, of 100 $\pm$ 20 mg/m^3.

The LAMAPP system shown in Figure 2 is described in greater detail detail in Ref. 2. A fine polydisperse aerosol is generated by a Laskin nozzle in a "cold pot" containing the test liquid. In a similar pot containing an NaCl solution, droplets are produced that evaporate to form salt condensation nuclei as they flow through a vaporization tube, where the DOP or other liquid aerosol is simultaneously vaporized. Upon cooling, the liquid recondenses on the salt nuclei to form droplets of controlled size and small GSD. These enter an aging chamber from which they are drawn for filter test purposes. Provision is made for calibration using polystyrene latex (PSL) or other standard aerosols. A laser aerosol spectrometer (LAS-X) and microcomputer permit GMD and GSD to be determined and printed on a strip chart.

Our Q-127 machine was a refurbished older model of the similar but redesigned and simplified "monodispersed aerosol penetrometer" presently being marketed by ATI under the model number TDA-100.[3] These machines generate "hot smokes" by the vaporization and recondensation of DOP or other liquids, having suitable vapor pressure and other physical properties, which are placed in a heated reservoir. Hinds, et al.,[4] described "hot DOP" aerosol size distributions produced by the ATI Q-127 machine more than a decade ago, and gave a good description of changes in aerosol output corresponding to various settings of the mechanical analyzer or "Owl" that is standard equipment on all Q-127s and TDA-100s. They found that the output aerosol could be varied over the GMD range 0.23-0.30 um correponding to angular settings of the Owl from 29^o to 45^o, respectively.

III. Results and Discussion

Our experiments identified several materials that are viable candidates to replace DOP in "hot smoke" penetrometer machines such as the Q-127/TDA-100, and in "cold pot" machines like LAMAPP. These are summarized in Table 1, with sources of supply.[5] The materials identified here as DOP alternatives or replacements are generally inexpensive, and readily available.

Synthetic hydrocarbons include poly-alpha olefins (PAOs), which are used as synthetic lubricants, and in other applications. These versatile, saturated synthetic hydrocarbons are produced by direct oligomerization of decene-1. Linear alpha olefins are polymerized and hydrogenated to manufacture PAOs. Three PAOs were investigated in our studies; these are designated "Emery 3002, 3004 and 3006." Data are summarized in Table 2. Of these, Emery 3004 was the material recommended to the U.S. Army Surgeon General for approval to replace DOP in "hot smoke" machines, and for general use. Emery 3002 performs somewhat better than Emery 3004 in cold-generation systems, but only one material could be designated for further chemical and mutagenic studies that are required for approval, owing to the expense involved.

Table 1. Recommended Replacement Materials for DOP in Q-127 and TDA-100 Machines, and in the LAMAPP Machine, Ranked in Order of Probable Success.

	Q-127 and TDA-100 Machines		LAMAPP Machine	
Ranking*	Chemical Name	Manufacturer[5] or Source	Chemical Name	Manufacturer[5] or Source
1	synthetic hydrocarbon Emery 3004	Emery Group Henkel Corp..	synthetic hydrocarbon Emery 3002	Emery Group Henkel Corp.
2	isostearic acid (76%) Emersol 875	Emery Group Henkel Corp.	isostearic acid (76%) Emersol 875	Emery Group Henkel Corp.
3	isostearic acid (66%) Emersol 871	Emery Group Henkel Corp.	methyl oleate stearate Emery 2219	Emery Group Henkel Corp.
4	synthetic hydrocarbon Emery 3006	Emery Group Henkel Corp.	synthetic hydrocarbon Emery 3004	Emery Group Henkel Corp.
5	oleic acid (71%) Industrene 206LP	Humko Chem. Div., Witco Chem. Corp.		
6	oleic acid (74%) Emersol 233LL	Emery Group Henkel Corp.		

* Highest rankings have highest probability of success.

Table 2. Properties of Poly-Alpha Olefins (PAOs).

Trade Name	Pour Point, °C	Flash Point, °C	Fire Point, °C	Auto-Ignition Point, °C	Specific Gravity
Emery 3002	-65	164	178	324	0.80
Emery 3004	-69	225	250	343	0.82
Emery 3006	-64	243	266	371	0.83

Emery 3004 and DOP were analyzed side-by-side in laboratory tests completed by us in July 1990. Fresh samples were compared to other samples aged in machines for up to 110 hours at temperatures up to 170°C, representative of "hot smoke" machine conditions. Analyses were performed using inductively coupled plasma (ICP) emission spectroscopy, infrared spectroscopy, and gas chromatography (GC/MS) for changes with aging. Levels of oxidation for both materials were below the detectable limit, 50 ppm. The aged Emery 3004 samples showed very low amounts, less than one percent, of compounds indicative of oxidative pyrolysis.

Thus having established that significant chemical decomposition does not occur in Emery 3004 even when heated for more than 100 hours at high temperatures, the next concern was submission of this material for mutagenicity testing. The "tier approach" to mutagenicity testing is advocated at CRDEC.

Tier 1 is designed to show primary capacity of the test compound for genotoxic effects at minimal cost. Screening of compounds for more costly test procedures can be accomplished in this tier, but results should not be used to estimate risk to mammalian systems. One of three gene mutation procedures normally is done involving microbes or mammalian cells- most frequently it is the Ames assay.

Tier 2 assays for gene mutation utilize in vivo and host mediated tests which usually are considered in making mutagenicity risk assessments in mammalian systems, such as the Sex-Linked Recessive Lethal Test that is conducted at CRDEC using fruit flies. Other tests including those for chromosomal aberrations and primary DNA damage normally are performed out-of-house on contract.

Tier 3 test protocols are more costly, longer term, in vivo studies that should be used to confirm results of less costly in vitro studies of the lower tiers. Information accumulated from the lower tiers should indicate which of these in vivo studies to use. Because they are long term fully in vivo mammalian studies they are usually relied on more heavily in assessing risk to humans. CRDEC conducts the Dominant Lethal Mutation Test in Rats. Others such as lung adenoma in mice, heritable translocations in rats, or specific locus tests in mice, would normally to be performed by contract.

Tier 1 Ames system assay was completed successfully and reported upon on 22 August 1990. It was concluded that no evidence of mutagenic potential was found in this testing, but that additional tests were needed for human risk assessment of Emery 3004.

Tier 2 testing used the sex-linked recessive lethal test in Drosophilia melanogaster (fruit flies), which measures the occurence and frequency of lethal mutations, both point mutations and small deletions, in the germ cell line of the fruit fly. The mutation results, as tested, classified Emery 3004 as a non-mutagen in the assay system used.

Tier 3 testing used the rodent bone marrow micronucleus assay, and was performed by the contractor Integrated Laboratory Systems, Research Triangle Park, NC 27709. Their report dated 31 October, 1991, concluded that "multiple treatments with Emery 3004 synthetic hydrocarbon 4CST fluid did not result in a significantly increased frequency of MN-PCE in the bone

marrow of male B6C3F1 rats.' 'In addition, the test article did not significantly depress the percentage of PCE in either experiment." Table 3 compares Emery 3004 approximate analyses to those of other PAOs, which are expected to have comparable toxicology.

Table 3. Approximate Analyses by Carbon Chain Length for Several Emery Poly-Alpha Olefins (PAOs).

Emery Product	Percentages by Carbon Chain Length					
	C20	C30	C40	C50	C60	C70
3002	97-99	1.0				
3004	0.60	82.1	16.0	1.0	2.0	
3006		30.9	42.8	20.4	4.8	1.1

On 15 March 1991, the Health and Veterinary Services Office (HVSO), CRDEC, staffed a letter to the Army's Office of the Surgeon General (OTSG), requesting approval of Emery 3004 as an Army-Wide substitute material for DOP. This was followed by a similar request from the Army Environmental Health Agency (AEHA), dated 24 December 1991, which summarized the structure, toxicity testing, and recent mutagenicity testing of Emery 3004. AEHA recommended that "Based on the relatively low order of toxic effects exhibited by Emery 3004, the absence of demonstrated mutagenic activity, and the relatively low exposure potential, recommend approval for the use of this substance as a replacement for dioctyl phthalate in filter test apparatus."

On 8 January 1992, the OTSG responded. "SUBJECT: Request for Approval of Emery 3004 as an Army-Wide Substitute Material for Dioctyl Phthalate (DOP)." "This office concurs with AEHA's recommendation of approval for use of the subject compound as a replacement for dioctyl phthalate." No restrictions on use were given. Thus Emery 3004 can be used in "hot smoke" machines, in which it performs exceptionally well, and for "cold smoke" or general aerosol testing as well.

IV. Conclusions

We conclude that Emery 3004:

- performs at least as well as DOP in hot-smoke filter penetrometer machines, and in many other machines and applications as well;
- is inexpensive, readily-available (and should continue to be so in the foreseeable future);
- is readily specifiable, unlike natural petroleum products;
- can replace DOP directly in existing penetrometer and other machines without machine modification, simply by adjusting existing machine controls;

- is non-corrosive, clean to work with, free of natural impurities, thermally and chemically stable;

- is a non-mutagen, safe to work with, and approved for Army-wide use without restriction as a replacement for DOP by the Army's Office of the Surgeon General.

V. Recommendations

We recommend that:

- the use of Emery 3004 to replace DOP in testing Army-wide be implemented as soon as is practicable;

- the Army consider stockpiling Emery 3004 since it is currently at an all-time low cost, is used in relatively small quantities but in many machines, is non-corrosive and would store indefinitely, and could be purchased from a large, single production batch to insure precise specifications;

- information concerning Emery 3004 be made available to, and that its use as a DOP replacement be encouraged by, other Government services and agencies, and non-Government companies and laboratories, as well.

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2. Carlon, H.R., Guelta, M.A., and Gerber, B.V., "A Study of Candidate Replacement Materials for DOP in Filter-Testing Penetrometer Machines," Technical Report CRDEC-TR-053, U.S. Army Chemical Research, Development and Engineering Center, Aberdeen Proving Ground, MD 21010-5423, March 1989.

3. Air Techniques, Inc. (ATI), Division of Hamilton Associates, Inc., 11,403 Cronridge Drive, Owings Mills, Maryland 21117-2247, (410) 944-6037.

4. Hinds, W., First, M., Gibson, D., and Leith, D., "Size Distribution of 'Hot DOP' Aerosol Produced by ATI Q-127 Aerosol Generator," Proc. 15th D.O.E. Nuclear Air Cleaning Conference Boston, MA, 7-10 August 1978:1130-1144 (1978).

5. "Emery" and "Emersol" products are available from Emery Group, Henkel Corp., 11,501 Northlake Drive, Cincinnati, OH 45249-1643, (513) 530-7418; "Industrene" products are available from Humko Chemical Div., Witco Chemical Corp., P.O. Box 125, Memphis, TN 38101, (901) 320-5941.

DISCUSSION

DORMAN: I heard about the carcinogenicity of DOP many, many years ago. Is there any well-documented evidence that cancers have been produced in human beings by inhalation of DOP?

CARLON: I know this is in dispute. I personally don't know of any hard evidence that human toxicity has ever been proven. Recent MSDSs of DOP manufacturers give good discussions of DOP toxicology, and might provide some insights.

GUEST: In your opinion, will we be able to use Emery 3004 to replace DOP in a hot aerosol generator?

CARLON: You are using DOP at 700° C!

GUEST: Yes, its OK. We produced enough smoke to test a 50,000 cfm system. We produced it at 700°C.

CARLON: It doesn't blow up or anything?

GUEST: Not yet. We don't drive it with air, we dry drive it with inert gas.

CARLON: I certainly wouldn't trust Emery beyond the flash point which I would have thought was not too far from DOP's. I am amazed at that number, I can't believe it. Does anyone else know of numbers like that?

CROSBY: I believe that he is talking about the TDA-5A thermal portable DOP generator which produces a polydisperse aerosol and uses an inert gas at 700° F. It does not produce a monodisperse aerosol.

CARLON: The gas picks up the vapors, is that the idea?

CROSBY: What you are doing is superheating it to a very high vapor concentration. At the tip of the jet, the ambient air condenses it into a polydisperse aerosol. People have used it with air and gotten away with it but there are people who used it with air and didn't get away with it.

CARLON: All I can say is, we never ran our device that hot.

A NEW METHOD FOR IN-SITU FILTER TESTING USING PULSES OF AEROSOL AND PHOTOMETRIC DETECTION WITH COMPUTER CONTROL *

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Abstract

This paper describes a new technique, developed at the Harwell Laboratory, for the in-situ testing of High Efficiency Particulate Air (HEPA) filters using multiple pulses of test aerosol. The pulse test apparatus consists of a modified forward light scattering photometer coupled to a portable micro-computer fitted with an internal data acquisition and control card. The micro-computer switches an aerosol generator on and off via an external relay driver unit. Using this apparatus the filter bank is challenged by a small number of equal length, constant concentration, pulses of aerosol at timed intervals. The aerosol concentration data upstream of the filter bank is logged, to disk, by the computer. The process is then repeated for the downstream concentration with the photometer gain increased to give maximum sensitivity. The collected data is analysed using a computer spread-sheet package; the recorded aerosol pulses are combined, integrated and the background data subtracted; the downstream data is then divided by the upstream pulse data to give the filter penetration. Using this technique the sensitivity of the in-situ filter test has been greatly improved, penetrations approaching 10^{-5}% can now be measured, allowing HEPA filters mounted in series to be successfully tested. In addition, filter loading is reduced considerably.

I. Introduction

The current method for the in-situ testing of High Efficiency Particulate Air (HEPA) filters consists of challenging the filter system with a constant flow of aerosol and then comparing the measured concentration upstream (C_u) with that measured downstream (C_d). The aerosol penetration through the filter is given by:

$$\text{Penetration} = \frac{C_d}{C_u} \times 100\,\%$$

In the conventional "DOP" test, a challenge aerosol, formerly of Di-(2-ethylhexyl)-phthalate (DOP) was produced either by a thermo-pneumatic (hot generation method) or Laskin nozzle (cold generation method) aerosol generator. DOP has been replaced in many facilities by other liquids with similar physical properties to DOP and producing similar aerosol size distributions; in our laboratory we decided to use a food grade mineral oil (ONDINA-EL, Shell UK Ltd.) [1]. Aerosol concentrations are measured using a forward light scattering photometer. Using this technique filter penetrations down to 1×10^{-3} % (a decontamination factor (DF) of 1×10^5) can be measured [2]. There is a need for a more sensitive test than the current technique so that filters in series can be tested as one unit. In addition the constant challenge to the filters by the test aerosol can result in a relatively high filter loading, especially if the system has to be repeatedly tested to cure a leak from a poorly seated filter. This paper describes a new technique for filter testing using multiple pulses of aerosol which aims to increase the sensitivity of the present "DOP" technique and to reduce filter loading by the test aerosol.

II. Apparatus

The apparatus is shown schematically in figure 1, it consists of a modified total forward light scattering photometer (Steptech Ltd., model SP101LL) coupled to a portable micro-computer (Toshiba, model T3200SX) which is fitted with an internal data acquisition and control card (Advantech Ltd., model PCL-812PG). The micro-computer is also coupled to a thermo-pneumatic type aerosol generator (C.F Taylor Ltd., model 3020) via an external relay driver unit (Advantech Ltd.).

This arrangement enables the micro-computer to log the reading and range information from the photometer whilst controlling the output of the aerosol generator.

Photometer modifications

The modifications to the photometer consisted of adding a 0 - 1 V dc analogue output corresponding to zero to full scale deflection of the meter (this modification was made by the suppliers of the instrument). The second modification was to make connections to the range indicator LED's on the photometer display - this enables the micro-computer to read which of the five sensitivity ranges has been selected by the user. The output signal and range information wiring is connected to a ribbon cable via a terminal board, mounted in the instrument's case. This enables all the connections between the photometer and the micro-computer to be made via a single ribbon cable.

Aerosol generator modifications

The only modification made to the aerosol generator was the addition of an external plug and socket connector to the standard remote control unit (a switch box connected to the generator by a 10 m lead): this is wired in parallel with the aerosol on/off switch, thus enabling it to be operated by a relay controlled by the computer.

Computer software

A computer software package (Labtech Notebook, Laboratory Technologies Corporation) was purchased along with the other equipment, but was found to be unsuitable for this application as there is no facility to direct the program flow easily. Therefore, we decided to write a computer code to utilise the assembler driver routines supplied with the data acquisition card. This code was developed in BASIC (since the demonstration programs supplied with the data acquisition card were written in BASIC).

The computer code allows the user to select the duration, interval between and number of aerosol pulses. It also prompts the user to make the correct connections of the sample lines to the ductwork serving the filter system. The data being logged by the system is displayed on the screen together with a graphical trend display. The code stores the logged aerosol concentration data to disk together with other relevant information such as: file name, time and date, photometer gain setting, pulse length, pulse period and number of pulses. The upstream and downstream data is each stored in a separate data file. Data is acquired at a rate of about ten samples per second.

III. Method

Preparation for upstream measurement

The apparatus is set up as shown in figure 1. The aerosol photometer is set to the linear mode of operation and a sample tube (6 mm bore PVC) connected to the upstream sample port and the aerosol switched on manually. With the photometer set on the 100 % range and sampling the upstream concentration, its gain (span) is set to give a reading of about 75 % of FSD to ensure that the reading does not go over range in the subsequent measurement. The aerosol is then manually turned off, and the photometer zero set, with the most sensitive range (full scale 0.01 %) selected while sampling clean air through its internal filter.

Upstream measurements

The computer control program is run and the required parameters (pulse length, interval, number, photometer gain and file name) entered. Four pulses are normally used; this is usually sufficient to demonstrate consistency of aerosol output, experiment has shown that the aerosol concentration integrated over the pulse normally has a standard deviation of $< \pm 5$ %. The photometer is set to the 100 % range and sampling is initiated from the duct upstream of the filters. The computer then takes over control of the upstream measurement (see section II) introducing pulses of aerosol and logging the photometer readings. When the upstream sequence is complete, the user is prompted to change over to the downstream sample location.

Preparation for downstream measurement

The photometer sample tube is connected to the downstream sample port. For maximum sensitivity, the gain of the photometer is increased to the highest value consistent with a reasonably stable reading, the value is recorded in the data file. The photometer is then zeroed, on the 0.01 % range (the most sensitive), by sampling the clean air in the duct downstream of the filter (this avoids a negative reading, since the air in the duct downstream of the filters will probably be cleaner than the air provided through the internal reference filter of the photometer).

