and to exchange ideas for improving their long- and short-term training programs. All participants expressed a need for enhanced training opportunities in biosafety and the need for continued mentorship after standardized training.

The Emory University Science and Safety Training Program (www.sph.emory.edu/CPHPR/biosafetytraining) is currently developing other training for high biocontainment laboratories, including training programs for emergency response activities, training for communicating laboratory issues to media and community organizations, and the development of a leadership program for biosafety professionals. Future trainings will be developed based on needs identified by participants of Science and Safety Training Programs and feedback provided at professional biosafety and scientific conferences. Initiatives for evaluating the effectiveness of the Science and Safety Training program are presently underway.

Acknowledgements

We thank David Stephens for his groundwork in development of the program; we thank Lee Alderman, David Bressler (CDC), Richard Henkel (CDC), Peter Jahrling (NIAID, NIH), Henry Mathews, Nate Powell (CDC), Mallory Tate (CDC), and Betsy Weirich (CDC) for their assistance in developing the course and training the participants. Thanks to SERCEB and the steering committee as this project is supported by SERCEB and NIH grant U54 AI057157. We would also like to thank the O. Wayne Rollins Foundation for their continued support.

References

Bandura, A. (1994). Self-efficacy. In V. S. Ramachaudran (Ed.). *Encyclopedia of Human Behavior, 4,* 71-81. New York: Academic Press. (Reprinted in H. Friedman [Ed.], *Encyclopedia of Mental Health*. San Diego: Academic Press, 1998).

Glanz, K., Lewis, F., & Rimer, B. (1997). Theory Research and Practice in Health Education. *Health Behavior and Health Education*, pp. 20-24. San Francisco: Jossey-Bass.

Green, L., & Kreuter, M. (1999). Planning Health Promotion Programs. Health Promotion Planning: An Education and Ecological Approach (3rd edition). Mountain View: Mayfield.

Gronvall, G. K., Fitzgerald, J., Chamberlain, A., Inglesby, T. V., & O'Toole, T. (2007). *Biosecurity and Bioterrorism: Biodefense Strategy, Practice, and Science, 5*(1), 75-85. doi:10.1089/bsp.2007.0902.

Hirschberg, R., LaMontagne, J., & Fauci, A. S. (2004). Biomedical research—An integral component of national security. *New England Journal of Medicine, 350,* 2119-2121.

Hochbaum, G. M. (1958). Public participation in medical screening programs: A socio-psychological study. Washington: U.S. Department of Health, Education, and Welfare, Public Health Service, Bureau of State Services, Division of Special Health Services, Tuberculosis Program.

Rosenstock, I. (1997). The Health Belief Model: Explaining Health Behavior through Expectancies. *Health Behavior and Health Education*, pp. 39-61. San Francisco: Jossey-Bass.

WHO. (2006). Biorisk management: Laboratory biosecurity guidance. WHO Report 2006. Geneva: World Health Organization. Available at: www.who.int/entity/esr/resources/publications/biosafety/WHO_CDS_EPR_2006_6.pdf

Reliability of ULPA Filters in Air Handling Systems

Gordon Abraham and Phillip McCabe

Australian Animal Health Laboratory, Geelong, Victoria, Australia

Abstract

Eighteen ultra low penetration air filters were installed in exhaust air systems in a microbiological high containment facility. Their performance was measured annually for integrity and efficiency. After seven years, their reliability was comparable with that of high efficiency particulate air filters in similar systems and are considered a suitable alternative to the latter.

Introduction

High efficiency particulate air (HEPA) filters having a minimum efficiency of 99.97% for particles 0.3 microns in diameter have been widely used to remove infectious aerosols from microbiological containment laboratories and animal rooms (Abraham, Le Blanc Smith, & Nguyen, 1996). The standards to which filters are manufactured and tested have been reviewed (First, 1996).

Ultra low penetration air (ULPA) filters (Liu, Rubow, & Pui, 1985; Avery, 1986) having a minimum collection efficiency of 99.997% for particles in the size range of 0.1 to 2 microns have been developed to provide higher efficiencies for removing particles from air for clean room technologies (Kapoor & Gupta, 2003; Schroth, 1996). ULPA filters have been used where dust-free environments are required for microelectronic, computer and pharmaceutical manufacturing industries. However, they have not been used for removing infectious particles from exhaust air streams in microbiological facilities.