Downstream measurement

With the photometer sampling, on the 0.01 % range, from the duct downstream of the filter system the computer program continues with the test as for the upstream measurement. The length and interval of the pulses are the same as for the upstream measurement but the number of pulses is chosen to enable the efficiency of the filter system (or the minimum required efficiency) to be determined. By using more pulses downstream than upstream the resolution of the technique is improved.

IV. Data processing of results

The files produced by the data logging / control program are processed and analysed using a spread-sheet software package (Excel 3.0 for Windows, Microsoft Ltd).

Each raw data file (for upstream or downstream measurement) is converted into spread-sheet format, then condensed by taking the average of sequential groups of twenty items of data, each group representing approximately two seconds of run time. This process is carried out on both the logged run time and aerosol concentration data. The condensed data is then saved to a new data file.

The condensed aerosol concentration data is then converted from arbitrary units to absolute concentration, using the calibration factor [3] appropriate to the gain setting used during that phase of the filter test. The aerosol concentration values are then plotted against the run time for the upstream and downstream measurements. Typical plots are presented in figures 2 and 3.

The plots are then used to determine the start and end of the pulses in terms of run time (the time for the aerosol pulse to pass through the filter system and duct-work serving it obviously varies from system to system). Each set of pulses is then added together to form a single pulse (figures 4 and 5). This has the effect of amplifying the low concentration (downstream) data, which may be swamped by background noise, since positive pulse data is additive, while the random background noise tends to cancel out. The pulse is then integrated above the background signal level. This process is carried out on both the upstream and downstream data.

Where an increase in concentration cannot be distinguished in the downstream values for individual pulses, summing over the interval between pulses, starting at an arbitrary zero, may enable the start and end of the detected pulses to be obtained. The data may then be re-summed using appropriate starting points.

V. Discussion

Using conventional filter test techniques aerosol penetrations down to 10^{-3} % (DF = 10^5) can be measured.

The pulse tests for the filter system shown in figures 2 to 5 gave the following results, based on the summed data (figures 4 and 5):

Upstream integral of summed pulse (above background) = 4235.4 mg m^{-3} s

Downstream integral of summed pulse (above background) = 0.024746 mg m^{-3} s

Therefore the filter penetration = 5.8×10^{-4} % (DF of 1.7×10^5)

This result is already an improvement on the conventional technique which can only measure down to 10^{-3} %. (A conventional test carried out on this system showed a downstream concentration below the lower limit of detection of the photometer i.e. a penetration of < 0.001 %).

During this work it was not possible to measure the limit of sensitivity of this technique for our equipment, as the large scale test rig we required was out of order. However from measurements of the background variation obtained during experimental trials such as those presented in figure 5, standard deviations of the background integrated over assumed downstream pulse lengths were obtained. These indicate that a limit of detection of two standard deviations would be about 3×10^{-5} % for the summation of four pulses. This could be improved by summation over a greater number of pulses.

VI. Conclusion

This new method for the in-situ testing of HEPA filtration systems is considerably more sensitive than the conventional test method, aerosol penetrations down to about 3×10^{-5} % (a DF of 3×10^{6}) can now be successfully measured.

VII. Acknowledgement

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VII. References

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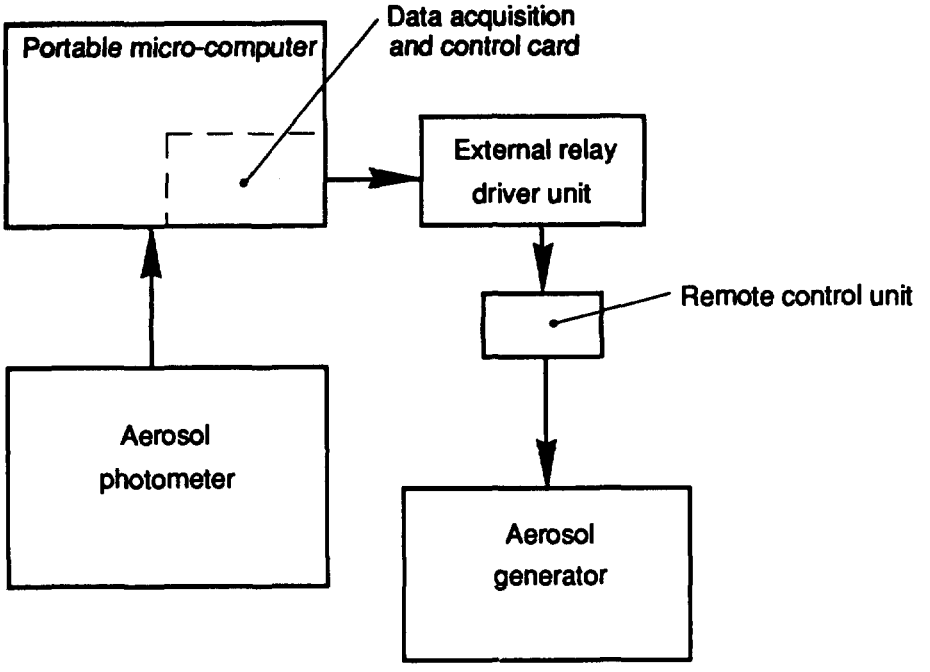

Figure 1: Schematic of pulse test apparatus

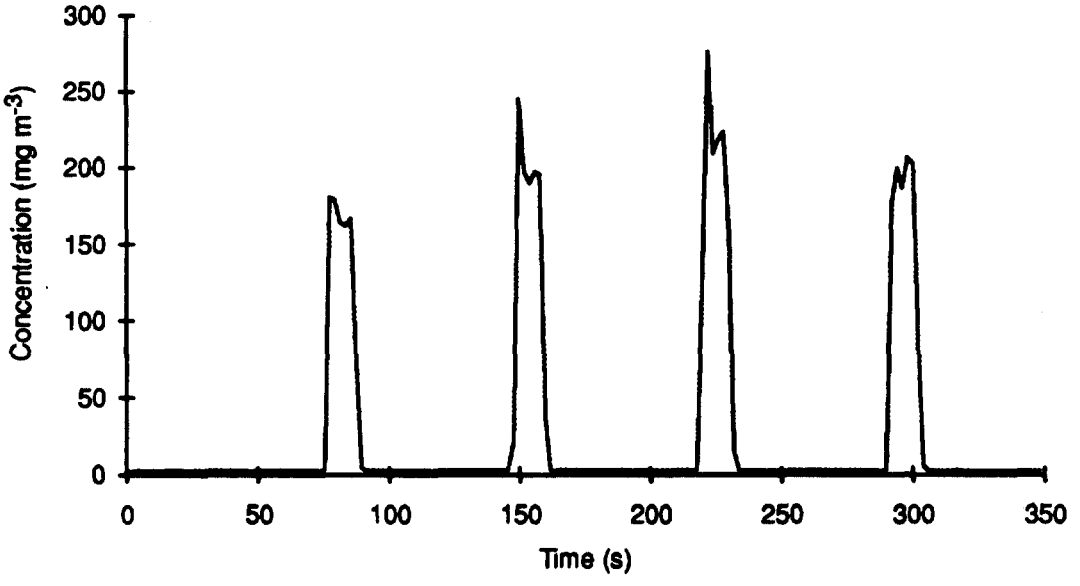

Figure 2: Typical upstream pulse data

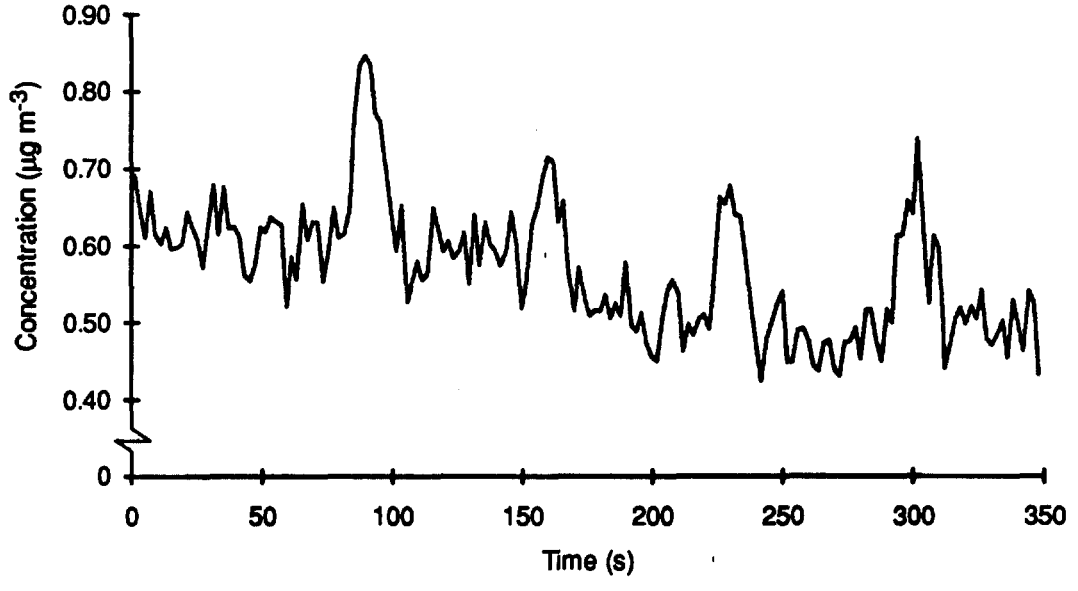

Figure 3: Typical downstream pulse data

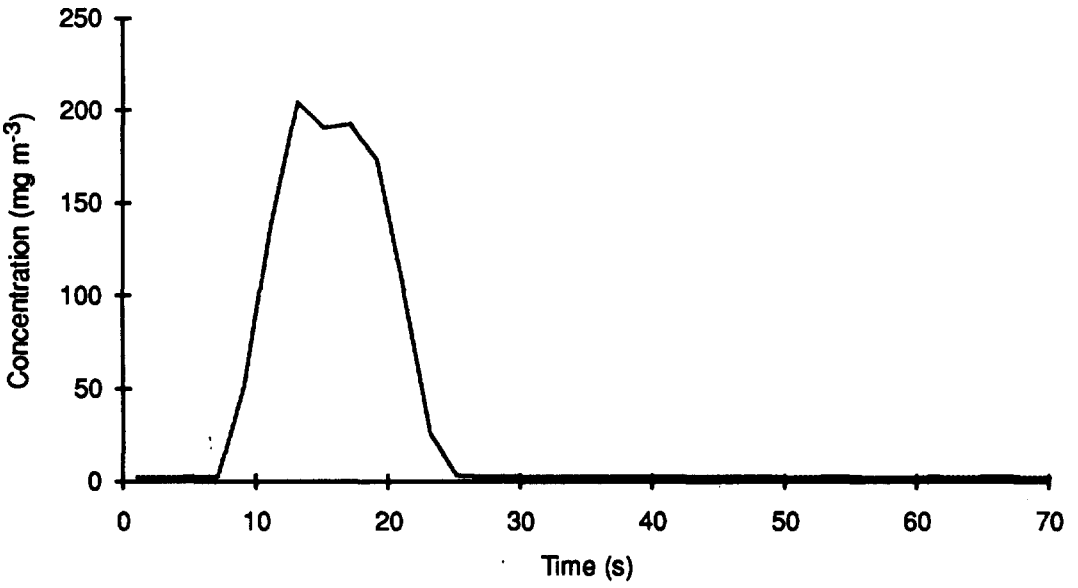

Figure 4: Sum of pulses in Figure 2

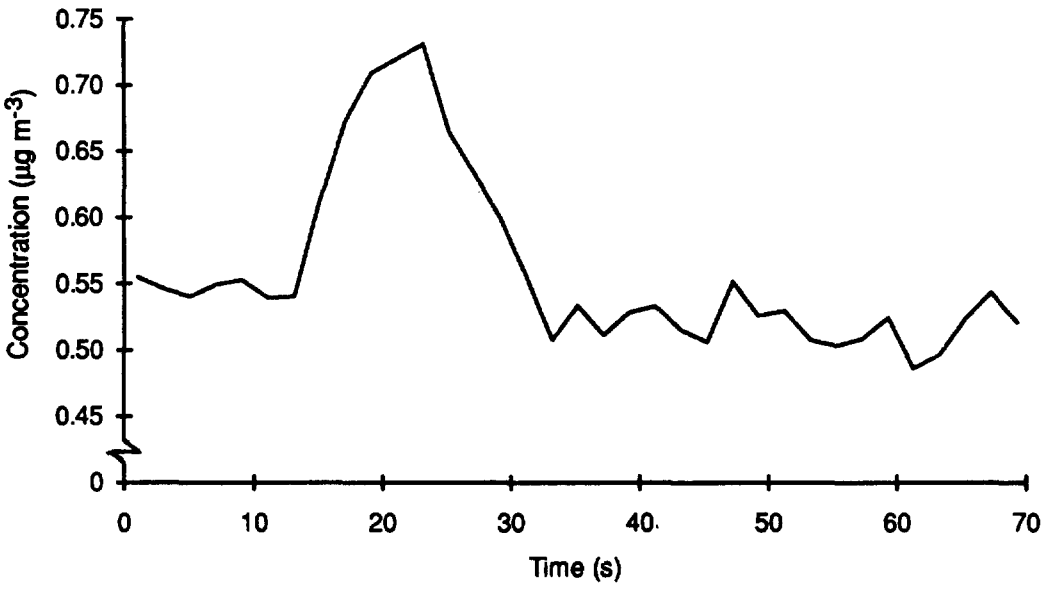

Figure 5: Sum of pulses in Figure 3

DISCUSSION

DORMAN: When switching the pulse on and off, do you not get a change in particle size?

PARKER, R.: We don't think so.

DORMAN: You don't get big ones at the end which are not useful for penetration measurements?

PARKER, R.: The pulse is long enough so that any change in size during the transition between on and off periods will be minimal.

DORMAN: As the particle sizes upstream and downstream are different, are you satisfied that measuring areas under the deflect-time graphs give a true penetration? Does not the difference in particle sizes effect the degree of scattering?

PARKER, R.: This effect also applies to the standard (current) in-situ test technique. The pulse test technique uses the same instrumentation. However, previous work, references 1 and 2, have shown that the forward light scattering photometer has a peak sensitivity at the maximum penetrating particle size for HEPA filters.

GUEST: Are you proposing that this equipment be used for field testing, taking it into a power plant and using it in there? Or is it strictly for lab use?

PARKER, R.: We do intend to use it for field work, but in a modified form. The apparatus I described here is a prototype. As I said, we would like to incorporate the PC into one instrument case. At the moment, if you are trying to take a portable PC around the plant, it is not going to last very long.

EDWARDS, JIM: I noticed the title of your paper contains the words, "New Method." You are not claiming a new, improved method for in-situ testing are you? Because with the usual DOP generator and conventional aerosol detector, a factory test or in-place test can be completed in ten seconds rather than the minutes that you had indicated would be required with the test you described. Is this an "improved method?"

PARKER, R.: We intend this instrument for use when the conventional test is not possible, e.g., when you have two or more filters mounted in series. The conventional test is not sensitive enough to measure penetration downstream of two filters; so here, you need a more sensitive method. You could carry out a conventional test which would last 10 seconds, but it would not tell you whether one of the filters is leaking. The method is "improved" in the sense that it greatly improves sensitivity.

WEBER: As an alternative method to achieve the higher sensitivity that you are looking for, we have done a good deal of work using conventional ATI Corporation hot aerosol generators in conjunction with a laser particle spectromemter. We found that the population of particles in the source aerosol is sufficient, at 10^{10} or 10^{11} particles per cubic foot and 0.15-0.30 μm for this kind of work. Therefore, as an alternative method, a laser detector can also be used to achieve higher sensitivity.

PARKER, R.: We have tried, at Harwell, using a laser particle spectrometer to measure the downstream concentration. You have a very high particle concentration upstream of the filters that cannot be sampled directly because of coincidence errors. Therefore you have to used a dilution apparatus upstream to get a meaningful reading on the laser spectrometer. Downstream, you can have

problems with background counts. For instance, if someone bangs the duct while you are making the measurement, you get a lot of particles coming through which will interfer with your readings.

WEBER: I agree with both of your conditions, but I haven't found problems when using a diluter on the upstream side. As I have only done the test in the laboratory, although in a factory location, I can not attest to the complications that would arise in the in-situ testing that is one of our objectives.

BERGMAN: The downstream pulse data in Figure 3 show a considerable random noise fluctuation. One has to be careful extracting a useful signal from the traces to avoid large errors in penetration. Adding multiple noisy signals does not necessarily improve the sensitivity of the downstream peak because noise is also included. Electrical engineers often deal with signals buried in noise using mathematical techniques such as the Weiner Kichner Theorem. I recommend that either a more detailed analysis be done or direct experiments with alternative methods be conducted.

DEVELOPMENT OF THE QUICKMIX INJECTOR FOR IN-SITU FILTER TESTING

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D Loughborough - AEA Decommissioning & Radwaste

AEA Technology - Harwell Laboratory
Oxfordshire, UK.

ABSTRACT

In-situ filter testing is routinely carried out on nuclear ventilation plant to assess the effectiveness of installed filter systems. Ideally the system is tested by introducing a sub-micron aerosol upstream of the filter, in such a way as to present a uniform challenge to the whole of the upstream filter face. Samples are withdrawn from upstream and downstream of the filter, and the respective concentrations are used to calculate the system (or filter) efficiency. These requirements are documented in the Atomic Energy Code of Practice, AECP 1054[1].

The Filter Development Section at Harwell Laboratory has been investigating methods of improving the accuracy and reliability of the in-situ filter test over the past ten years. The programme has included the evaluation of devices used to mix the aerosol[2] and multi-point samplers to obtain representative aerosol samples[3].

This paper reports the results of laboratory trials on the "QUICKMIX" injector developed and patented by Harwell. The Quickmix injector is designed to mix the test aerosol with the air stream and thereby reduce the duct length required to produce uniform concentrations. The injector has been tested in ducts ranging from 150 mm diameter to 610 mm square, at air velocities up to 26 m/s. Upstream mixing lengths required to achieve a ±10% concentration variation on the mean were reduced to between 2 and 5 duct diameters, with a very small pressure drop.

This simple, compact device is being installed in new and existing plant in the UK to improve the accuracy and reliability of in-situ filter testing. Some examples of plant applications are given, together with some of the first results from operating plant.

1. INTRODUCTION

The Atomic Energy Standard Specifications (AESS)[4],[5] for circular and rectangular filter inserts have recently been revised. In-situ filter testing is required to demonstrate that the filter continues to meet these more stringent requirements during its lifetime. A typical filter system may have two or even three filters in series, and, in most cases, all but the first must be regularly tested.

Current recommendations for in-situ filter testing[1] necessitate long lengths of ducting before and after the filter to ensure a reasonably accurate test (25 diameters or more with natural mixing). This in turn leads to larger and often more complex plant. Previous development work[6] concentrated on using devices such as the Stairmand disc to reduce the upstream mixing length, with disc and doughnut baffles to reduce the downstream length. Mixing lengths can be reduced to about 10 duct diameters in this way.

These devices produce high pressure drops. At moderate duct velocities the pressure drop is often larger than that of the HEPA filter itself (250 Pa). They can be "feathered" when not in use, but this adds complexity to the plant. As a result they are not commonly used.

As filtration systems are designed to operate with higher volumetric flowrates, the use of thermal type aerosol generators becomes increasingly necessary. These have a much greater output than the atomising type[7], but produce aerosol at atmospheric pressure with a relatively low exit velocity. This in turn means that mixing is poorer and longer mixing lengths (of order 15 diameters with Stairmand disc) are required.

A need therefore exists for a mixing device which is capable of producing well mixed aerosols from a thermal generator in less than 10 duct diameters, and which operates with a negligible pressure drop.

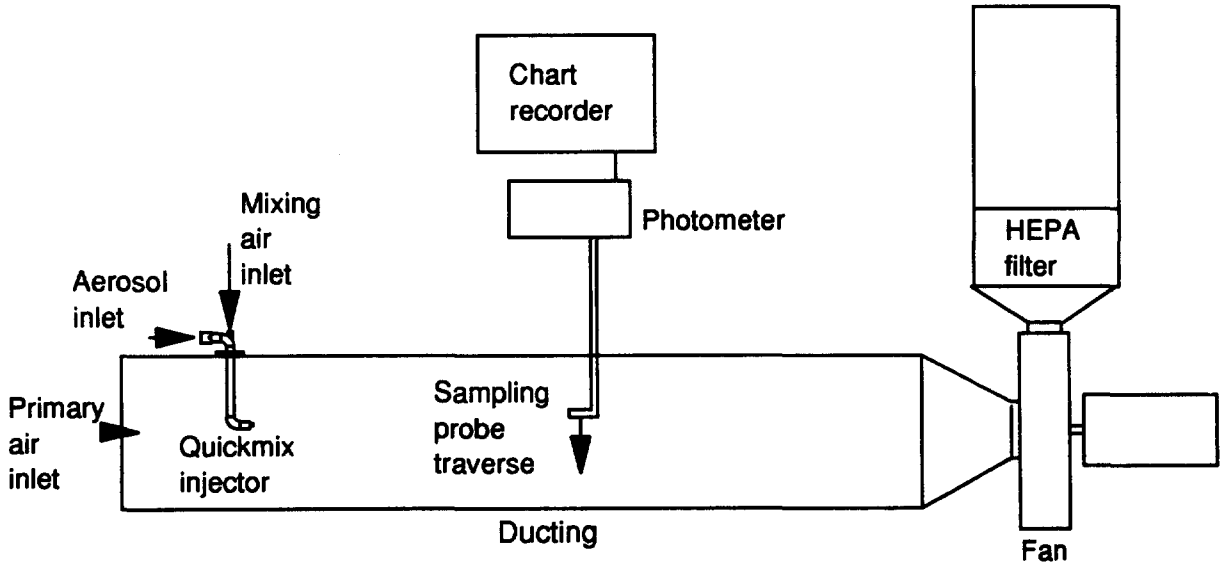
The Quickmix injector was developed to meet this need. Ease of use and the ability to retro-fit the unit into existing plant were major considerations in its design. The device uses a small amount of compressed air to mix the aerosol with the air stream. It is of similar dimensions to the aerosol injectors currently used on most plant.

2. APPARATUS AND TEST PROCEDURE

2.1 Apparatus

A diagram of the test rig used in this work is given in figure 1. A centrifugal fan drew air through ductwork and exhausted it to atmosphere through a bank of HEPA filters. The size of the ductwork was either 150 mm diameter or 350 mm diameter or 610 mm square as detailed below. The air flow rate was controlled by a manual damper. Air velocity was measured using a traversing TSI heated filament anemometer. Pressure tappings located approximately five diameters upstream and downstream of the device under test enabled pressure drop to be measured by a micromanometer.

Figure 1 Arrangement of apparatus.



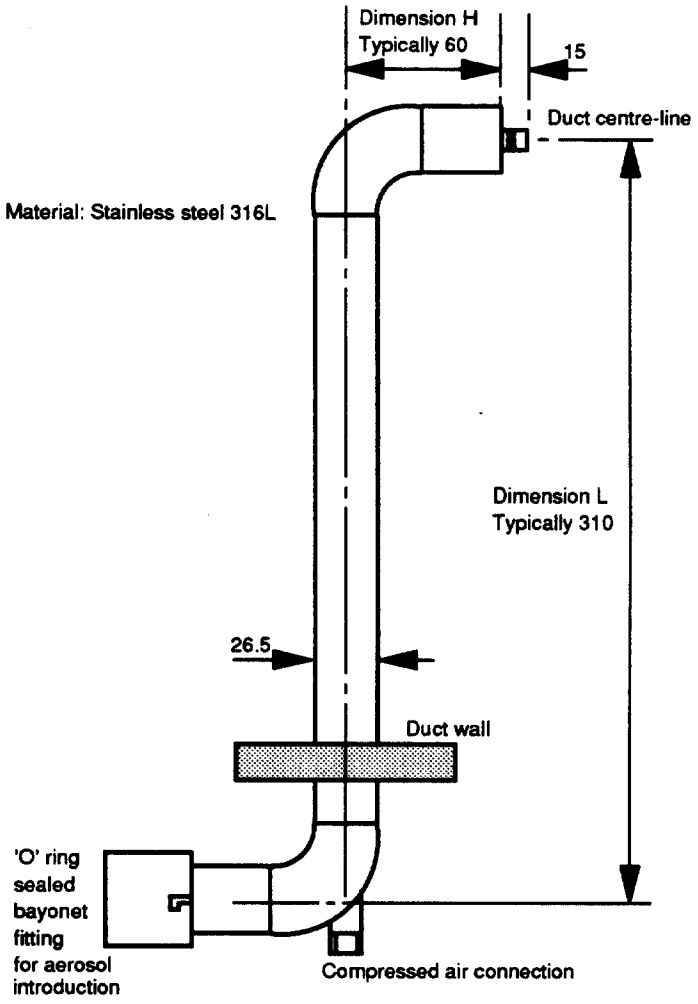
The aerosol generator used was a Taylor 3020 thermal type. Tests[7] have shown that this generator can provide up to 10 g/minute of aerosol, depending on the CO_2 supply pressure.

The relative aerosol concentration was measured by drawing a sample of air through a 6 mm diameter probe facing into the airflow. The sample was passed through a JM 8000 light

scattering photometer. The signal from the photometer was passed through a smoothing circuit, which reduced the signal noise level, and then to a chart recorder. The chart recording was analysed by the operator on completion of each test.

Figure 2 shows the basic Quickmix injector arrangement. A stainless steel injector tube (nominally 25 mm bore) has been modified by the addition of a smaller tube (approximately 12 mm O.D.) located within it. One end of this smaller diameter tube is connected to a compressed air supply, whilst the other end terminates in a nozzle. The nozzle is located centrally at the open end of the aerosol injector and projects from it. Small diameter holes are drilled radially through its wall. These produce high velocity jets of air directed towards the wall of the duct. The number and diameter of these holes significantly alter the performance of the injector. Aerosol from the generator is aspirated through the larger tube by the low pressure produced in the region of these jets. The aerosol is then entrained by the jets and mixed with the primary air.

Figure 2 The Harwell Quickmix Injector.



The device described above is strikingly similar to that developed at CEA Saclay[8], the principal difference is in the nozzle arrangement. These designs were arrived at independently, however, and a patent application for the Quickmix design was filed on 6th April 1990 (Patent No. GB 2242705A). This was prior to the publication of [8].

2.2 Initial development of the Quickmix injector

The basic configuration of the injector (figure 2) was established after evaluating a series of different designs. Having decided that the Quickmix arrangement was the most promising, further tests were carried out in a 350 mm diameter duct to investigate the effects of:

(a) the distance between air holes and the outer pipe;
(b) the size of the air holes;
(c) the number of air holes.

Item (a) influences the flow of aerosol through the outer tube. With the correct separation the high velocity air creates a region of low pressure at the aerosol tube exit which enhances the flow. This is advantageous when thermal aerosol generators are being used. On the other hand, if the holes are too close to the exit, pressure builds up in the aerosol tube reducing the flow. Items (b) and (c) control the distribution and flow rate of "mixing" air and hence the effectiveness of the injector as a mixing device.

The nozzle arrangement used in the tests reported here was a compromise between optimum performance and ease of manufacture.

2.3 Performance tests on the Quickmix injector

Tests were carried out in 150 mm diameter, 350 mm diameter, and 610 mm square ducting to determine the mixing length as a function of duct air velocity. The aerosol was assumed to be well mixed when a traverse indicated that the concentration variations were less than ±10% of the mean concentration.

At each air velocity in each duct the CO_2 and compressed air pressures were varied to establish the values which gave the minimum mixing length.

Pressure drop measurements across the injector were made in the 350 mm diameter duct. The pressure drop was measured at velocities up to 14 m/s with no mixing airflow and with the maximum mixing airflow.

The compressed air flow rate was measured as the air pressure was varied from 0.5 bar to 4.5 bar to determine the level of dilution of the primary airflow caused by operation of the injector.

Aerosol particle size measurements from different aerosol generators had been previously measured[7]. Further measurements were made for each generator, operating with a Quickmix injector, to ascertain the effect of the injector on the aerosol particle size.

3. RESULTS AND DISCUSSION

Most of the characterisation tests were performed on the 350 mm diameter ducting. For comparison purposes a duct velocity of 10 m/s was used; this represents a flow of 960 litres/s which is very close to the rated flow of a large circular filter insert designed to AESS 30/95100[4], which is becoming the preferred size of filter in the UK for nuclear applications.

3.1 Mixing length

3.1.1 Duct diameter 350 mm

Figure 3 shows the results of tests at three velocities: 5, 10 and 15 m/s. The maximum concentration variation was measured at intervals of 2 duct diameters, from 2 to 10 diameters downstream of the Quickmix injection point. At the lowest velocity (5 m/s) the concentration variation was less than 20% (i.e. less than ±10% of the mean) at the first measuring point. At 10 and 15 m/s full mixing is established between 4 and 5 diameters downstream. In terms of transit time at the highest duct velocity mixing takes place in about 0.1 seconds.

The mixing length variation at 960 litres/s in the 350 mm diameter duct is shown in figure 4. This illustrates the effect of varying the mixing air supply pressure. A significant improvement in mixing length results from raising the pressure from 2.4 to 3.4 bar gauge.

The increase in mixing length with increased duct air velocity is typical of all results. This behaviour is expected since the axial momentum of the duct air tends to inhibit the radial spread of the mixing airflow. Figure 4 shows that the effect can be compensated for, to some extent, by increasing the pressure of the mixing air supply.

Fig. 3 - Mixing lengths in 350 mm diameter duct

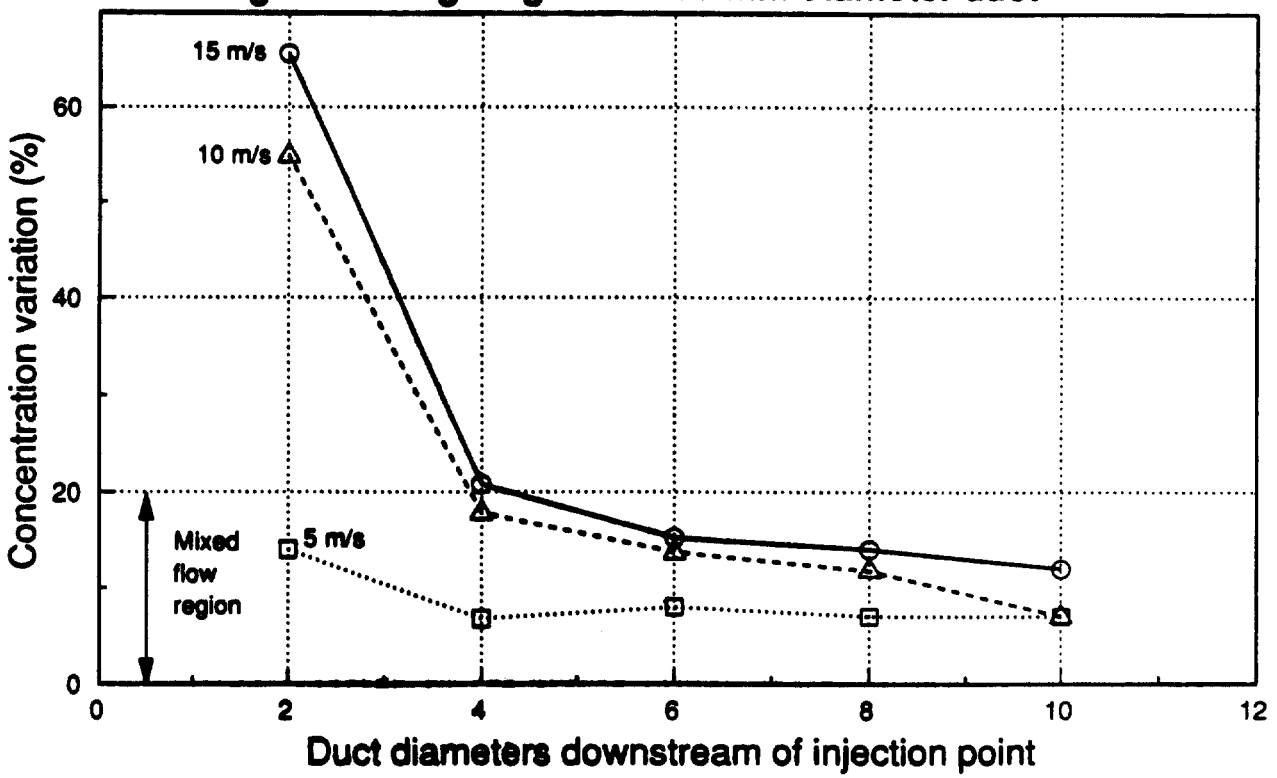
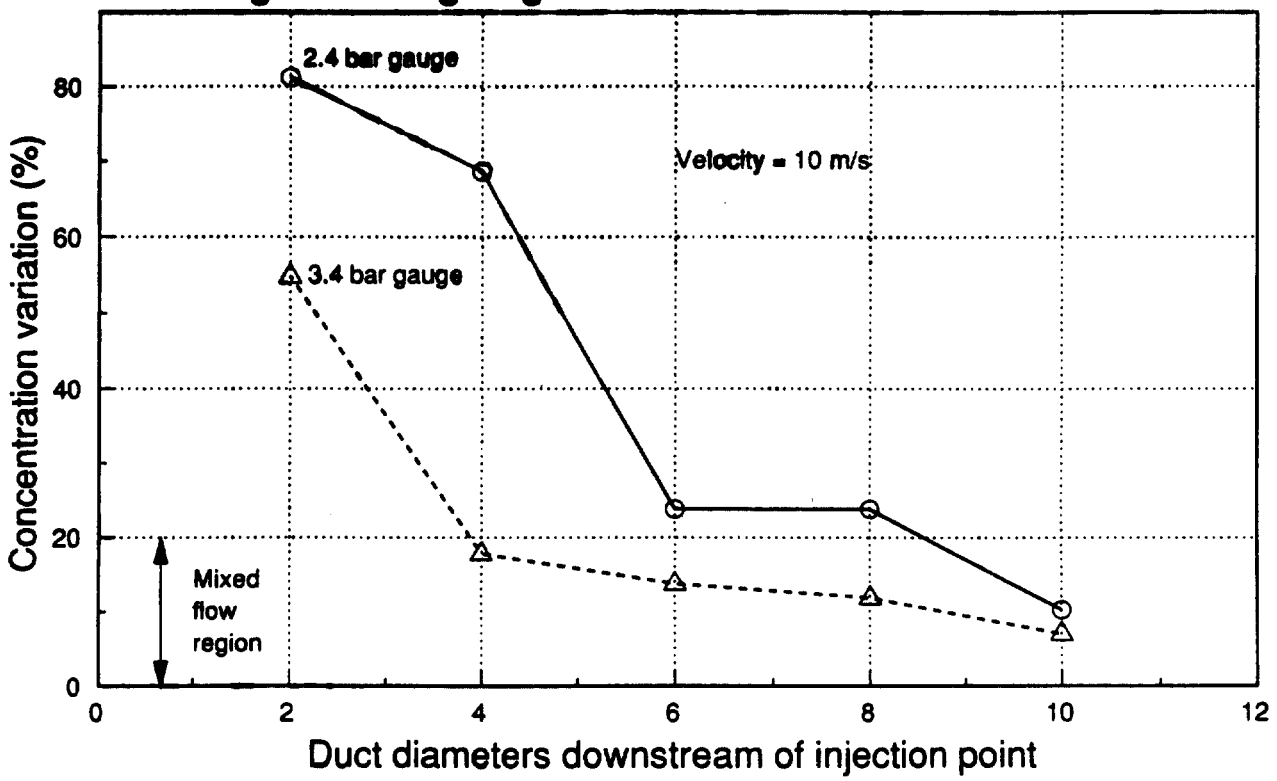


Fig. 4 - Mixing lengths in 350 mm diameter duct



3.1.2 Duct diameter 150 mm

In the 150 mm diameter duct a reduced diameter aerosol injector tube was used in conjunction with the same mixing air tube. The unit was tested at 6.5, 13 and 26 m/s (11.5, 23 and 46 litres/s). Figure 5 shows that the performance of the Quickmix at the lower velocities is very similar with good mixing occurring within 2 duct diameters. At the highest velocity the aerosol becomes well mixed before 4 diameters.

3.1.3 Square duct 610 x 610 mm

UK standard rectangular filter inserts (both deep-pleat and mini-pleat) are tested in ducting of these dimensions. The velocities of 2 and 5 m/s correspond to flow rates of 744 and 1860 litres/s. Once again it can be seen from figure 6 that the aerosol is well mixed after 4 duct diameters.