The efficiencies of both HEPA and ULPA filters measured by aerosols of polydisperse sodium chloride were measured to be 1,000 and 10,000 fold higher respectively than the manufacturer's minimum specifications (Jamriska, Martin, & Morawska, 1997).

Where microbiological biocontainment in laboratories and animal facilities is important, HEPA filters form a critical component of microbiological barriers. As air handling systems in buildings run continuously, the integrity and efficiency of HEPA filters must be checked at defined intervals to ensure that biocontainment standards are met. In general, annual testing of filters is adopted to ensure the integrity of the filter medium, the efficacy of the filter seal in its housing, and that the pressure drop across the filter is acceptable. Reports describe the reliability and performance characteristics of HEPA filters in nuclear (Carbaugh, 1982), both nuclear and non-nuclear (Robinson et al., 1985) and microbiological laboratory (Abraham, Le Blanc Smith, & McCabe, 1999) installations.

Prior to the availability of data (Jamriska et al., 1997) to verify the efficiency of HEPA filters, ULPA filters were installed in exhaust air ducts in several microbiological high hazard areas of the Australian Animal Health Laboratory (AAHL) to provide an anticipated higher level of aerosol containment. This report compares the seven-year performance of ULPA filters with that of HEPA filters in similar air exhaust systems.

Materials and Methods

610 x 610 x 292 mm HEPA filters were supplied by Gelman Sciences (Australia) and ULPA filters by Flanders Filters (USA). The manufacturing data provided was:

HEPA Filters: Gelman HEPA absolute type model 7590, arrestance efficiency >99.995%, penetration of rated airflow <0.005%, rated airflow 472 L s^{-1}, penetration at rated airflow <0.0003%, resistance at rated airflow 239 Pa, tested in accordance with BS 3928 sodium flame test.

ULPA filters: Flanders-laminar flow grade VLSI ULPA filter model 0-012-6-07-00-SU-33-00-gg-6, serial number V 235958, test flow 100FPM (velocity), efficiency @ test flow 99.99999% @ 0.12 microns, filter size 610 x 610 x 150 mm, dimple pleat construction, no separators.

The laboratory design, air handling systems, filter installations and HEPA filter specifications at the AAHL have been described previously (Abraham et al., 1996 and 1999; Jamriska et al., 1997). Laboratories, animal rooms and support service areas are all enclosed within an outer microbiological barrier. One hundred percent fresh air is drawn from outside the building into a common plenum, and large particulate matter is removed by pre-filters prior to final filtration through HEPA filters to its final destination. For higher hazard zones, including animal rooms, two HEPA filters are used in series for the supply air to ensure against any infectious particle backflow. Air is exhausted from laboratories and animal rooms through clarification pre-filters prior to filtration through two 610 mm square HEPA filters (or in this case, one HEPA and one ULPA filter) in series. All filters are housed in separate cylindrical canisters with removable ends, and sealed in mountings using compressible gaskets that meet required standards for airtightness measured by cold dioctyl phthalate particle penetration. Where two filters are installed in series, both filters are integrity tested sequentially.

Eighteen ULPA filters were installed in four selected laboratories and 14 selected animal rooms. In such rooms, two HEPA filters in series for exhaust air systems is the normal installation configuration. All ULPA filters were installed in the secondary exhaust position following a standard HEPA filter. After initial installation and commissioning, each filter was tested annually to confirm the absence of leaks around the gasket seals for the filter housings and to ensure that the pressure drop across the filter face was within operating limits. The scan testing of ULPA filters to demonstrate filter integrity conformed to the Australian Standard 1807.6 (2000) and was identical to that done routinely for HEPA filters in other parts of the facility.

Results

Over a seven-year period from 1995 to 2002, five of the 18 ULPA filers were replaced by standard HEPA filters for non-conformance with the performance criteria. The reasons for these replacements are shown in Table 1.

Table 1

Numbers of ULPA filters replaced in room exhaust systems within seven years.