3.1.4 Comparison of mixing lengths

A comparison of mixing lengths achieved using the Quickmix, a Stairmand disc and natural mixing is shown in figure 7. The Stairmand disc and natural mixing measurements had been made for a previous investigation in 305 mm diameter ducting, rather than the 350 mm duct used here. Therefore the comparison is based upon the same volumetric flowrate (960 litres/s) in each test. This corresponds to a velocity of about 10 m/s in the 350 mm duct. The reduction in mixing length brought about by using the Quickmix is evident from the figure.

3.2 Pressure drop measurements

The results of pressure drop measurements made in the 350 mm diameter duct at 5, 10 and 14 m/s are shown in figure 8. It can be seen that, when the Quickmix is operating, there is a slight increase in pressure drop compared to when there is no flow of mixing air. The pressure drop at 10 m/s (960 litres/s) is 32 Pa.

Again for comparison purposes pressure drop measurements across a Stairmand disc in a 305 mm diameter duct are shown, the basis of the comparison is the volumetric flow rate of primary air. The figure shows that, at 960 litres/s the pressure drop produced by an operating Quickmix is less than one tenth of that produced by a Stairmand disc mixer. In addition it can be seen that, at this flowrate, the Stairmand disc pressure drop is greater than that of the equivalent circular HEPA filter (<350 Pa in a standard test housing or <250 Pa vented to atmosphere).

These are significant reductions in pressure drop, particularly for large plant which may require mixing devices upstream and downstream of the filter(s). They show that considerable savings in fan power are possible when using the Quickmix compared to other conventional mixing devices.

3.3 Flowrate of mixing air

To ascertain the level of dilution of the primary air when the Quickmix is operating, mixing air mass flow rates were measured as a function of air supply pressure. The results are given in figure 9 expressed as litres/s of air at atmospheric pressure and temperature. At 960 litres/s and a pressure of 3.4 bar gauge (see figure 4) the mixing air flow contributes an extra 14 litres/s - equivalent to less than 1.5% of the rated flow.

Fig. 5 - Mixing lengths in 150 mm diameter duct

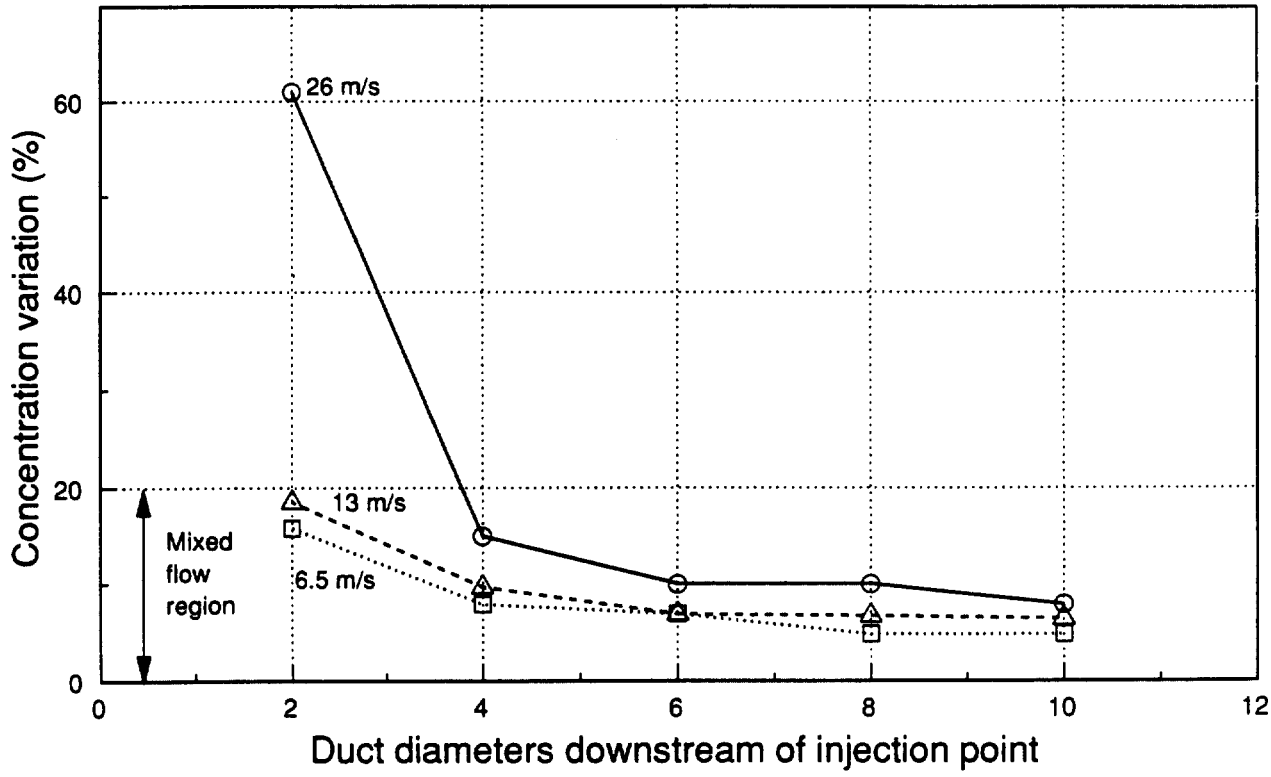


Fig. 6 - Mixing lengths in 610 mm square duct

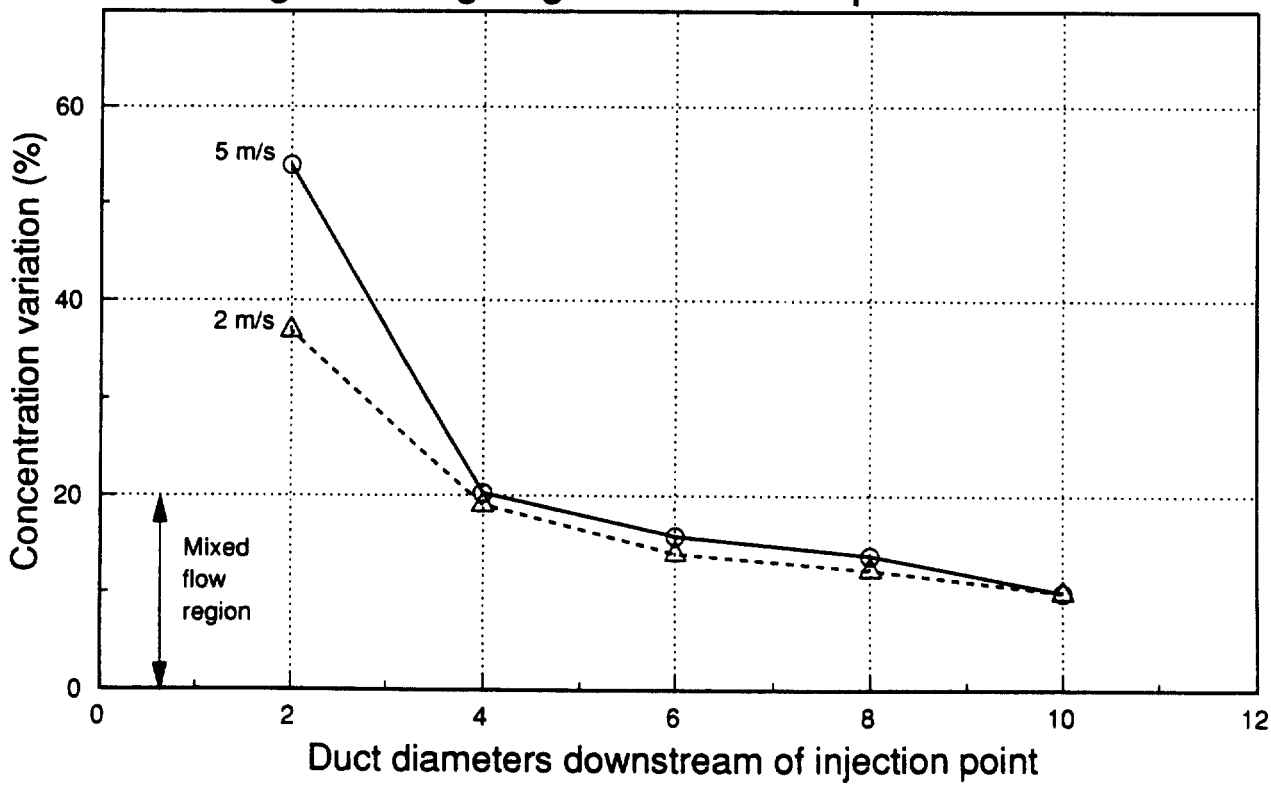


Fig. 7 Comparison of mixing lengths in circular ducts at 960 litres/s.

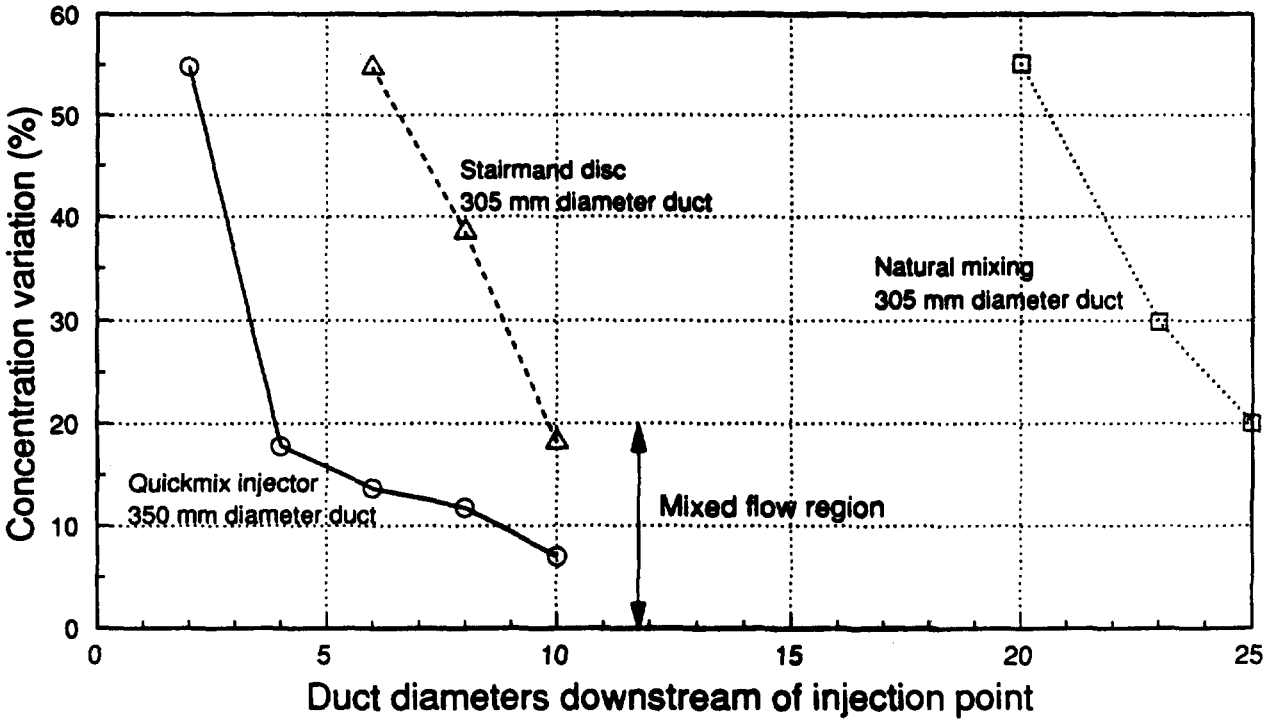
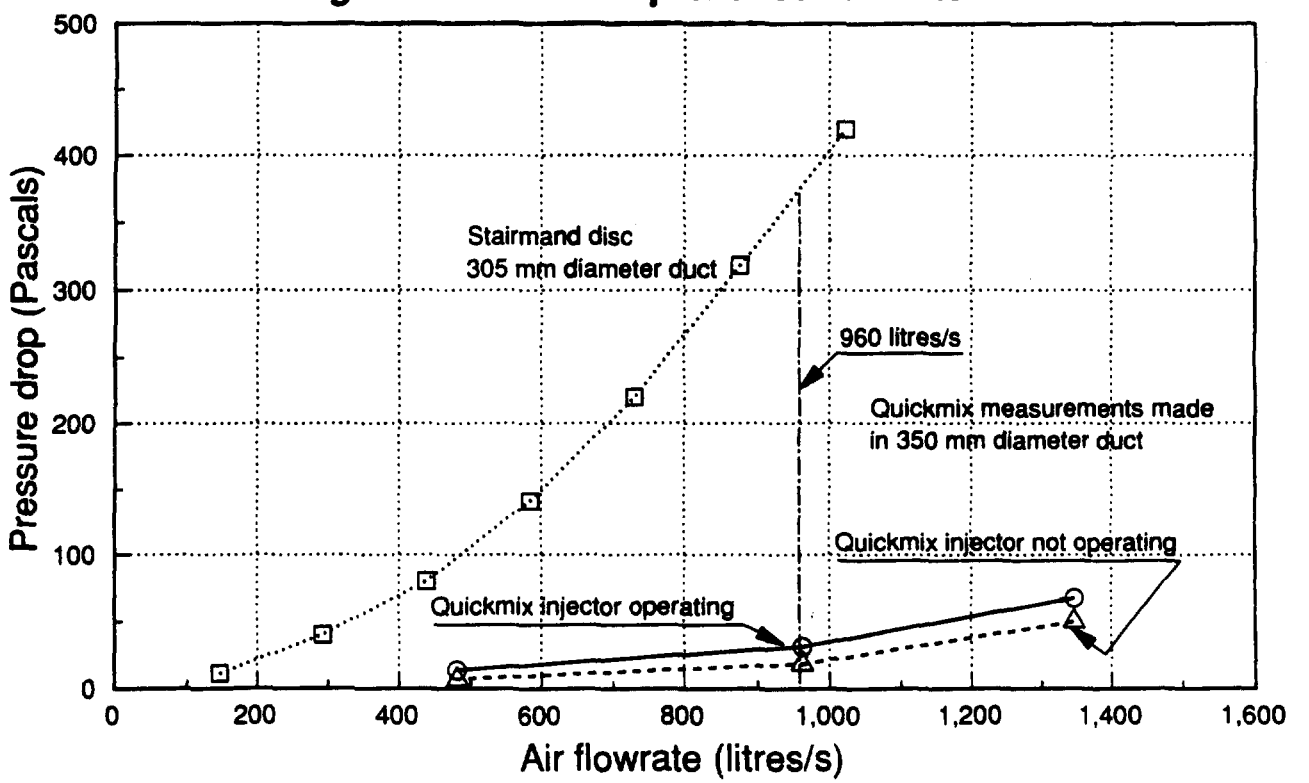


Fig. 8 - Pressure drop in circular ducts



This is an insignificant quantity when the Quickmix is being used to test high flowrate filters. However, figure 9 also shows that the mixing air flow is 5 litres/s at the lowest operating pressure. If the Quickmix were to be used to test lower flow rate filters (perhaps as low as 35 litres/s) it would form a significant percentage of the filter's rated flow. For these applications, however, a smaller unit with different performance characteristics would probably be more appropriate.

3.4 Effect of Quickmix on aerosol size

Measurements of the size of aerosols produced, using Ondina-EL, by thermal and atomising generators were made with a TSI 3020 Electrical Aerosol Analyser. Tests over the full range of operating pressures showed no significant variation in diameter due to the operation of the Quickmix.

4. TESTS ON VENTILATION PLANT

Whilst continuing to develop the Quickmix injector in the laboratory, we are conscious of the fact that real ventilation systems rarely reproduce laboratory wind tunnel conditions. There is pressure to minimise the space occupied by new ventilation systems and ducts are frequently designed to fit into existing spaces, resulting in less than ideal ducting arrangements. Bends will induce secondary flows which may inhibit aerosol distribution. A variant of the Quickmix to operate in a wide duct is shown in figure 10.

A number of Quickmix injectors has now been delivered to customers in the UK nuclear industry. The customers have evaluated the design and provided useful feedback on their requirements. Units are now being installed in new and existing plant. Wherever possible we plan to monitor their performance in-situ. To date the only plant operational, in which Quickmix injectors have been installed, is a new ventilation system in the main radiochemical building at Harwell. Figure 11 is a sketch of the air flow route in the vicinity of the HEPA filters and figure 12 is a view of the plant in the direction of arrow 'A' in the diagram.

The ducting dimensions are 400 mm by 800 mm and, if the filters operate at their rated flow, the average duct velocity is about 9 m/s. Quickmix injectors are installed for filter test purposes at approximately 16 and 12 equivalent diameters upstream of the first and second banks of filters respectively. The second Quickmix can be seen in the top left hand corner of figure 12. Injection and sample points are indicated on figure 11.

Commissioning tests were carried out on the filters with the Quickmixes operating with a temporarily reduced air supply pressure of 1.9 bar gauge rather than the recommended value of 3.4 bar gauge. Both filter banks performed well within the AESS 30/95100 specifications, with the overall decontamination factor exceeding the specified value by almost three orders of magnitude.

A check on concentration variation across the duct at the sampling positions showed that the maximum concentration variation was less than ± 15%. This exceeds the preferred value of ± 10%. It is probable that, when the Quickmix operates with the correct supply pressure, a more uniform distribution will be achieved (see figure 4). These results suggest that natural mixing alone would have produced a much less homogeneous aerosol in this ventilation system when the number of duct diameters available is considered. When the filters are changed these results will be checked in more detail.

5. CONCLUSIONS

1. The Quickmix injector is a compact device, similar in size to existing injection pipes.

2. Its design makes it suitable for retro-fitting into existing plant.

3. It works well with the larger aerosol output from thermal generators, providing a means of aspirating the aerosol through the injection tube.

4. Adequate mixing in all cases tested was achieved in less than five diameters of ducting.

5. The pressure drop arising from its operation is very small when compared with the recommended alternative, the Stairmand disc.

6. The volume of mixing air injected is insignificant in the case of high flow filter inserts.

7. The device is being fitted to new and existing plant. First results indicate that it contributes to the efficiency and reliability of filter testing.

ACKNOWLEDGEMENTS

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Industrial Technology
Decommissioning and Radwaste
Environment and Energy
Fuel Services.

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Fig. 9 - Airflow through the Quickmix injector

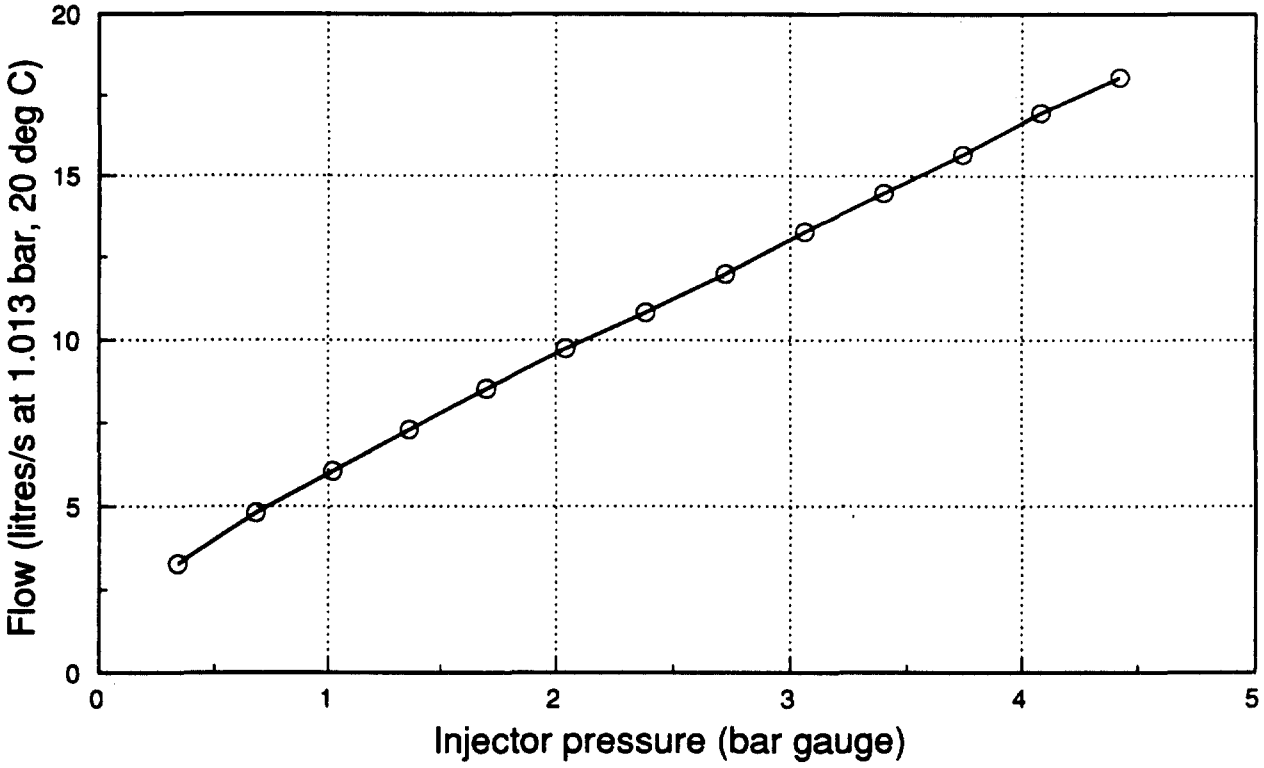

Figure 10 Injector arrangement used on large ducts

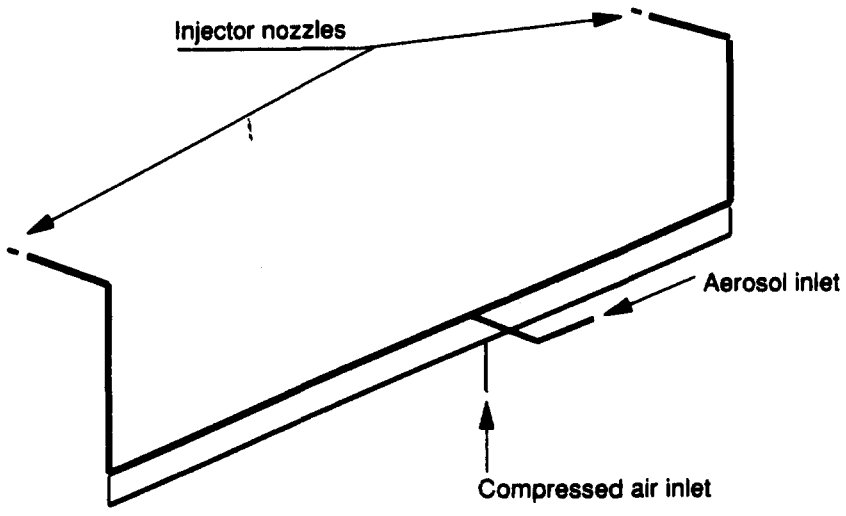

Figure 11 Arrangement of HEPA filtration system in the main radiochemical building at Harwell

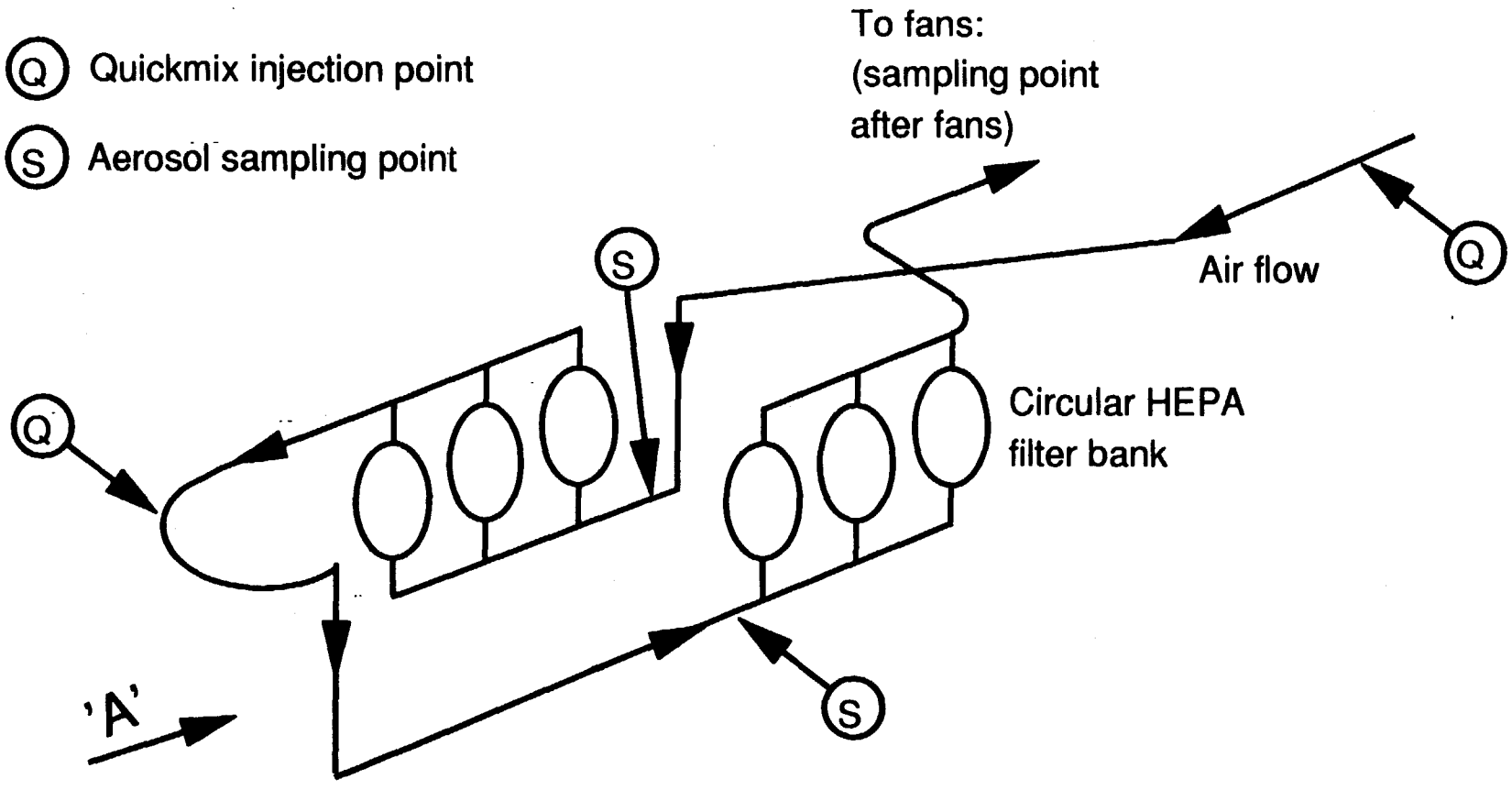

Figure 12 HEPA filters in the main radiochemical building at Harwell

DISCUSSION

DORMAN: What is the position with regard to development of the device vis-on-a-vis the French development at Saclay? What is the patent situation? Are you engaged in an argument with the French as to who was the first?

COSTIGAN: We applied for a patent on this device in May 1990. The French presentation was, I think, in August 1990, at this particular Conference. So there is some evidence that we did have the idea before them. We and the French have filed patent applications. I am not currently aware of what the differences between the devices are for purposes of patent approval.

REVIEW OF DEPARTMENT OF ENERGY HEPA FILTER TEST ACTIVITIES FY 1990 - FY 1992*

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Abstract

Filter Test Facilities (FTFs) and the FTF Technical Support Group (TSG) continue to provide services to the Department of Energy (DOE). Additional tasks relating to the HEPA filter cycle have been added to the TSG. The tasks include the quality assessment review for the in-place testing of HEPA filters at DOE sites and the formation of an in-place testing standards writing group. Summary of ongoing FTFs and TSG activities for FY 1990-FY 1992 including the technical input for implementation of the High Flow Alternative Test System (HFATS), update of the DOE Standards, the status of the quality assessment review and in-place testing standards writing group are discussed.

I. Introduction

The history and activities of the FTFs and FTF TSG HEPA Filter Test activities have been reported at previous DOE/NRC Nuclear Air Cleaning Conferences[1-8]. It is the intent of this paper to review and report the activities of the FTFs and FTF TSG for FY 1990 - FY 1992. Ongoing activities include the continuation of the Round Robin Testing (RRT) program[9], preparation of semi-annual report summaries[10] with associated multi-year trend analysis, status of implementing the High Flow Alternative Test System (HFATS)[11-13] and revision of the DOE Nuclear Standards[14-17]. Additional TSG tasks of the HEPA filter cycle include the quality assessment of in-place testing at DOE sites and the formation of the DOE In-place Testing Standards Writing Group.

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**Employed by Environmental Health Sciences, Inc., contracted to Los Alamos National Laboratory

II. Filter Test Facility and Related FTF Technical Support Group Activities

A. Round Robin Testing (RRT)

Specifications for the RRT program are referenced in the DOE Standard NE F 3-43 Section 11[15]. The standard specifies that RRTs are to be conducted twice each fiscal year and that each RRT is to include testing by each FTF on three Size 5 filters and three filters Size 4 or smaller. The RRTs are scheduled to begin in October and April of each fiscal year. A total of 15 RRTs have been completed and 2 RRTs, October 1991 and April 1992 are in progress.

Data from the FTFs are reviewed and analyzed using analysis of variance (ANOVA) techniques to determine if statistically significant differences exist in the resistance (in. w.g.) and penetration measurements results. Differences detected by ANOVA are examined to determine their practical significance relative to the accuracy and precision required for the FTF measurements. Practical significance has been established at limits which can affect the acceptance/rejection of filters with the criteria of resistance measurements set at >0.10 in. w.g. and >0.01% for penetration measurements. Differences that have practical significance are reported to the FTFs at the annual FTF Manager meetings and potential causes are investigated by the TSG at the FTFs technical consultation visits.

The RRT program continues to fulfill its goals of: 1) documenting measurement consistency among and within individual FTFs; 2) suggesting areas where improvement of FTF measurement accuracy and precision may be possible; and 3) monitoring and documenting effects that the improvements have on FTF measurements.

B. Semi-annual Report Summaries

The objective of the semi-annual report summary is to provide a reference frame against which performance statistics of individual FTFs can be evaluated and provide information on filters being procured and used in DOE facilities. The semi-annual report summary is a requirement of DOE Standard NE F 3-43, Section 10[15]. For purposes of this paper the summary of the annual filter test results by FTF, test results grouped by manufacturer, number of filters tested by size and multi-year trend analysis will be discussed for FY 1990 and FY 1991, analysis of data for one of the FY 1992 summary reports is in progress.

Table 1 illustrates a summary of test results by FTF for FY 1990 and FY 1991. The total number of 18,301 filters listed in Table 1 excludes the 249 filters tested but categorized for use in non environmental protection or non nuclear applications. As with past fiscal years, Rocky Flats FTF tested the highest number of filters when compared with the other two FTFs. The table depicts a relatively low acceptance with waiver (0.28%) when compared with the acceptance with waiver (3.7%) reported for Fiscal Years FY 1986-FY 1989[8]. 100% of the acceptance with waiver occurred in FY 1990. The overall rejection rate of 2.8% was higher than the rejection rate of 2.3% reported for the period FY 1986-FY 1989[8]. This slight increase can be attributed to the FTFs strict adherence to the double reporting requirements of NE F 3-43 Standard[15]. After February 1990, filters accepted with waiver are also reported as rejected and downrating the flow of Size 4 filters and higher to comply with the 1.0 in. w.g. pressure differential is not permitted.

TABLE 1
Summary
Test Results By Filter Test Facility
FY 1990 - FY 1991

	No. Tested	No. Accepted w/Waiver	No. %	Range %	Rejected	%	Range %
HANFORD	2,455	22	0.9	0-2.2	34	1.4	1.3 - 4.5
OAK RIDGE	6,984	30	0.4	0-0.7	365	5.2	5.2 - 5.3
ROCKY FLATS	8,862	0	0	0	111	1.2	1.2 - 1.3
TOTALS	18,301	52	0.28		510	2.8	

Table 2 illustrates a summary of test results as grouped by filter manufacturer. Data are reported for those filter manufacturers that supplied >100 filters for both fiscal years combined. The reported range of acceptance with waiver was 0-2.2% with an overall rate of 0.18%. Rejection rates ranged from 0-14.0%.

TABLE 2
Summary
Test Results Grouped by Manufacturer
>100 Filters

Manufacturer	No. Tested	No. Accepted w/Waiver	%	Range %	No. Rejected	%	Range %
Flanders	13,790	2	0.01	0-<1	157	1.1	1.1 - 1.2
American Air*	2,107	30	1.4	0-2.2	290	13.8	14
Cambridge**	1,954	0	0	0	39	2.0	1.3-4.3
HAKO***	114	0	0	0	12	10.5	0-14.0
TOTALS	17,965	32	0.18		498		2.77

* Of the 290 rejected American Air Filters, only 28 (1.4%) were rejected for performance criteria, penetration.
** Cambridge Filters, Inc. was acquired by Farr Company in 1991.
*** HAKO supplied filters for vacuum cleaner applications only and rejections were attributed to loose filter packs and penetration.

Table 3 lists the 8 filter sizes with the associated nominal flow in cubic feet per minute (cfm) and ranges of flow to accommodate the seperatorless type of filter units.

TABLE 3
Filter Size

Size	Nominal Flow - CFM	Flow Range - CFM
1	25	<37.5
2	50	37.5 - <87.5
3	125	87.5 - <312.5
4	500	312.5 - <750
5	1000	750 - <1125
6	1250	1125 - <1375
7	1500	1375 - <1750
8	2000	≥1750

The summary of the number of filters tested by size is illustrated in Table 4 and includes the 249 filters categorized for non environmental protection or non nuclear applications. As with past fiscal years, the majority of the workload is represented by Size 5 filters followed by the categories of Size 2 and Size 3 filters, respectively. The Size 5 filters represent 72.3% of the total workload with an overall rejection rate of 3.0%, Size 2 filters represent 10.3% of the work load with a 0.70% rejection rate and Size 3 filters represent 8.9% of the work load with 1.8% rejection rate.

TABLE 4
Summary - Number of Filter Tested by Size
FY 1990 FY 1991

Size	No. Tested	No. Accepted w/Waiver	%	No. Rejected	%	% Total
1	996	0	0	33	3.3	5.4
2	1,876	0	0	14	0.7	10.3
3	1,619	20	1.2	29	1.8	8.9
4	315	0	0	8	2.5	1.7
5	13,229	32	0.2	397	3.0	72.3
6	188	0	0	4	2.1	1.0
7	78	0	0	25	32	0.4
8	0	0	0	0	0	0
TOTAL	18,301	52	0.28	510	3.0	100.0

C. Multi-year Semi-Annual Report Data Trend Analysis

Beginning with FY 1990, the FTF semi-annual report filter acceptance - rejection data base was sufficient to merit additional statistical trend analysis in comparing historical FTF and manufacturer data. Trend analysis was performed on the data in two ways, first to determine trends between the FTFs for each filter size and manufacturer for filter rejection data and second to determine trends between manufacturer within each FTF for each filter size rejection data. Trend analysis is reported for manufacturers supplying >100 filters. The manufacturers reported include Flanders Filters, Inc., American Air Filter, Company, Cambridge Filters, Inc. and HAKO. This trend analysis is of potential benefit to DOE in substantiating consistencies among the FTFs and the quality of filters provided by manufacturers over a longer period of time. In essence it provides a multi-year trend analysis.(10)

The trends between the FTFs for each filter size and manufacturer are shown in Table 5. The trends indicate that patterns in filter rejection data are beginning to develop. For Size 1 filters, the Oak Ridge FTF demonstrates a higher rejection rate for Cambridge Filters, Inc. than Hanford and Rocky Flats FTFs. Since FY 1986, the Rocky Flats FTF has demonstrated a lower rejection rate for Size 2, Flanders Filters, Inc. filters than the Oak Ridge and Hanford FTFs. Rocky Flats also demonstrates a lower rejection rate for Size 4 Flanders Filters, Inc. with the exception of FY 1985. The Oak Ridge FTF demonstrated a lower rejection rate for Size 4 filters for both Flanders Filters, Inc. and American Air Filter, Company and the Size 5, American Air Filter, Company filters rejection rate is on an upward trend when compared with the other two FTFs. The Hanford FTF demonstrates a high rejection rate for Size 5 Flanders Filters, Inc. filters when compared with the other two FTFs with the exception of one fiscal year, FY 1991.