	Replacement Reason			
Filter location and number of filters	Media leak	Gasket seal failure	Media blockage	Still in service
Laboratories (4)	1			3
Animal rooms (14)	2	1	1	10

Discussion

This report analyzes the performance of 18 ULPA filters in continuous use in air exhaust systems in containment laboratories and animal rooms. Five (28%) were replaced in the first seven years of operation, which compares with 18.4% of HEPA filter replacements in the same period of service in a previous study (Abraham et al., 1999). Like the previous study, there were three main reasons for filter replacement; defects in the filter medium, failure of the gasket seal holding the filter in place, and blockage of the filter medium. Due to the small numbers in this study, the percentages of filter failures in each category were not statistically significant.

All of the ULPA filters were installed in the secondary position behind a primary HEPA filter. Blockages were measured by the pressure drop (generally, rising from 200 to 500 Pa) across the filter by Magnehelic gauges and confirmed by subsequent air flow measurements through the filter directly. Filters in the secondary position are expected to be impacted by fewer larger particles and should be less susceptible to media blockage; the data supports this view. The origin of the blockages is unknown, but is probably particulate matter. Although only one ULPA filter was considered blocked in this study, ULPA filters do not appear to block more readily than HEPA filters in similar positions.

Although testing in workshop conditions has demonstrated the high filtration efficiency of ULPA (and HEPA) filters (Jamriska et al., 1997), sensitive methods to prove their continued performance in the field are not routinely available. During this study, the same cold dioctyl phthalate (DOP) tests used to screen HEPA filters were done annually to identify significant faults in ULPA filters. It was this test that allowed for the detection of filter media leaks and gasket seal leaks and the replacement of non-performing filters (Table 1). However, the cold DOP test does not demonstrate the continued high efficiencies of either HEPA or ULPA filters whilst in service. This study shows ULPA filters can be used in air exhaust systems in a large containment laboratory and function reliably for at least seven years.

Acknowledgements

The proposal to install ULPA filters was pioneered by David Martin. Rob Dandy, Neil Slater, and Ross Cook did the majority of the monitoring of air filters and their careful attention to detail is gratefully acknowledged. Steven Edwards and Mat Bojmic offered constructive comments on the manuscript.

References

Abraham, G., Le Blanc Smith, P. M., & Nguyen, S. (1996). The effectiveness of gaseous formaldehyde decontamination assessed by biological monitoring. *Journal of the American Biological Safety Association, 2,* 30-38.

Abraham, G., Le Blanc Smith, P. M., & McCabe, P. (1999). HEPA filter replacement experience in a biological laboratory. *Journal of the American Biological Safety Association, 3,* 134-142.

Australian Standard 1807.6 (2000). Cleanrooms, workstations, safety cabinets and pharmaceutical isolators—Methods of test—Determination of integrity of terminally mounted HEPA filter installations.

Avery, R. H. (1986). Selection and uses of HEPA and ULPA filters, pp. 119-123. *Heating/Piping/Airconditioning,* January.

Carbaugh, E. H. (1982). A survey of HEPA filter experience. *Proceedings of the 17th DOE Nuclear Air Cleaning Conference*, CONF-820833, M. W. First (Ed.), Springfield, Virginia.

First, M. W. (1996). Aging of HEPA filters in service and in storage. *Journal of the American Biological Safety Association, 1,* 52-62.

Jamriska, M., Martin, D., & Morawska, L. (1997). Investigation of the filtration efficiency of HEPA and ULPA filters in submicron particle size range. *Clean Air, 31,* 31-37.

Kapoor, J. C., & Gupta, M. (2003). Elements of clean room technology and contamination control. *Defence Science Journal, 53*(3), 249-258.

Liu, B. Y. H., Rubow, K. L., & Piu, D. Y. H. (1985). Performance of HEPA and ULPA filters, pp. 25-28. *Proceedings of the 31st Annual Technical Meeting*, Institute of Environmental Sciences, Las Vegas, Nevada.

Robinson, K. S., Hamblin, C., Hodierne, R. C., & Smith, M. J. S. (1985). In-service ageing effects on HEPA filters. Proc. Gaseous Effluent Treatment in Nuclear Installations, G. Fraser & F. Luykx (Eds.). Committee of the European Commission, Luxembourg.

Schroth, T. (1996). New HEPA/ULPA filters for clean room technology. *Filtration and Separation, 33,* 245-250.