TABLE 5
Trends Between FTFs
Filter Rejection Rate Data
Manufacturer >100 Filters

Filter Sizes	FTF Rocky Flats	Oak Ridge	Hanford
1	*	Cambridge High	*
2	Flanders Low	*	*
3	*	*	*
4	*	Flanders & AAF** Low	*
5	*	AAF Upward	Flanders High
6	Flanders low	*	*
7	*	*	*

*Indicates that no overall trend is apparent at this time.
**American Air Filter Company (AAF)

The trends between manufacturers filter rejection data for each filter size tested at the three FTFs is shown in Table 6. The majority of the trends are attributed to Flanders Filters, Inc. filters. Trend analysis indicated that for Flanders Filters, Inc. Size 1 filters, the Rocky Flats FTF rejection rate was high until FY 1987 when compared with the other manufacturers. For Flanders Filters, Inc. Size 2 filters, the Rocky Flats FTF demonstrates a low rejection rate since FY 1987. Both the Hanford and Oak Ridge FTF had lower rejection rate for Size 3 Flanders Filters, Inc. when compared with other manufacturers. All three FTFs demonstrated lower rejection rates for Flanders Filters, Inc. Size 5 filters. The Oak Ridge and Rocky Flats FTFs demonstrated low rejection rates for Flanders Filters, Inc. Size 6 filters and Size 7 filters at the Oak Ridge FTF when compared with the other manufacturers.

Statistical trend analysis indicated that two trends were apparent for American Air Filters, Company both occurring at the Oak Ridge FTF. The first trend is Size 4 filters where Oak Ridge FTF rejection rate is low for the time period FY 1987 - FY 1991 and the second trend is for Size 5 filters where Oak Ridge FTF demonstrates an overall high rejection rate for FY 1984 - FY 1991 when compared with the other manufacturers.

For Cambridge Filter, Inc., four statistical trend analysis were apparent. For Size 1 filters, the Rocky Flats FTF reported a low rejection rate until FY 1987 when compared to the other manufacturers. The Oak Ridge FTF reported an overall high rejection rate for Cambridge Filter, Inc. Size 3 filters, low rejection rate for FY 1985 - FY 1987 for Size 4 filters and low rejection rates for Size 5 filters when compared to the other filter manufacturers.

TABLE 6
Trends Between Manufacturers
Filter Rejection Rate Data
Rocky Flats (RF), Oak Ridge(OR) and Hanford(H)
FTFs

Filter Size	Manufacturer			
	Flanders	American	Cambridge	HAKO
1	RF High	*	RF Low	*
2	RF Low	*	*	*
3	OR, H Low	*	OR High	*
4	*	OR Low	OR Low	*
5	RF,OR, H Low	OR High	OR Low	*
6	RF & OR Low	*	*	*
7	OR Low	*	*	*

*Indicates that no overall trend is apparent.

D. Status of the High Flow Alternative Test System

The research, development and intent for implementation of the High Flow Alternative Test System (HFATS) as an approved DOE test method has been reported and published at previous Air Cleaning Conferences[7, 8, 11, 12, 13]. Since the 21st DOE/NRC Nuclear Air Cleaning conference, the following items have been completed to qualify the HFATS as an approved DOE test method:

1. Installation and prooftesting of the HFATS at the Hanford FTF completed, November 1990.

2. Initial HFATS RRT, December 1990. Results indicated that the HFATS statistically demonstrated a higher degree of reproducibility and comparability than the Q107 penetrometer.

3. Presentation of the collective HFATS summary data to the DOE Nuclear Standards Technical Review Committee (TRC) completed, July 1991. Conclusions of the summary report indicated that the HFATS meets the requirements of Annex 6 of NE F 3-43, the HFATS at all three FTFs compare well with the HFATS prototype, the HFATS shows better reproducibility and comparability than the Q107 penetrometer at the FTFs, and DOE should therefore be petitioned to accept the HFATS for use at the FTFs. The TRC suggested that the TSG perform readiness reviews at all three of the FTFs before implementing the HFATS.

4. Ballots sent to the TRC, August 1991. All but one were in favor of adopting the HFATS and there was one abstention. This marks the completion of compliance with all the applicable DOE requirements.

5. FTF Coordinator petitioning DOE to concur in the decision to adopt the HFATS as an authorized test method, November 1991.

6. FTF Coordinator and LANL representative visit the Hanford and Rocky Flats FTF to perform readiness reviews for implementation of the HFATS. It was noted that both facilities required training programs and operating procedures. Review of the operating procedures, training programs, and documentation that the operators have been trained will result in the implementation of the HFATS at the Hanford and Rocky Flats FTF, December 1991.

7. FTF Coordinator and LANL representative visit to the Oak Ridge FTF. Documentation indicated that the Oak Ridge FTF after training personnel is ready to implement the HFATS, May 1992.

At this time, all three FTFs require completion of the HFATS written training programs and training of FTF technicians before authorization to use the HFATS as the DOE approved test method can be granted. Without unforeseen program delays, it is anticipated that all three FTFs will be authorized to use the HFATS by September 1, 1992.

E. Revision of DOE Nuclear Standards

The four DOE HEPA Filter Nuclear Energy (NE) Standards developed in 1981, governing the procurement and testing of HEPA filters for DOE facilities have recently been revised. The revision took place from March through November 1991. The standards have been in use since 1983, issued under Defense Waste Management (AR0515050) and published by the Performance Assurance Project Office, Oak Ridge National Laboratory. The recent 1991 revisions include a

mechanism and method for approving new test mediums and methods. The standards are now performance type standards instead of prescriptive type. Issuance of the standards is pending DOE decision to first issue the standards as Office of Defense Programs (DP) Limited Standards with later conversion of the standards to the new DOE Standards program or to issue the standards in the new DOE Standards program[18].

III. Quality Assessment Review for In-place Testing of HEPA Filters at DOE Selected Facilities

In response to the need for a comprehensive HEPA filter program within DOE, DOE funded a HEPA Filter Technical support (HEPA FTS) program at Los Alamos National Laboratory. The intent of a comprehensive HEPA filter program is to provided assurance that from fabrication to disposal, all HEPA filters used by DOE provide the highest quality and measure of environmental protection. This program is an expansion of a DOE program that provided technical support to DOE FTFs and development of modern quality assurance (QA) HEPA filter test systems.

Specific tasks of the HEPA FTS included a technical quality assessment review of in-place testing of installed HEPA filters at five DOE selected facilities: Los Alamos National Laboratory, Savannah River and Hanford (Westinghouse Hanford 200 and 300 area, Battelle - Pacific Northwest Laboratory and Hanford Environmental Health Foundation) in FY 1991 followed by Lawrence Livermore National Laboratory and Oak Ridge National Laboratory and associated Oak Ridge facilities (Y-12 and K-25) in FY 1992.

The elements of this quality assessment included reviewing DOE Orders, Standards and reference documentation for specific criteria required for in-place testing, and review, evaluation and observing in-place testing and associated procedures, practices and records for elements of compliance with DOE Orders and Standards. A review of supporting documentation indicated that DOE's guidance to contractors includes the DOE Order 6430.1A "General Design Criteria"[19], ERDA 76-21 "Nuclear Air Cleaning Handbook"[20] and the national consensus standards ASME N509 1989 "Nuclear Power Plant Air Cleaning Units and Components,"[21] and ASME N510, 1989 "Testing of Nuclear Air Cleaning Systems."[22] DOE's guidance documents are excellent sources for compliance of systems that are ASME N509 fabricated and ASME N510 testable, but guidance is not provided for nuclear air cleaning systems within the DOE system that are not constructed to ASME N509. Review of the Session 5, "How to Use N510 Testing Methods and Acceptance Criteria for Air Treatment Systems Not Constructed According to N509" at the 21st DOE/NRC Nuclear Air Cleaning Conference [23-28] assisted in providing the basic guidance prior to Los Alamos performing the technical quality assessment at each facility.

A summary of the technical quality assessment review of the five DOE selected sites included the evaluation of in-place testing procedures for implemented test methods and associated test criteria and documentation. Highlights of the evaluation are listed below:

1. Evaluation of the selected DOE contractors procedures indicated that the present test methods for in-place testing of installed HEPA filters used by the five DOE selected sites include systems testing using N510-1989 single-point sampling method for systems fabricated to N509-1989, application of N510 single-point sampling method for systems that are not constructed in accordance with N509, multi and modified multi

sampling test method prescribed in N510-1980, ANSI N101.1 - 1972 test methods and DOE NE F 3-41T Standard laser spectrometer method (presently the method is in the process of conversion to a ASTM standard)[29,30]. All contractors procedures and test methods met the intent of N510.

2. System acceptance criteria for Los Alamos National Laboratory, Savannah River and Hanford sites are established at a maximum penetration of $5x10^{-4}$ (decontamination factor of 2,000) for one stage of filtration and $2.5x10^{-7}$ (decontamination factor of 2,000 for each stage) for two stages in series. The Lawrence Livermore National Laboratory and Oak Ridge Y-12 established acceptance criteria is a maximum penetration of $3x10^{-4}$ (decontamination factor of 3333) for each filter stage.

3. All DOE contractors testing documentation followed the guidelines specified in N510.

In conclusion, the information gained from the quality assessment reviews indicated that a DOE guidance standard is required to include all acceptable test methods currently used by DOE contractors. The only currently approved test method is the N510 single-point sampling method. Participation by DOE contractors would assist in preparation of a standard for DOE approval.

IV. In-place Testing Standards Writing Group

A recommendation following the technical quality assessment review included establishing a Standards Writing Committee of DOE contractors and Technical Review Committee of industry recognized experts on in-place testing and aerosol technologists. The intent of the Writing Group is to develop a DOE in-place testing standard that provides for consistency of test methods and system acceptance criteria determined acceptable for DOE facilities with appropriate technical review. Under the direction of DOE, Los Alamos National Laboratory is currently funded to coordinate an in-place testing standards writing group. The Writing Group will issue a draft standard for technical review in the first quarter FY 1993. The Technical Review Committee is in the process of being established. The current writing group includes the following participants:

Project Manager

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DP-622
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Project Support

H. Moseley
Project Assurance Project Office
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J. Ortiz
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B. Bettencourt
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J. Stacy
Westinghouse Hanford

K. Slape
Hanford Environmental Health Foundation

M. Garcia
EG&G Idaho, Inc.

J. Fretthold
EG&G Rocky Flats, Inc.

V. Summary

In summary, the FTF and FTF TSG continue to provide services to DOE assuring that the critical quality component, the HEPA filter, performs to established standards. The HFATS, as a new DOE test method is ready for implementation at the three DOE FTFs. Implementation is expected to occur by the first of FY 1993.

The quality assessment of in-place testing at DOE facilities indicates that the facilities reviewed to date has provided the basis for writing a DOE in-place testing standard. A Writing Committee has been established with the intent of writing a standard that will ensure the uniformity of in-place testing of nuclear air cleaning system throughout the DOE complex. The Writing Committee met the third week of July 1992, to produce a draft DOE in-place testing standard scheduled for distribution and review to the Technical Review Committee and interested industry personnel.

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DISCUSSION

BERGMAN: Concerning the high flow alternative test system, HFATS, that are in all the three filter test stations, did I understand you correctly that they will be implemented to replace the current DOP photomometer test. And if that is correct, what is the particle size you are going to zero in on for the HFATS?

McINTYRE: Yes, the high flow alternative test system (HFATS) is installed at all FTFs. It has been proof-tested, round robins have been conducted. The particle size will be that of maximum penetration in accordance with DOE Standards.

GILBERT: This list of manufacturers is a departure from prior use of coded manufacturers' names, ABCD. Who is HAKO?

McINTYRE: HAKO is a manufacturer of vacuum cleaner filters.

GREENE: Is an annual report available for the last two fiscal years showing your quality assurance surveillance testing results at various sites?

McINTYRE: One, for 1991 and the 1992, will be written for distribution in October.

GREENE: Can we get one from you?

McINTYRE: Yes, it will be available from me on request.

CHRONIC INHALATION STUDIES OF MAN-MADE VITREOUS FIBERS

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Abstract

Inhalation studies were conducted to determine the chronic biological effects in rodents of respirable fractions of several man-made vitreous fibers (MMVFs) having compositions representative of commercial insulation products. Rats were exposed nose-only, six hrs/day, five days/week, for 24 months to several concentrations (3 to 30 mg/m^3) of refractory ceramic fiber (RCF) or fibrous glass (FG). Positive control rats were exposed to chrysotile asbestos (10 mg/m^3) and negative controls to filtered air. At three to six-month intervals, interim sacrifices took place to monitor progression of pulmonary changes and to analyze lung fiber burden. Lung fibrosis was evident within three months of initial exposure to chrysotile asbestos and within six months of exposure to 30 mg/m^3 RCF. The highest exposure level of RCF and asbestos also induced an elevation in lung tumors and pleural mesotheliomas by the end of the study. A single mesothelioma was observed in animals exposed to 9 mg/m^3 of RCF.

In the FG study, the only exposure-related effect was a dose-related increase in mild lung cellularity that did not appear to progress after six months of exposure. These cellular changes are thought to be reversible and are similar to the effects observed after inhalation of an inert dust. No lung fibrosis or mesotheliomas were observed in the FG exposed animals. When FG exposed groups were compared to negative controls, there was also no statistically significant increase in lung tumor incidence. The negative FG results are especially significant in view of the similarities in lung fiber burdens for the FGs and the RCF. These data suggest that the chemical composition of MMVFs is an important determinant of their toxic potential to the lung.

Introduction

There is a logical concern about the safety of any material which has the potential to release particles or vapors that can be inhaled. Because fibrous materials can fall into this category, many studies have been and continue to be conducted to evaluate the possible health risks of such materials. The present studies are part of a series of investigations into the chronic inhalation

effects of the three major categories of man-made vitreous fibers (MMVFs).

MMVFs are fibrous inorganic substances that are made primarily from rock, clay, slag, or glass. The three major classes of MMVF are refractory ceramic fibers (RCFs), fibrous glass, and rock/slag wool. RCFs are of particular value in high temperature, industrial environments. A variety of RCF types are produced by altering the proportions of alumina and silica with other refractory oxides. Fibrous glass is the largest category of the MMVFs. Respirable fractions of fibrous glass are found in glass wools, which are used in insulation, air handling, filtration and sound absorption.

RCF toxicity has been evaluated in three previous chronic inhalation studies, one using rats (Davis, et al., 1984), one using rats and hamsters (Smith, et al., 1987), and the third using hamsters (Hesterberg, et al., 1991a). One mesothelioma was observed in a rat in the Davis study and in a hamster in the Smith study. The two studies differed sharply in the incidences of pulmonary tumors. In the third study, RCF1 (kaolin) induced mesotheliomas in the lungs of 42% of the hamsters as well as pulmonary fibrosis (Hesterberg, et al., 1991a).

A variety of fibrous glass compositions have also been evaluated in animal inhalation models (Gross, et al., 1970; Lee, et al., 1981; Wagner, et al., 1984; McConnell, et al., 1984; Mitchell, et al., 1986; Muhle, et al., 1987; Le Bouffant, et al., 1987; Smith, et al., 1987). None of these studies identified a significant increase in either fibrosis or neoplasms following glass fiber inhalation in spite of FG lung burdens in excess of several hundred thousand fibers/mg dry lung tissue. As with the study described in this paper, the results of all of these studies demonstrated the absence of any significant adverse health effects following glass fiber inhalation.

However, because of technical limitations, no single previous study was considered adequate by the EPA for health risk classification of FG (Vu, 1988). In particular, there was a lack of comparative dose-response effects with asbestos or other carcinogenic fibers. ; Therefore, in accordance with the recommendation of the EPA, the present studies were initiated.

Materials and Methods

Fibers

A single composition of refractory ceramic fiber (RCF 1) and two fibrous glass compositions (MMVF 10 and MMVF 11) were presized so that they would be comparable to the dimensions of fibers found in workplace air and also rat respirable. Positive control animals were exposed to intermediate length NIEHS chrysotile asbestos (Jeffrey Mine, Asbestos, Quebec).

Fiber Aerosol Exposure

Rats were exposed in nose-only inhalation chambers, 6 hrs/day, 5 days/week, for 24 months to various concentrations of test fiber. Target concentrations were 3, 9, 16, or 30 mg/m^3 for RCF and 3, 16, and 30 mg/m^3 for the two fibrous glass compositions (MMVF 10 and MMVF 11). Negative control rats were exposed similarly to filtered air. Positive controls were exposed to 10 mg/m^3 of chrysotile asbestos. Aerosol concentrations were monitored at the level of the animal's nose for both fiber mass (mg/m^3) and fiber number (fibers/cm^3). Fiber size distributions were determined on a quarterly basis using scanning electron microscopy. Aerosol concentrations and fiber size distributions of the RCF aerosol are shown below in Table 1.

Table 1. RCF Aerosol Characteristics
Means±Standard Deviation

Exp. Grp.	Average Aerosol		Means	
	mg/m3	WHO fibers/cc	Diameter (μm)	Length (μm)
Geometric			0.82 ± 1.89	13.7 ± 2.4
Arithmetic			0.98 ± 0.15	22.3 ± 4.2
1	3.0 ± 0.4	26 ± 12		
2	8.8 ± 0.7	74 ± 36		
3	16.5 ± 1.1	115 ± 31		
4	29.2 ± 5.9	187 ± 53		

Aerosol concentrations and fiber size distributions of the two fibrous glass aerosols (MMVFs 10 and 11) are shown below in Table 2.

Table 2. Fibrous Glass Aerosol Characteristics

Exp. Grp.	Means±Standard Deviation			
	Average Aerosol		Means	
	mg/m3	WHO fibers/cc	Diameter (μm)	Length (μm)
MMVF 10				
Geometric			1.22 ± 0.14	12.4 ± 2.2
Arithmetic			1.40 ± 0.13	16.5 ± 3.0
Low	3 ± 0	29 ± 8		
Medium	15 ± 1.0	145 ± 35		
High	28 ± 1.0	232 ± 57		
MMVF 11				
Geometric			0.68 ± 2.10	12.0 ± 2.3
Arithmetic			0.90 ± 0.06	16.7 ± 2.4
Low	3 ± 0	41 ± 29		
Medium	16 ± 1.0	153 ± 69		
High	28 ± 1.0	246 ± 76		

Animals - Weanling Fischer 344 male rats, obtained from Charles River were randomly distributed into the exposure groups. Following the 24-month exposure, the animals were held for lifetime observation (until ~20% survival), and were then sacrificed and examined. Rats were euthanized via intraperitoneal injection of pentobarbital sodium.

Pathology - Three to six rats were randomly selected from each exposure group and killed at 3, 6, 12, 18, and 24 months. A complete necropsy was performed on each animal and pathology observations were made on a number of different organs. Lungs were removed in to, sectioned and stained with hematoxylin and eosin (H&E) and Masson's trichrome stain for collagen deposition. Histopathology of the lungs was examined and each lung was given a Wagner Pathology Grading Score (Figure 1) in accordance with the guidelines presented at the WHO Conference on "Biologic Effects of Man-made Mineral Fibres" in 1982 (McConnell, et al., 1984).

Figure 1. Wagner Pathology Grading Scale

Cellular Change:	Normal	1	No lesion
	Minimal	2	Macrophage response
	Mild	3	Bronchiolization, inflammation
Fibrosis:	Minimal	4	Minimal fibrosis
	Mild	5	Linking of fibrosis
	Moderate	6	Consolidation
	Severe	7	Marked fibrosis and consolidation
		8	Complete obstruction of most airways

Lung Burden Analysis

Immediately after necropsy, the infracardiac lobe of each animal's lung was removed and frozen for later analysis of lung fiber burden. To recover fibers from the lung, the tissue was rapidly dehydrated with acetone and ashed using a low-temperature process. Recovered fibers were dispersed in distilled water and examined using scanning electron microscopy. Number, dimensions and other physical characteristics of the inhaled lung fibers were determined.

Results

Refractory Ceramic Fiber Study

Histopathology - At the three-month sacrifice, the various RCF treatment groups showed a dose-related increase in lung cellularity (pulmonary change grades from 2 to 3.3 on the Wagner Scale, Table 3). Animals exposed to chrysotile asbestos (10 mg/m^3) at the three-month time-point were given a grade 4, indicating lung fibrosis. At the six month sacrifice, the lungs of animals exposed to 16 mg/m^3 or less RCF showed a minimal progression of the pulmonary alterations observed at three months. In contrast, the lungs of the 30 mg/m^3 RCF animals had progressed to minimal fibrosis (Wagner grade 4).

Table 3. Pathology Scores (Wagner Scale) After RCF Exposure

		RCF Concentrations (mg/m^3)				Chrysotile
Time	Air	3	9	16	30	10 mg/m^3
3 Mo	1.0	2.0	2.3	3.0	3.3	4.0
6 Mo	1.0	2.0	2.7	3.0	4.0	4.0
12 Mo	1.0	3.0	4.0	4.0	4.0	4.0
18 Mo	1.0	3.2	4.0	4.0	4.0	4.0
24 Mo	1.0	3.2	4.0	4.2	4.0	4.0
Terminal	1.0	2.9	3.8	4.2	4.0	4.0

By the 12-month sacrifice, all but the low dose RCF group (3 mg/m^3) had developed minimal lung fibrosis (Wagner grade 4). The lung pathology scores did not change appreciably from the 12-month to the 24-month sacrifices. The terminal sacrifice (animals held without further exposure for six months after the cessation of inhalation treatment) pathology scores were also very similar to the 18 and 24 month time-points (Table 3).

In addition to the lung fibrosis observed in animals exposed to 9 mg/m^3 or higher levels of RCF, a significant increase in lung tumors (adenomas and carcinomas) and the two pleural mesotheliomas (1.6%) were observed in animals exposed to 30 mg/m^3. In addition, one pleural mesothelioma was found in the 9 mg/m^3 RCF group. Chrysotile exposed animals developed pulmonary fibrosis, a 17.4% incidence of lung tumors, and one mesothelioma (1.6%). Results of

the chronic inhalation study of RCF in rats served to validate this model system for assessing both fibrotic and tumorigenic properties of other MMVFs.

Table 4. Summary of Lung Tumor Findings in RCF Study

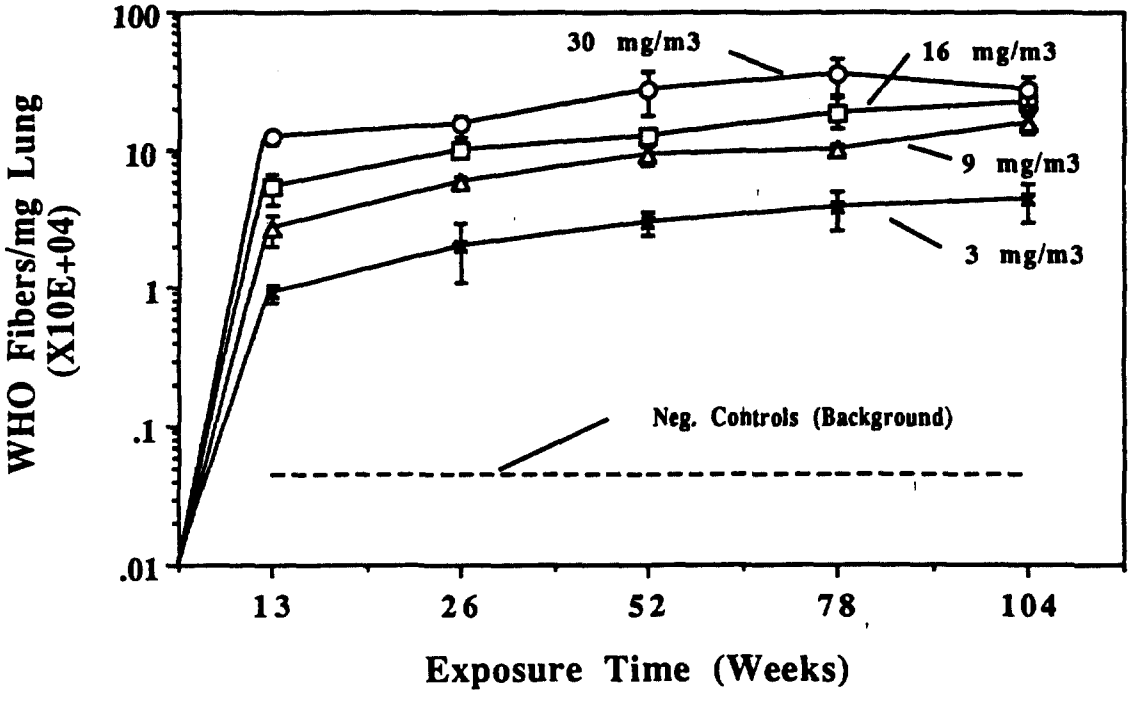
Fiber Group	Adenoma	Carcinoma	Total Lung Tumors	Mesothelioma
Air Control 1*	2 (1.5%)	0	2 (1.5%)	0
Air Control 2*	1 (0.8%)	0	1 (0.8%)	0
Chrysotile	6 (8.7%)	6 (8.7%)	12 (17.4%)	1 (1.4%)
RCF 1 (3 mg/m^3)	3 (2.4%)	0	3 (2.4%)	0
RCF 1 (9 mg/m^3)	3 (2.4%)	2 (1.6%)	5 (3.9%)	1 (0.8%)
RCF 1 (16 mg/m^3)	1 (0.8%)	1 (0.8%)	2 (1.6%)	0
RCF 1 (30 mg/m^3)	8 (6.5%)	8 (6.5%)	16 (13.0%)	2 (1.6%)

* Air Control 1 was the negative control group used with the 30 mg/m^3 RCF group, while the Air Control 2 was used with the other three RCF exposure groups (3, 9, and 16 mg/m3).

RCF Lung Burden Analyses

The RCF lung fiber burden data is expressed as the number of WHO fibers per mg dry lung weight and is graphed in Figure 2. The accumulation of fibers in the lung reached steady state after six to 12 months of exposure. The steady state number of fibers per mg dry weight of lung increased linearly with dose. The maximum number of fibers ($2.8 \pm 0.6 \times 10^5$ fibers/mg) was observed in the lungs of animals exposed to 30 mg/m^3 of RCF for 24 months.

Figure 2. RCF 1 Lung Burden



Fibrous Glass Study

Histopathology - No lung fibrosis or mesotheliomas were observed in the FG (MMVF 10 or 11) exposed animals. When FG exposed groups were compared to negative controls, there was also no statistically significant increase in lung tumor incidence. The negative FG results are especially significant in view of the similarities in lung fiber burdens for the FGs and the RCF.

The first evidence (3 months) of fiber-induced, microscopic changes in the lung consisted of a dose-related influx of pulmonary macrophages. Occasional microgranulomas were noted along the walls of the alveolar duct in the high dose groups of both FGs. A minimal amount of alveolar bronchiolization was observed in the high dose MMVF 11 group. A Wagner grade of 2.0 was given to each of the groups except the high dose MMVF 11, which was given a grade of 3.0 (Table 5).

Table 5. Pathology Scores (Wagner Scale) After Fibrous Glass Exposure

	MMVF 10 Concentration (mg/m^3)				MMVF 11 Concentration (mg/m^3)			Chrysotile Asbestos*
Time	3	16	30	Air	3	16	30	10 mg/m^3
3 Mo	1.0	2.0	2.0	1.0	1.0	2.0	3.0	4.0
6 Mo	1.0	2.7	3.0	1.0	1.3	2.3	3.0	4.0
12 Mo	2.2	3.0	3.0	1.0	2.2	3.0	3.0	4.0
18 Mo	2.7	3.0	3.0	1.0	2.5	3.0	3.0	4.0
24 Mo	2.2	2.7	3.0	1.0	2.5	2.7	2.5	4.0
Term.	2.2	2.8	2.7	1.0	1.9	2.1	2.4	4.0

* These chrysotile results are from RCF MTD Inhalation Study conducted in parallel.

After six months exposure there was a slight increase in the macrophage response and number of microgranulomas. Bronchiolization was noted in both the MMVF 10 and 11 high dose rats. Fibers were present in many macrophages and within the interstitium. Short fibers were also noted in macrophages within the peribronchial lymphoid sheaths. At six months the overall lung response was similar for both FG types, ranging from Wagner grade 2.0 for the low dose to 3.0 for the high dose (Table 5).

At 12 months the macrophage and microgranuloma responses were slightly more intense. Bronchiolization was noted in the mid dose as well as the high dose lungs of both MMVFs 10 and 11. Average Wagner grades were 2.5 for low-dose of both types of fibers and 3.0 for the mid- and high-dose groups. At 18 and 24 months the pulmonary changes observed were comparable to those observed at 12 months for all dose groups (Table 5).

The primary difference seen in the rats killed at the end of the study (those animals removed from exposure at 24 months and held until the terminal sacrifice at 29 months, i.e., terminal sacrifice) was a reduction in the severity of the macrophage response in all the FG exposure groups. This was also true for the "recovery" group rats (those animals removed from exposures at various times and sacrificed at 24 months). There was no evidence of treatment related interstitial lung fibrosis at any time point in the study.

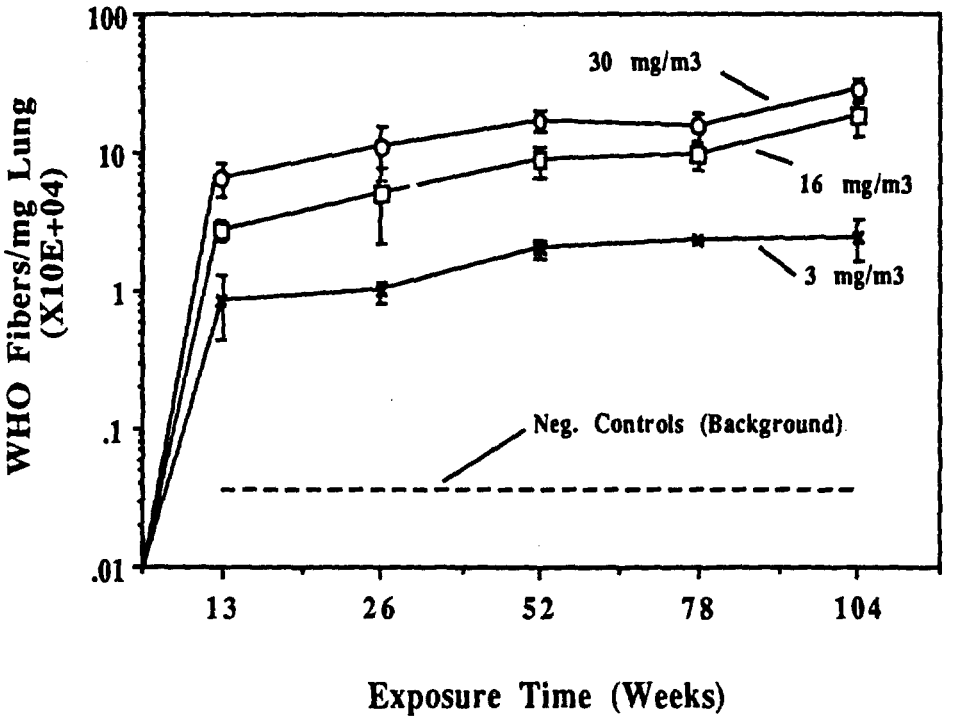
In addition to the finding of no interstitial lung fibrosis in the FG exposure groups, there were no mesotheliomas, nor was there a statistically significant elevation of lung tumor incidence (Table 6).

Table 6. Incidence of Thoracic Tumors in Animals at Risk for Tumor Formation.

Exposure Group	No. Animals	No. Adenomas	No. Carcinomas	Total Lung Tumors	No. Mesotheliomas
Air Controls	123	3 (2.4%)	1 (0.8%)	4 (3.3%)	0
MMVF 10					
3 mg/m^3	117	0	0	0	0
16 mg/m^3	118	1 (0.8%)	0	1 (0.8%)	0
30 mg/m^3	119	6 (5.0%)	1 (0.8%)	7 (5.9%)	0
MMVF 11					
3 mg/m^3	118	3 (2.5%)	1 (0.8%)	4 (3.4%)	0
16 mg/m^3	120	6 (5.0%)	3 (2.5%)	9 (7.5%)	0
30 mg/m^3	112	3 (2.7%)	0	3 (2.7%)	0

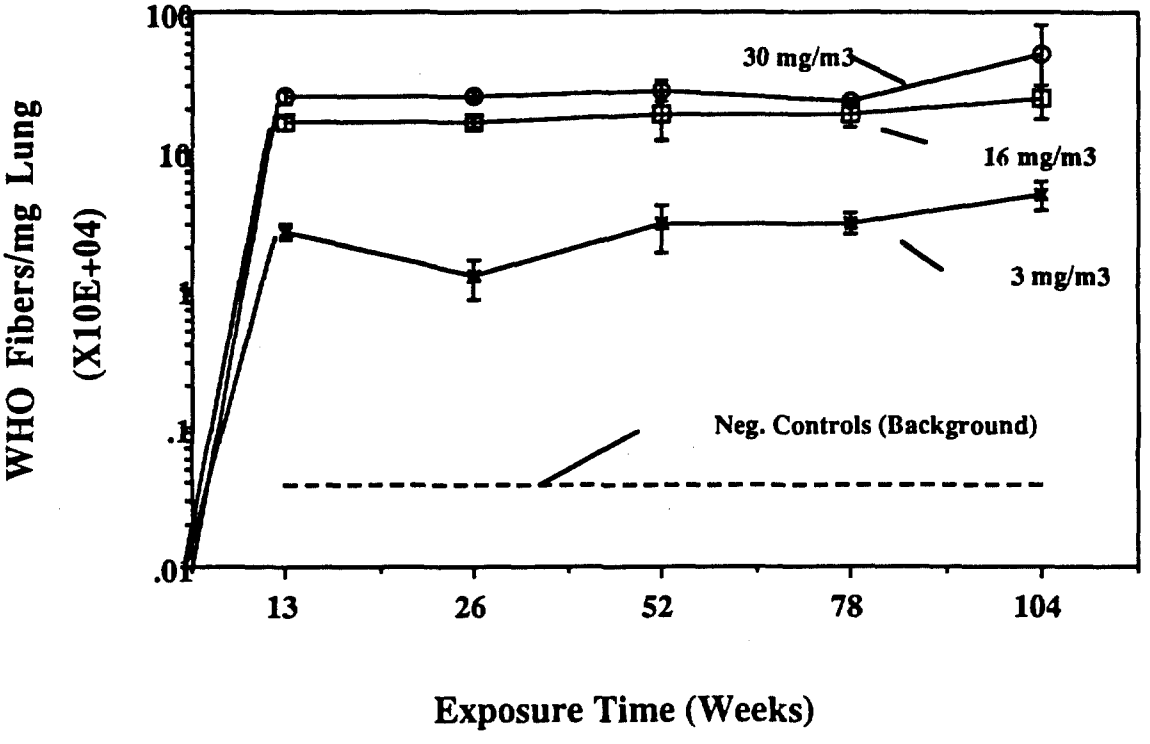
FG Lung Burden Analyses - The FG lung fiber burden data is expressed as the number of WHO fibers per mg dry lung weight and is graphed in Figures 3 and 4. The steady state number of fibers per mg dry weight of lung was reached after 12 months and increased linearly with dose. The maximum number of fibers ($2.9 \pm 0.6 \times 10^5$ fibers/mg) was observed in the lungs of animals exposed to 30 mg/m^3 of MMVF 10 for 24 months.

Figure 3. MMVF 10 Lung Burden



Lung burden for MMVF 11 was consistently higher than for MMVF 10, for each dose group (low, medium and high) and at each exposure time. The steady state number of fibers per mg dry weight of lung was reached after three months and increased linearly with dose. The maximum number of fibers ($5.0 \pm 2.9 \times 10^5$ fibers/mg) was observed in the lungs of animals exposed to 30 mg/m^3 of MMVF 11 for 24 months.

Figure 4. MMVF 11 Lung Burden



Discussion

In the present study, RCF induced pulmonary fibrosis and significant increases in lung tumors in a rodent chronic inhalation model. Pleural mesothelioma formation was also associated with RCF exposure. In parallel studies using the same animal model, two different compositions of glass fibers failed to produce pulmonary fibrosis or a significant increase in lung tumors (fiber dimensions and doses of FG were matched to those of RCF). The only exposure related finding in the FG-exposed animals was a dose-dependent increase in mild cellularity in the lungs that did not appear to progress after six months of exposure. These cellular changes are reversible and are similar to the effects observed after inhalation of an inert dust. The FG study has been reported in more detail elsewhere (Hesterberg, et al., 1992).

The chronic toxicity of 30 mg/m^3 of another RCF composition (RCF 3) has been reported previously (Hesterberg, et al., 1991b, Mast, et al., 1992) and is compared to 30 mg/m^3 of one of the fibrous glass compositions (MMVF 11) in Table 7. Fiber concentrations in the aerosol and in the lung of FG and RCF exposed animals were comparable. However, pulmonary interstitial fibrosis

and significant increases in lung tumors and mesotheliomas were only found in the RCF exposed animals. These results demonstrate that chemical composition is an important determinant of fiber toxicity in the lung.

Table 7. Comparison of Chronic Inhalation Toxicity of Fibrous Glass and RCF

Fiber Group	Aerosol[1] Fiber No. (WHO)	WHO Lung[2] Fibers ($X10^4$)	Wagner[3] Score	Total Lung Tumors[4]	Mesotheliomas[4]
Air Control [5]	ND	-	1.0	4 (3.3%)	0
Air Control [6]	ND	-	1.0	2 (1.6%)	0
MMVF 11 (30 mg/m^3)	246	28	3.0	3 (2.7%)	0
RCF 3 (30 mg/m^3)	182	21	4.2	18 (14.9%)	2 (1.7%)

[1] All aerosols averaged over the study are expressed as fibers/cc
[2] All lung burdens at 52 weeks expressed as fibers/mg dry tissue X 10^4, background controls had 200-600 f/cc
[3] Wagner Pathology Score at 52 weeks
[4] Tumor findings at the end of the study
[5] Air control animals from the Fibrous Glass Multidose Study
[6] Air control animals from the RCF MTD Study

In conclusion, these findings demonstrate that this advanced rodent inhalation model provides a sound basis to identify the potential hazards of fibrous materials in man. Further, these results demonstrate the toxicologic potential of a MMVF is dependent upon its chemical composition. And finally, these results suggest that respirable fibrous glass represents no significant hazard for fibrotic or neoplastic disease in humans.

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EFFECTS OF FILTER HOUSING AND DUCTWORK CONFIGURATION ON AIR FLOW UNIFORMITY INSIDE AIR CLEANING FILTER HOUSINGS (U)

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ABSTRACT

Each new HEPA filter installation presents a different physical configuration based on the system requirements, the available space and designer preference. Each different configuration can result in variations of air flow uniformity inside the filter housing across the filter banks. This paper will present the results of air flow uniformity testing for six different filter housing/ductwork configurations and discuss if any of the variations in air flow uniformity is attributable to the difference in the physical arrangements for the six cases.

INTRODUCTION

Achieving air flow uniformity across filter banks is important to ensuring the filters achieve their required performance over the filter changeout cycle. ASME N510-1989 entitled "Testing of Nuclear Air Treatment Systems" gives the acceptance criteria of +/- 20% for the maximum allowable deviation of air flow uniformity across a multiple filter system. Uneven air flow distribution across the filter banks can lead to uneven dust loading of the filters within the housings and result in a more frequent filter changeout than would be required if the air distribution were uniform. It can also result in reduction in the required air residence time in carbon adsorbers, thus reducing their ability to remove radioactive iodine.

DESCRIPTION OF AIR FLOW UNIFORMITY TESTING

At the Savannah River Site, HEPA filter housings that are part of nuclear air cleaning systems are required to successfully pass the air flow uniformity testing prior to system turnover for operation in accordance with the requirements of ASME N509-1989 and ASME N510-1989.

Savannah River's nuclear air cleaning HEPA filter housings are bag-in bag-out side loaded. The acceptance testing for air flow uniformity on these housings is performed with the use of an air flow measuring grid (which measures velocity pressure downstream of the HEPA filters) which is inserted through an opening in a clear lexan fabricated bulkhood door. This door is used to replace the vendor's stainless steel side access door during the

unformity testing. The velocity pressures are recorded and averaged and the data is placed in tabular form similar to the six cases presented.

The sketches shown on the following cases represent six typical HEPA filter and duct arrangements that have been installed in recently completed projects at the Savannah River Site. The sketches depict the physical arrangement of the inlet and outlet ductwork to the HEPA filter housing. Inlet and outlet isolation dampers and inlet and outlet plenums are also shown because of their potential effects on the air streams entering and leaving the filter housings and their potential effects on the results of the air flow uniformity testing.

CASE 1

The first case is a small housing with two filters and the testing shows nearly perfect air flow uniformity between the two filter units. In this particular case the air flow is not affected by the absense of a discharge air plenum.

Other air flow uniformity test results for housings with two HEPA filters also fell well within the ASME N510 acceptance criteria and in general these small housings have presented little difficulty in meeting the requirements even with a wide variation in physical configurations.

CASE 2

The second case is a two wide by three high HEPA filter housing with air flow uniformity that meets the required acceptance criteria. It is hypothesized that the reason that the middle set of filters are receiving the highest air flows is because the filters had been in place for some time before the air flow uniformity testing and the filters had not unloaded uniformly.

CASE 3

The third case is a two wide by three high HEPA filter housing with air flow uniformity that meets the required acceptance criteria.

CASE 4

The fourth case is a 3 wide by three high HEPA filter housing with air flow uniformity that meets the acceptance criteria.

CASE 5

The fifth case is a three wide by three high HEPA filter housing with air flow uniformity that meets the required acceptance criteria.

CASE 6

The sixth case is a filter housing with a HEPA bank which is 2 wide by 4 high. This particular design configuration has no inlet and outlet plenum. In addition the filter housing isolation dampers are located upstream and downstream of the inlet and outlet duct transition pieces respectively. The data indicates that three of the eight filters have air flows that are outside the air flow uniformity acceptance criteria. It is concluded that if there had been inlet and outlet plenums the air uniformity criteria would have been met. The conversion from velocity pressure to static pressure due to the inlet duct transition piece and the non symmetrical configuration of the discharge duct transition piece contributed to the non conforming test results.

CONCLUSION

The use of inlet and outlet plenum on HEPA filters are useful in ensuring that the air flow uniformity can be met. Their use particularly at the inlet of HEPA filters can "even out" non uniformities in the air flows before they reach the HEPA filters.

In addition if it is required to have inlet and outlet isolation dampers for performing maintenance and filter changeout the preferred location for these isolation dampers is integral with the filter housing or downstream of the inlet plenum and upstream of the filter housing discharge plenum.

References

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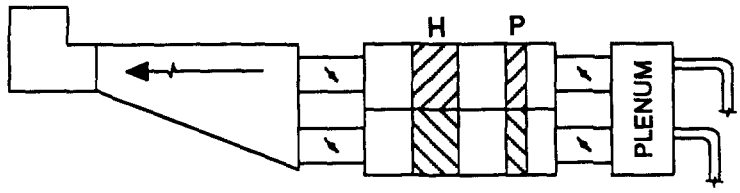
2. ASME N510-1989 entitled "Testing of Nuclear Air Treatment Systems".

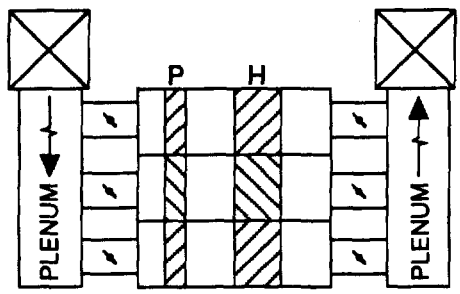


Housing / Ductwork Configuration

Actual FPM	485
% of Avg. FPM	97%
Actual FPM	510
% of Avg. FPM	102%

Air Flow Uniformity Test Results (Filter Assembly viewed in direction of air flow)

Case 1
(1 Wide x 2 High)

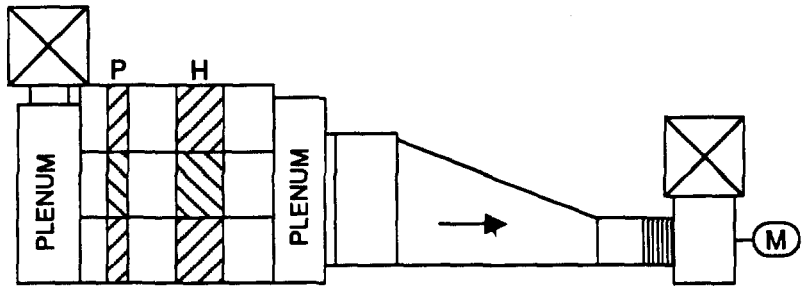


Housing / Ductwork Configuration

Actual FPM 134	Actual FPM 120
% of Avg. FPM 96%	% of Avg. FPM 86%
Actual FPM 165	Actual FPM 165
% of Avg. FPM 119%	% of Avg. FPM 119%
Actual FPM 136	Actual FPM 114
% of Avg. FPM 98%	% of Avg. FPM 82%

Air Flow Uniformity Test Results (Filter Assembly viewed in direction of air flow)

Case 2
(2 Wide x 3 High)



Housing / Ductwork Configuration

Actual FPM 408	Actual FPM 329
% of Avg. FPM 114%	% of Avg. FPM 92%
Actual FPM 358	Actual FPM 365
% of Avg. FPM 100%	% of Avg. FPM 102%
Actual FPM 358	Actual FPM 332
% of Avg. FPM 100%	% of Avg. FPM 93%

Air Flow Uniformity Test Results (Filter Assembly viewed in direction of air flow)

Case 3
(2 Wide x 3 High)

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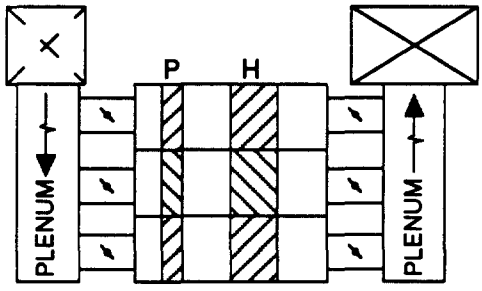
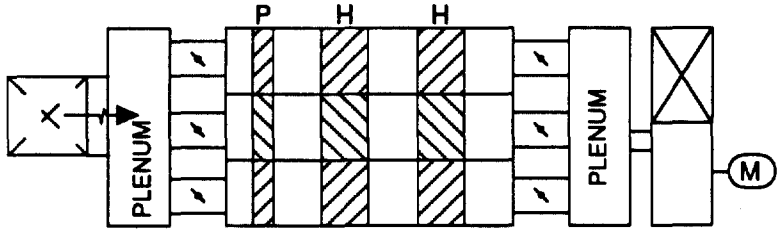


Actual FPM 230 % of Avg. FPM 100%	Actual FPM 240 % of Avg. FPM 104%	Actual FPM 208 % of Avg. FPM 90%
Actual FPM 189 % of Avg. FPM 82%	Actual FPM 208 % of Avg. FPM 90%	Actual FPM 229 % of Avg. FPM 100%
Actual FPM 238 % of Avg. FPM 103%	Actual FPM 238 % of Avg. FPM 103%	Actual FPM 249 % of Avg. FPM 108%

Housing / Ductwork Configuration

Air Flow Uniformity Test Results (Filter Assembly viewed in direction of air flow)

Case 4
(3 Wide x 3 High)

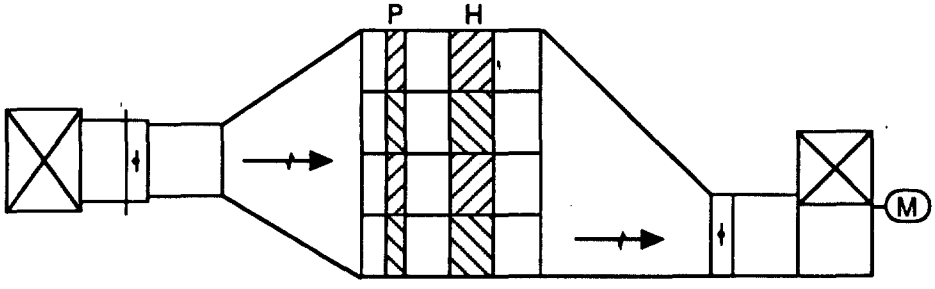


Actual FPM 360 % of Avg. FPM 101%	Actual FPM 317 % of Avg. FPM 81%	Actual FPM 313 % of Avg. FPM 88%
Actual FPM 414 % of Avg. FPM 118%	Actual FPM 317 % of Avg. FPM 90%	Actual FPM 317 % of Avg. FPM 90%
Actual FPM 414 % of Avg. FPM 118%	Actual FPM 327 % of Avg. FPM 93%	Actual FPM 328 % of Avg. FPM 94%

Housing / Ductwork Configuration

Air Flow Uniformity Test Results (Filter Assembly viewed in direction of air flow)

Case 5
(3 Wide x 3 High)



Actual FPM 671 % of Avg. FPM 122%	Actual FPM 624 % of Avg. FPM 113%
Actual FPM 624 % of Avg. FPM 114%	Actual FPM 626 % of Avg. FPM 114%
Actual FPM 353 % of Avg. FPM 64%	Actual FPM 414 % of Avg. FPM 76%
Actual FPM 533 % of Avg. FPM 97%	Actual FPM 542 % of Avg. FPM 99%

Housing / Ductwork Configuration

Air Flow Uniformity Test Results (Filter Assembly viewed in direction of air flow)

Case 6
(2 Wide x 4 High)

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DISCUSSION

BURWINKEL: Case 6, the failing case was at a much greater velocity. For Case 2, velocities are in the range of 130 fpm; Case 3, about 350, but for Case 6 the velocity average is a little bit above 500 fpm. What effect do you think velocity had on uniformity?

PAUL: Velocity had little effect on uniformity. Velocity for Case 6 is strikingly high. I have got to confess that I didn't notice it when reviewing the data. We do have variations in airflow. Typically, we design our filters at Savannah River to meet 1,000 cfm and, theoretically, velocity shouldn't vary if the air is flowing uniformly. I am not sure of the reason for the design differences in velocity; I find it hard to believe they are attributable to design differences. Typically, we use 24 x 24 in. filters and generally, we have a flow of 1,000 cfm. A 4 sq. ft. filter area would give 250 fpm. I would normally expect to see that velocity. These look abnormally high. It may be nothing more than a typo, I will check on it.

EDWARDS, Jim: New Size 5 HEPA filters may have a clean pressure drop variation of some 25%. That is, new filter A's pressure drop may be 0.80 in. w. whereas filter B's might be 1.0 in w. Did you take into consideration that variations in new filters might have affected uniformity.

PAUL: No, I didn't. That could be another factor, but only if the pressure drop was not across the faces of the filters.

TSAL: The performance of the filters depends very much on the ratio of air velocities between plenum and ducts connected to the filter (Q plenum/Q duct). The lower this ratio the better uniformity. Did you use computational built dynamic computer codes?

PAUL: Computer modeling was not a part of the study. I was just studying actual test results. I was not trying to predict what the results might be. It might be useful to compare model computer program predictions against test results to find out if the computer programs are valid.

KUMAR: This is an observation. Filter failure could also be due to the unsymmetrical downstream (transition) ductwork. Data pertaining to the exact location of the failed filter with respect to the bank configuration, if published, would be beneficial in arriving at the right conclusion.

PATLOVANY: I am concerned that variability of flow capacity through new filters was not adequately considered. One Rocky Flats test in a 3 x 3 filter plenum with new, unloaded filters measured flow variations from 400 to 540 cfm for identical filters with the same differential pressure. Duct flow uniformity tests should, therefore, first verify that the new filter elements used for the test have minimal or no differences in flow capacities.

PAUL: At Savannah River, we do not verify, up front, that HEPA filters within a bank have similar pressure drop characteristics. Typically this has not been an issue since the vast majority of our housings pass the uniformity test without this accounting.

CLOSING COMMENTS OF SESSION CO-CHAIRMAN DORMAN

We have had four papers dealing with filtration, either directly or indirectly. We have had one dealing with the possible carcinogenic effects of fibers and one which has been concerned with flows in various shapes of ducts. All of these are very important.

Mr. Carlon's paper dealt with an alternative to DOP. In my question to him, I said that I believed that there was no well-known case of human cancer due to inhalation of DOP aerosols. However, many years ago, beryllium paints were not suspected of causing any damage. Neither was asbestos thought to be as serious as it has transpired in the last 20 years or so. It is, therefore, better to err on the side of safety than to take risks - especially in the present climate in the USA where very large sums have been awarded in legal actions.

The second paper by Mr. Parker concerned a method of in-situ filter testing. It is somewhat similar to methods used in testing for vapor penetration, although I had not come across it for particulate tests. As the particle sizes in the aerosol are different on each side of the filter (in addition to mass concentration) I would like to know Mr. Parker's views on what is actually measured by light scattering. Is it a straightforward matter to convert an unknown size distribution into a mass concentration? If so, the method appears to have considerable potential.

The third paper from Mr. Costigan concerned the development of the Quickmix injector for in-situ filter testing. I saw the injector in England last year but have had no practical experience of its use. In the past, 10 to 20 duct diameters have been necessary for thorough mixing, unless baffles have been inserted with consequential increase in pressure loss. The Quickmix represents a great improvement over baffle systems. I hope that there will be no legal arguments with Sacley about the origin of the device.

Paper number 5 was about fibers in the lungs. Some two decades ago there was much controversy about possible carcinogenic effect of fine glass fibers. I have lost touch with more recent work but am pleased to see in this paper that there is no serious problem. There could be with other fibrous materials and my advice is to treat all fibers with respect. Four of my friends have died as a result of inhaling crocidolite asbestos so I speak with some feeling.

The sixth paper on the effects of filter housing and ductwork configuration by Mr. Paul is a thorough investigation allied to mixing devices for even distribution of aerosols in ducts. Together with the report by Costigan it makes a valuable contribution to the solution of some of our experimental problems.

CLOSING COMMENTS OF SESSION CO-CHAIRMAN GILBERT FOR PAPER 4

Julie McIntyre gave us a rundown on the statistics for the filter test stations for the past two years and for the installation of HFATS at the stations. There does seem to be a tendency for the filter rejection rate to be continually lower because of improved filter quality. However, I wish to make this observation. In the original concept of the role of test stations, they were to act as a service organization to test deliveries of filters to the requirements of purchase orders. The test stations had no legal standing in the contract between vendor and purchaser, except to test the filters to the specification of the purchase order. To my knowledge, this has not changed.

If there is a standard to be imposed upon filters coming into the test station, it should be handled with the purchaser and not superimposed on filter deliveries.